ITU-T

ITU-T Focus Group on Aviation Applications of Cloud Computing for Flight Data Monitoring

Avionics and Aviation Communications Systems

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April 2016

Foreword

The International Telecommunication Union (ITU) is the United Nations specialized agency in the field of telecommunications, information and communication technologies (ICTs). The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of ITU. ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The procedures for establishment of focus groups are defined in Recommendation ITU-T A.7. The ITU-T Focus Group on Aviation Applications of Cloud Computing for Flight Data Monitoring – FG AC – was established by the ITU-T Telecommunication Standardization Advisory Group (TSAG) in June 2014 and completed the work on its deliverables in December 2015. More information is available at http://itu.int/en/ITU-T/focusgroups/ac/.

Deliverables of focus groups can take the form of technical reports, specifications, etc. and aim to provide material for consideration by the parent group in its standardization activities. Deliverables of focus groups are not ITU-T Recommendations.

SERIES OF FG AC TECHNICAL REPORTS	
Deliverable 1	Existing and emerging technologies of cloud computing and data analytics
Deliverable 2/3	Use cases and requirements
Deliverable 4	Avionics and aviation communications systems
Deliverable 5	Key findings, recommendations for next steps and future work

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1. Executive summary

In accordance with the terms of reference of FG AC Working Group 4, this Report examines the feasibility of using recent developments in commercial broadband services, as well as reusing existing infrastructure, for real-time flight data streaming where appropriate.

There are a number of current and future infrastructure components and data link services which will satisfy the objectives of the global aeronautical distress and safety system (GADSS). These are examined in detail in this Report.

2. Background and context

The global aviation community in its quest for continuous and sustainable safety of air navigation shortly after the Malaysia Airline MH 370 disappearance at the behest of the Government of Malaysia held an Expert Dialogue Meeting in Kuala Lumpur that culminated in the setting up of the Focus Group on Aviation Applications of Cloud Computing for Flight Data Monitoring (FG AC) by the International Telecommunication Union.

Based on the above, the FG AC held its first meeting in Kuala Lumpur, Malaysia, 1-3 December 2014, during which four sub-working groups were established. Since then, four other meetings were held: February 2015 in Montreal, Canada (ICAO HQ), May 2015 in Geneva, Switzerland (ITU HQ), August 2015 in Los Angeles, USA (Teledyne Controls), and December 2015 in Frankfurt, Germany (Deutsche Lufthansa HQ).

The terms of reference of Working Group 4 (WG4):

"The deliverable examines the feasibility of using recent developments in commercial broadband services, as well as reusing existing infrastructure, for real-time flight data streaming where appropriate."

The following input contributions were received for Deliverable 4:

i) **AC-I-018** – Implementation considerations for real-time flight data monitoring by Teledyne Controls, United States.

ii) **AC-I-017** – Broadband services for flight data monitoring by Inmarsat, United King-dom.

iii) **AC-I-013** – Input to Deliverable 4 by Intelsat, Luxembourg.

iv) **SITA Aviation Cloud**

v) Further to the above, additional inputs have come from group members, ICAO, ITU, and RTCA SC –206 DO-349 Appendix C published in 2014, groups, and during plenary sessions and meetings as well as other stakeholders.

This Report is based on inputs received from FG AC participants.

The following were areas of focus in this work:

- Ground-based infrastructure;
- On-board information systems infrastructure; and
- On-board data links infrastructure.

Other considerations were capability limitations, cybersecurity and International Civil Aviation Organization (ICAO) Standards and Recommended Practices (SARPs).

Additional experts contributed in the course of WG4 deliberations. The full list is contained in Appendix 5.

3. Structure of the Report

This Report covers two major areas as indicated below:

i) The feasibility of using recent developments in commercial aeronautical data link services: this covers recent developments from various commercial broadband technologies and services for the aeronautical environment.

ii) Reusing existing infrastructure for real-time flight data streaming where appropriate: this covers the various existing aviation satellite technologies and services (safety and non-safety purposes) as being provided currently to the aviation community and its potential to support real-time flight data streaming.

4. Relationship with other FG AC working groups

In accomplishing its tasks, WG4 took into account relevant inputs from the other working groups.

5. Definitions

A central consolidation of acronyms and definitions has been produced (see WG5 deliverable).

6. Real-time transmission

Real-time transmission of various data from the aircraft has become a significant focus for global aviation safety authorities. The ability to transmit relevant operational and safety data from aircraft operating in all regions of the globe is seen as an important factor and referenced in the ICAO global aeronautical distress and safety system (GADSS) report.

This Report examines the feasibility of using recent developments in commercial aeronautical data link services, as well as reusing existing infrastructure, for real-time flight data streaming where appropriate. This Report examines in detail the combination of airborne systems, ground systems and/or associated services that support the generation, collection, analysis, transmission, storage and sharing of flight data.

7. Assumptions

7.1 Introduction

Fundamental assumptions in relation to the use cases were made, as much of the required information is either proprietary or not available at all. Wherever this is the case, assumptions were made based on industry knowledge and experience (see Appendix 4 for the data volumes associated with flight data recording standards).

A detailed description of the use cases are found in Deliverable 2/3.

The following examples of use cases were considered:

1. Flight tracking for safety and security (e.g. search and rescue, border protection);
2. Flight tracking for route planning and optimization (e.g. crew scheduling and fuel optimization);

3. Air traffic management (ATM) (e.g. air traffic control (ATC) including ground movement and airspace optimization);
4. Predictive maintenance;
5. Inflight and post-flight trouble-shooting;
6. Reliability;
7. Accident investigation;
8. Flight crew techniques;
9. Approach statistics;
10. Original equipment manufacturers (OEMs) – Airframers and engines;
11. Meteorological purposes;
12. Cargo information;
13. Environmental efficiency;
14. Research and development (R&D) information;
15. Information for regulatory purposes.

It is assumed that these use cases remain valid for the foreseeable future. In accordance with its terms of reference, WG4 focused on flight data monitoring for safety and security.

7.2 Definition of "real-time data"

For the purposes of this Report, "real-time data" is defined as data with adequate update rate and latency to meet the operational requirement.

7.3 Categories of "flight data"

The following categories of flight data parameters were considered:

1. Navigational and trajectory data (e.g. position, altitude, speed, climb rate, attitude, etc.);
2. Engineering data (e.g. N1, (EGT), hydraulic line pressures, error codes, etc.);
3. Mission planning and identity information (e.g. call sign, flight number, flight plan, passenger lists and cargo manifests, etc.).

8. Real-time data transmission performance

8.1 Introduction

There is a need to ensure consistent definition and use of data communication capabilities to apply the required communication performance for a global data communications. This section provides a description of real-time data and supporting data transmission performance. The material in this section referenced relevant ICAO document 9869 AN/462 MANUAL ON REQUIRED COMMUNICATION PERFORMANCE (RCP). This Report has drawn on this manual to set a baseline of possible real-time data communication performance.

This section examines examples of current communication performance standards relevant to navigation and surveillance, and explores the data volumes and bandwidth requirements associated with real-time flight data transmission that may meet GADSS flight data recovery objectives. The purpose of this Report, "real-time data" is defined as data with adequate update rate and latency to meet the operational requirement.

8.2 Background

Data communication capabilities provide for the integration of capabilities to exchange information between ground-based operations and aircraft. To establish more context, the following describes some of the primary parameters which are considered:

i) Communication transaction time – The maximum time for the completion of the operational communication transaction after which the initiator should revert to an alternative procedure.

ii) Continuity – The probability that an operational communication transaction can be completed within the communication transaction time.

iii) Availability – The probability that an operational communication transaction can be initiated when needed.

iv) Integrity – The probability that communication transactions are completed within the communication transaction time with undetected error.

v) Further definitions with regard to current communication standards are:

   1. RCP 240 would be used for controller intervention capability supporting separation assurance in a 30/30 separation environment.

   2. RCP 400 would be used for controller intervention capability supporting separation assurance in current environments where separations are greater than 30/30 and alternative technologies are planned

8.3 Data streaming

Data streaming can and will be used for a variety of purposes. Its application may range from search and rescue, accident investigation to aircraft and engine maintenance management. The performance requirements will vary depending on the application. Further definitional work will be required to set out what will be the required performance for real-time data streaming based on the expected application. It is anticipated that real-time data streaming performance values or standards are likely to be selected based on the anticipated ICAO SARPs for GADSS.

8.4 Bandwidth needs analysis for real-time flight data transmission and data link systems performance summary

A study of the bandwidth needs for real-time flight data streaming and resulting data volumes generated as well as a survey of various terrestrial and satellite data link systems in use on aircraft today are provided in Appendices 4 and 3, respectively, and are summarized below.

8.4.1 Bandwidth needs analysis for real-time flight data transmission

There are two possible modes of real-time flight data transmission that may be considered:

- The first mode is continuous real-time flight data streaming at all times even during normal operations;
- The second mode is for triggered transmission of flight data which involves manual or automated activation of flight data streaming when a distress situation is encountered.

Performing routine and continuous real-time flight data streaming on aircraft generates a relatively low bandwidth requirement per aircraft but generates the largest global requirement.

Relevant studies, including the report published by BEA after the 2009 Air France Flight 447 accident and the National Transportation Safety Board (NTSB) Recommendation letter published on 22 January 2015, recommend that solutions enabling triggered transmission of flight data (TTFD) are employed for aircraft used on extended overwater operations (EOO).

NTSB proposes that "(flight) data should be captured (and transmitted) from a triggering event until the end of the flight and for as long as a time period before the triggering event as possible." Performing triggered transmission of flight data in this manner introduces a higher bandwidth requirement for an aircraft in distress and the bandwidth need increases closer to the end of the flight and the longer the time period before the end of the flight. However, with a low number of distress situations, the global bandwidth needs will be a fraction of that from continuous routine real-time data streaming.

An analysis illustrating the data transmission bandwidth performance needs for both continuous routine black box streaming and TTFD modes of flight data transmission is provided in Appendix 4. The appendix has two sets of tables. The first set of tables describes the global bandwidth need and the global data volumes generated if up to 20,000 aircraft were to be simultaneously streaming flight data. Three sets of values are provided illustrating the data volumes and bandwidth needs associated with a three-example flight data black box recording rates:

- Aircraft position data recording only;
- 64 words per second (wps) standard flight data recording (circa 1995 common standard);
- 1024 words per second standard flight data recording (circa 2015 common standard).

Flight data recorder (FDR) standard	Aircraft position only	64 wps FDR	1024 wps FDR
Bandwidth needed for routine continuous FDR streaming	72 bps per (1) aircraft	768 bps per (1) aircraft	12.3 kbps per (1) aircraft
Global bandwidth needed	690 kbps for 10,000 aircraft	7.32 Mbps for 10,000 aircraft	117 Mbps for 10,000 aircraft
Global FDR data volume	130 GB per month for 10,000 aircraft	1.4 TB per month for 10,000 aircraft	22 TB per month for 10,000 aircraft

The 1024 wps FDR bandwidth analysis is really a worst case analysis and the overall global bandwidth needs are likely to be significantly less than illustrated. This is because the analysis assumes no data compression is achieved and the FDR standards and actual data volumes are expected to be much less on most aircraft in service. While many newer aircraft record flight data at the 1024 wps standard, the most common standards in use are 256 wps or less for narrow body aircraft and 512 wps or less for wide body aircraft.

Appendix 4 provides various TTFD analysis illustrating how many hours of flight data could be transmitted through 432 kbps bandwidth based on a triggering event occurring at various times from 1 to 15 minutes prior to the end of the flight. Calculations are provided for 1024 wps, 512 wps, 256 wps and 64 wps FDR standards and some extracted results of how much accumulated data could be streamed are shown below:

FDR standard	Time of triggering event		
	2 minutes before end of flight	5 minutes before end of flight	10 minutes before end of flight
1024 wps	1 flight hour of data sent	2 hours of data sent	5 hours of data sent

FDR standard	Time of triggering event		
	2 minutes before end of flight	5 minutes before end of flight	10 minutes before end of flight
512 wps	2 hours of data sent	5 hours of data sent	11 hours of data sent
256 wps	4 hours of data sent	11 hours of data sent	23 hours of data sent
64 wps	18 hours of data sent	45 hours of data sent	99 hours of data sent

8.4.2 Data link systems performance

Information relating to the capabilities and bandwidth of various terrestrial and satellite data link technologies are defined in Appendix 3. Appendix 3 includes two tables: one with terrestrial data link characteristics for VDL Mode 0/A, VDL Mode 2, HF (high frequency) data link (DL), VDL Mode 4, UAT/978, 1090ES, GBAS/GRAS VDB and air-to-ground (ATG) using EvDO and LTE technologies, and the other one with satellite data link characteristics for L-band GEO Equatorial of various generations (I3, I4), L-band LEO, Ku-band GEO and Ka-band GEO technologies.

Appendix 3 provides information for each technology including example providers, link use mode (air-ground, ground-air, and air-air), altitude restrictions, geographic coverage, frequency band, data rate, safety classification and latency. The data rates associated with each link are extracted and provided in the tables below:

Satellite technology	L-band GEO		
	Classic Aero H/H+	Swift64	SwiftBroadband
Data rate (from aircraft)	0.6 –10.5 kbps	64 kbps	432 kbps

Satellite technology	L-band LEO	Ku-band GEO	Ka-band GEO
Data rate (from aircraft)	2.4 kbps	1 Mbps	5 Mbps

Terrestrial technology	VDL 0/A	VDL 2	HF DL	VDL 4	UAT/978
Data rate (from aircraft)	2.4 kbps	31.5 kbps	0.3 – 1.8 bps	19.2 kbps	1 Mbps

Terrestrial technology	1090ES	GBAS/GRAS VDB	ATG EvDO Rev. A	ATG EvDO Rev. B	ATG LTE
Data rate (from aircraft)	0.695 kbps	31.5 kbps	1.8 Mbps	3.6 Mbps	TBD

8.5 Conclusions

- The total data volume associated with flight data recording at the latest common FDR standard of 1024 wps is considerably less than might be expected (less than 22 TB for 10,000 aircraft).
- The total bandwidth requirements to routinely transmit flight data at 1024 wps in real time (less than 117 Mbps total for 10,000 aircraft) is considerably less than might be expected.
- Many narrowband data link systems have the potential to be used to stream basic flight data since only 72 bps is required to continuously stream aircraft position data from any aircraft.
- Terrestrial data links cannot support extended overwater operations (EOO) which is a primary focus for GADSS.
- Existing Ku-band and Ka-band satellite data link systems have enough significant bandwidth to support both routine flight data streaming and triggered transmission of flight data.
- Classic Aero (over the I3, I4 and MTSAT system) provides near global coverage, has had safety classification for many years and has sufficient bandwidth to achieve some forms of limited data streaming.
- SwiftBroadband provides near global coverage, is expected to have safety classification in the near term and provides enough bandwidth to support both routine flight data streaming and triggered transmission of flight data
- Iridium provides 100% global coverage and has safety classification but does not have sufficient bandwidth today to support streaming of most commonly used flight data (FDR) standards such as 256 wps or 512 wps. Iridium NEXT will have sufficient bandwidth.

9. Ground-based systems and services infrastructure

9.1 Current infrastructure

9.1.1 Introduction

This section explores using existing ground-based infrastructure and services for real-time flight data streaming where appropriate. This section explores current computing capabilities and provides a high level summary of each technology. This section is supported by Appendix 1 – Summary of ground-based infrastructure capabilities.

Infrastructure that can be used to support real-time flight data streaming can be broken into several components of technology, products and services. It is important to note that the content in Appendix 1 is limited to available information from those organizations who participated or contributed to the work of WG4.

9.1.2 Summary of ground-based infrastructure capabilities

The table in Appendix 1 provides an overview of different communication service providers (CSPs) that could potentially provide real-time flight data streaming solution. While numerous factors will influence final market outcomes, it is probable that any real-time flight data streaming solution may require regulation based on the anticipated ICAO SARPs for GADSS.

In addition, this Report is based on knowledge of existing operations and as such the data does not reflect future equipage, commercial or technology changes.

9.1.3 Flight data monitoring, flight tracking and alerting solutions and services

Every airline should have a flight data monitoring (FDM) application utilized for post-flight data analysis. Although not designed for real-time flight data monitoring, these systems may be adapted for real-time flight data monitoring use cases. Examples of FDM software and services providers include:

- Teledyne Controls;
- Airbus;
- Sagem;
- Aerobytes;
- GE Aviation (former Austin Digital).

Airlines may utilize a cloud service for FDM hosted by another party. It is worth noting that ICAO Annex 6 does make provision for airlines to outsource their FDM activities should they choose to do so.

There are also other flight data solutions that may be cloud based, which are used for flight tracking that may also support real-time flight data monitoring, reporting and alerting. Examples of these systems include:

- FlightWatching;
- SITA OnAir's AIRCOM ® Flight Tracker;
- Data centres (e.g. Google, Microsoft, SAP, Oracle);
- Flight Radar 24;
- Rockwell Collins MultiLink℠.

9.2 Ground-based infrastructure

9.2.1 Introduction

The aviation industry is now focused on interoperability and seamless air traffic management practices. This section explores some of the concepts that deliver a global approach to data management and sharing.

9.2.2 System wide information management (SWIM)

Currently, there is no efficient or effective ground-air/air-ground mechanism for data management, exchange, and sharing of aeronautical information.

The aircraft access to SWIM (AAtS) initiative is the effort that will define how and what is necessary to connect aircraft to SWIM infrastructure during all phases of the flight. It is important to realize that the AAtS initiative will not implement a specific infrastructure to create the actual link to the aircraft, but it will define a set of operational and technical requirements that will be used to drive that infrastructure. This infrastructure will create a full data information exchange (i.e. uplink/downlink) capability.

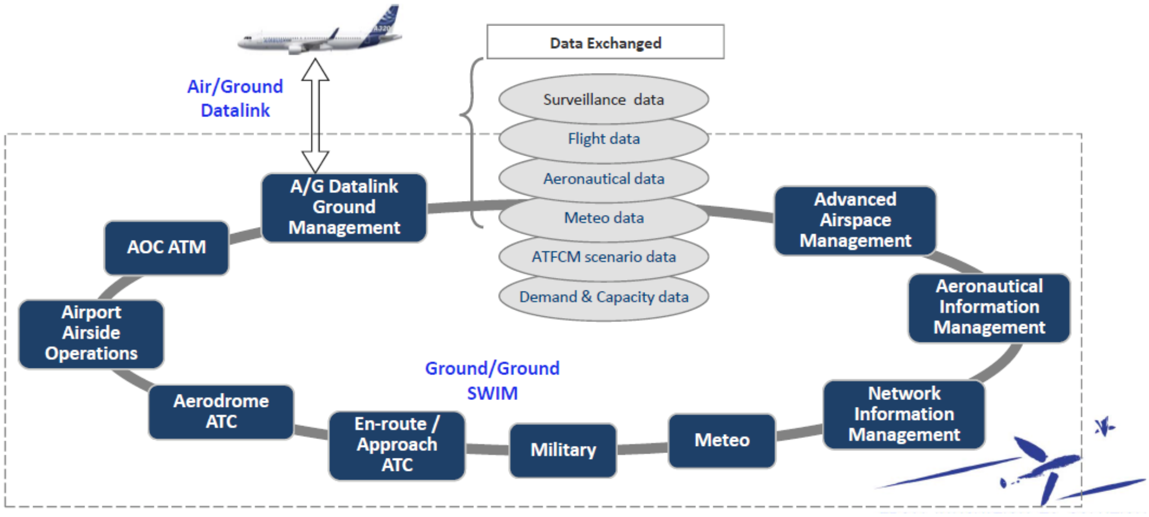
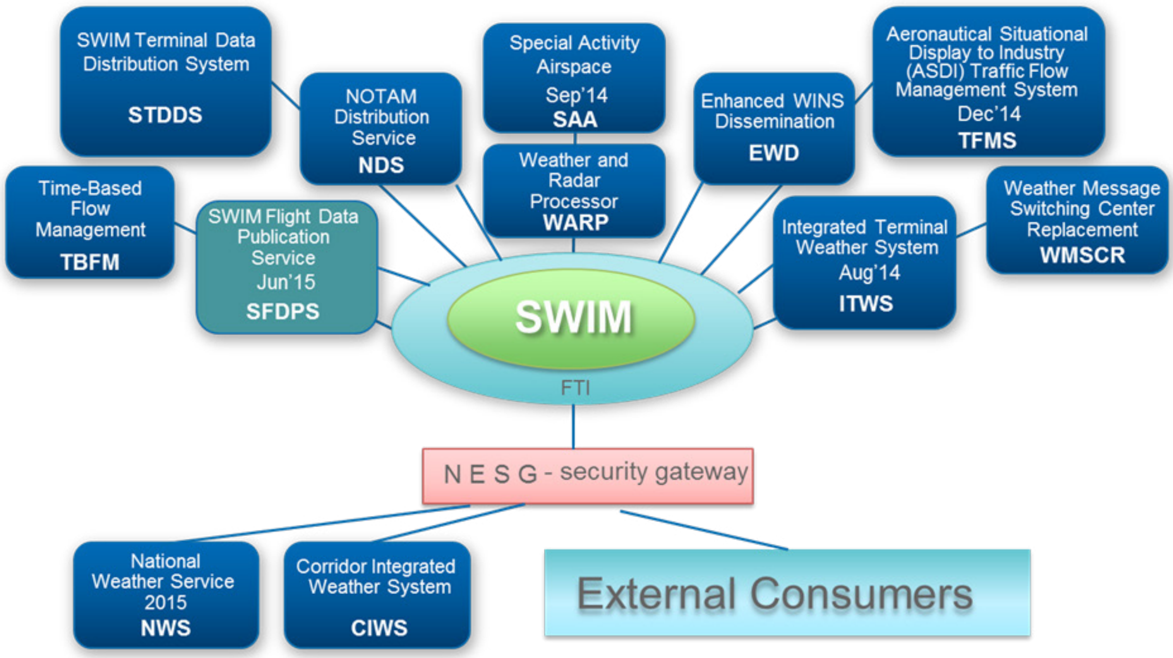


Figure 1 – Diagram illustrating aircraft access to SWIM (AAtS) (picture courtesy of SESAR Joint Undertaking)

AAtS will provide aircraft with guidance on how to connect to a common collection of aeronautical services provided from multiple sources. Example sources include services from FAA, Department of Homeland Security (DHS), airports and other information sources publishing to the SWIM platform. Using FAA SWIM services and a standards-based approach will create a globally interoperable and shared aviation information environment. System wide information management (SWIM) is an advanced technology program designed to facilitate greater sharing of air traffic management (ATM) system information, such as airport operational status, weather information, flight data, status of special use airspace, and daily ATM operational limitations. SWIM is designed to support current and future ATM programs by providing a flexible and secure information management architecture for sharing ATM information.

The SWIM concept will be an important and influencing element in facilitating the streaming of real-time flight data. Major global programs such as NextGen and SESAR regard SWIM as central to delivering their programs.



https://www.faa.gov/nextgen/programs/swim/qanda/media/swim_service.png

9.2.3 Flight data sharing programs

There are several multi-airline and multi-national data sharing programs that exist today that involve centralizing airline flight data storage. IATA's flight data exchange (FDX) program and the FAA's aviation safety information analysis and sharing (ASIAS) system are two examples.

i) International Air Transport Association's (IATA) global aviation data management (GADM)

a. Techniques to improve aviation safety have moved beyond the analyses of isolated accidents to data-driven analyses of trends and the interaction between the links in the air transport chain.

b. This approach is supported by the global aviation data management (GADM) program. GADM, evolving from the global safety information centre (GSIC), is becoming a broader data management platform, aiming at integrating all sources of operational data received from various channels and IATA unique programs, such as flight operations, infrastructure, IATA audits, etc., into a common and interlinked database structure.

c. With GADM, IATA will be in a position to provide the industry with comprehensive, cross-database analysis and with this to support a proactive data-driven approach for advanced trend analysis and predictive risk mitigation.

d. Pulling from all areas of operations sources, GADM will be the most comprehensive airline operational database available. These sources include the IATA accident database, the safety trend evaluation analysis and data exchange system (STEADES) database, IATA operational safety audit (IOSA) and IATA safety audit for ground operations (ISAGO) audit findings, flight data exchange (FDX), ground damage database (GDDB), maintenance-related and other operational databases.

e. More than 470 organizations around the globe submit their data to GADM. Over 90% of IATA member carriers are participating.

ii) Federal Aviation Administration (FAA)

a. The Federal Aviation Administration (FAA) promotes the open exchange of safety information in order to continuously improve aviation safety. To further this basic objective, FAA developed the aviation safety information analysis and sharing (ASIAS) system. The ASIAS system enables users to perform integrated queries across multiple databases, search an extensive warehouse of safety data, and display pertinent elements in an array of useful formats.

b. A phased approach continues to be followed in the construction of this system. Additional data sources and capabilities will be available as the system evolves in response both to expanded access to shared data and to technological innovation.

c. Systems that support data sharing and offer data protection to airlines may be suitable platforms to support centralized "escrow" services for hosting airline streamed black box data.

10. On-board infrastructure

10.1 On-board information systems infrastructure

10.1.1 Introduction

This section explores the feasibility of using existing information and data systems infrastructure on-board aircraft that could be used to support real-time flight data transmission and data streaming.

The section is structured around specific and current avionics and electronics systems that are often standard and are widely installed and utilized for normal airline operations. On-board information systems infrastructures that are already installed on aircraft that could possibly be used to support real-time flight data transmission or streaming can be broken into several groups of avionics and electronics systems. Aircraft data links systems which transmit data off the aircraft are covered in section 11 and are not described in this section, which focuses on the systems that generate and provide flight information and data.

This section is supported by Appendix 2: ADS-B mandates.

10.1.2 High-level summary

The following is a high-level summary of each avionics and electronics system that may be considered a data source that could support flight data transmission or streaming.

10.1.3 On-board information systems

On-board information systems can be grouped as follows for the purposes of considering them for their suitability for streaming aircraft information and flight data:

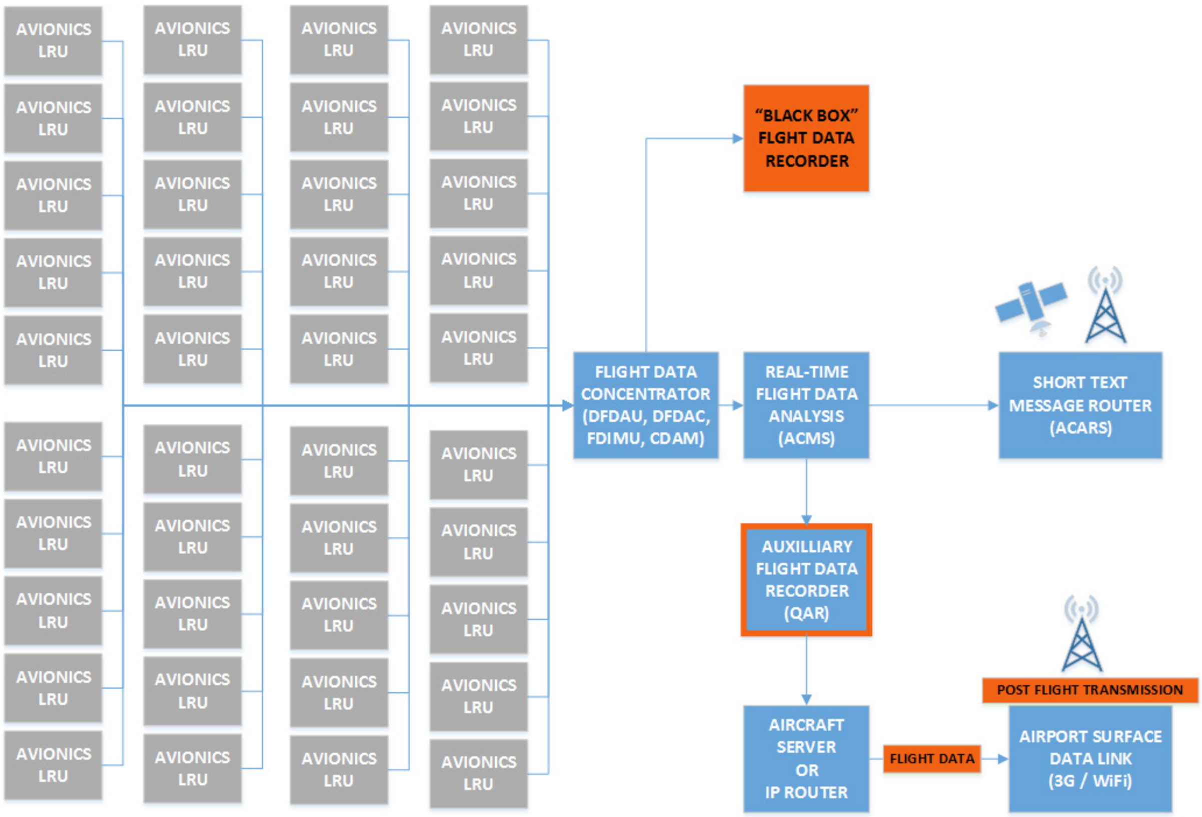
i) Aircraft flight data management and recording systems;

ii) Other avionics and electronic systems.

10.1.4 Aircraft flight data management and recording infrastructure

These are the systems on board today that are used to collect, process, analyse, store and forward flight data via available off-board data links such as aircraft communications addressing and reporting system (ACARS) data links and other data link systems in the flight deck or cabin. Aircraft is also increasingly equipped with airport surface data links that are used to transmit recorded flight data that is equivalent to black box data. Most airlines and half of aircraft in the world are already equipped and are routing flight data this way post flight on a routine basis for safety and maintenance applications. Small packages of data from on-board flight data management systems are sent via short text messages using ACARS on a large majority of aircraft in the global fleet.

The diagram below illustrates typical aircraft flight data management and recording infrastructure that is present on virtually every large passenger and cargo aircraft built since the late 1990s which represents the majority of aircraft in service today. While the names of the units on various aircraft types vary, the functionality provided is the same. In the diagram below, generic terms are used for the various functions.



10.1.5 Flight data concentrator and flight data recorder

There are typically between 20 and 50 avionics line replaceable units (LRUs) on the aircraft and on the engines that collectively have access often to thousands of flight data parameters. A selected sub-set of these data parameters is collected together in real time in a flight data concentrator which in turn packages the incoming data into a stream which feeds into the crash survivable flight data recorder (FDR) more commonly known as the black box. The data stored in the flight recorder is utilized for accident and incident investigation purposes.

10.1.6 Real-time flight data analysis

The flight data acquired by the flight data concentrator is also made available to a real-time analysis function on the aircraft which is most often known as the aircraft condition monitoring system (ACMS) which also has been a standard feature in aircraft since the late 1990s. The real-time analysis function enables various aircraft systems and the engines to be monitored continuously, and based on certain triggers or conditions small packages of flight data are sent to airline operations and maintenance through a short text message router (ACARS) which has been commonly used by airlines on most aircraft for more than twenty years. The real-time analysis function also independently sends flight data that can be equivalent to or greater than the black box recording to an auxiliary recorder function on the aircraft.

10.1.7 Auxiliary flight data recording

Since the advent of ICAO Annex 6 Part 1 requirements in 2005, virtually every airline in the world has had a need to routinely collect recorded flight data from the aircraft and perform post-flight flight data analysis for flight operations safety monitoring and improvement purposes. Many airlines were already performing flight data analysis not only for safety benefits but also to realize maintenance and operational efficiency improvements, and the industry had already developed several auxiliary flight data recorders. Auxiliary flight data recorder functions such as quick access recorder (QAR), digital ACMS recorder (DAR), and search and rescue (SAR) are now also standard on most aircraft since they make it easier to routinely harvest flight data rather than accessing and downloading data from the black box (FDR). Auxiliary flight data recorder technology has moved from magnet tape, to Magneto-Optical disk to Personal Computer Memory Card International Association (PCMCIA) and other solid state cards, and increasingly today the auxiliary recorder function is connected with or hosted on a networked system on the aircraft.

10.1.8 Aircraft servers, Internet protocol (IP) data routing and airport surface data communications

Over the last five years, aircraft is increasingly installed with a network server or other IP data routing capability and an airport surface data communication capability that features IEEE 802.11 wireless fidelity (Wi-Fi) or second, third or fourth generation (2G, 3G or 4G) cellular technologies. With all these technologies coming together, over 170 airlines and around 8,000 aircraft today are routinely transmitting auxiliary recorder flight data post flight while on the ground at the airport.

10.1.9 Other avionics and electronics systems

Other systems that generate and collect data that may be suitable or relevant for transmitting aircraft data in-flight include the following:

- Flight management system (FMS): FMS is an important source and destination for aircraft information. The ACARS system is the data communication system available to FMS but working together with FMS and the ACARS system enables the important applications of automatic dependent surveillance-contract (ADS-C) and the future air navigation system (FANS) utilized on many long haul aircraft operations. FMS also is connected to and outputs flight data parametric data to the flight data concentrator and the real-time flight data analysis (ACMS) systems.
- Centralized aircraft fault monitoring or maintenance computers: These systems include the central maintenance computer (CMC), centralized fault display interface unit (CFDIU), electronic centralized aircraft monitor (ECAM) and others. Most avionics units and systems are required to monitor themselves and report any fault conditions and codes in a standard format. CMC, CFDIU, ECAM or similar systems centralize all the fault information from all the avionics systems on the aircraft. The fault information is made available for download and the most important information that is critical to aircraft maintenance and trouble-shooting is relayed to the airline's maintenance provider via ACARS data links.
- Other ACARS peripherals and end systems: There are many other avionics units that typically have dedicated applications that are also connected to ACARS and are therefore able to send short text message data via ACARS data links. As FMS, and maintenance computers provide data to the ACMS and FDR systems so do most avionics systems also provide flight data to ACMS and FDR.
- Airline operational communication system (AOC): This system is typically resident inside the same unit that is also the ACARS router. AOC is used to send short text message operational reports such as start of flight, end of flight, take-off and landing out, off, on, in (OOOI) reports.
- Aircraft interface devices (AIDs): AIDs are discrete devices or avionics interface functions hosted in other avionics systems that are designed to safely provide flight data and connectivity services to other less critical or non-certified systems installed or portable electronic flight bags (EFBs). ARINC 834 defines an aircraft data interface function (ADIF). Although EFBs were the intended clients for ADIF flight data feeds, it is worth considering that fielded AID ADIF functionality may be re-purposed to support real-time transmission of flight data parameters. Although AIDs have not seen widespread deployment yet on new aircraft by aircraft manufacturers, it is expected that AID and ADIF functionality will become widespread due to the increasing use of tablets by airline crew on board. It is therefore worth considering connecting AID's ADIF functions via aircraft data links to provide real-time data off board.

10.1.10 Conclusion

Of all the on-board information systems, ACMS has access to the richest source of data on all aircraft types. ACMS is connected with ACARS and can use all the data links available to the ACARS router. ACMS also provides much larger data volumes to aircraft servers and some QAR units that also function as IP data routers transmitting flight data post flight. These routers if they are connected with and/or integrated with ACMS are well placed to provide flight data for inflight streaming. ACMS can support triggering and sending anything from small amounts of data up to full black box data or more and because it is classified as user modifiable software (UMS), ACMS can be easily changed and deployed on in-service aircraft without need for costly aircraft re-certification.

All the other on-board information systems listed can send data via ACARS but they cannot support flight data streaming. They are not easily connected to satellite communication (SatCom) data links and it is not easy to change triggering or data content sent on all these systems. ACARS AOC has a UMS reprogrammable capability but it has very limited access to aircraft flight data parameters compared to ACMS.

10.2 On-board aircraft surveillance and tracking infrastructure

10.2.1 Introduction

Aircraft surveillance is considered an air traffic control function. Primary radar was and is used to track aircraft and it does not require any avionics equipment on the aircraft. Secondary surveillance radar (SSR) was introduced to expand surveillance to provide additional information related to the aircraft. SSR technology requires ATC transponders (transmitter/responders) avionics on board the aircraft. Initially Mode A and Mode C was used for commercial transport, but today aircraft utilize Mode S which is an enhanced SSR mode with selective interrogation capabilities. ATC or Mode S transponders ignore interrogations not addressed with their unique identity code, reducing channel congestion. SSR is now being phased out in favour of automatic dependent surveillance-broadcast (ADS-B) but avionic-wise is an extension of ATC Mode S transponders.

For surveillance needs over oceanic and remote regions which are beyond the reach of terrestrial SSR, very high frequency (VHF) and ADS-B technologies, there are two main approaches. The first approach is ADS-C. This is the position report (and other avionics data) which is obtained by the ATC flight data processing (FDP) system setting up a 'contract' for information from its peer aircraft avionics ADS-C function (this can be in the FMS on a Boeing aircraft or the air traffic service unit (ATSU) on an Airbus aircraft). This utilizes the ACARS data link system for communication. ADS-C is the only solution available to ATC today. The second approach, which will be available in the near future, is space-based ADS-B which is enabled by new ADS-B payloads deployed on satellite constellations 'listening' to ADS-B 'broadcast' positional data and then relay to the ground. The same Mode S transponders that are used in terrestrial ADS-B are planned to be used to support space-based ADS-B.

10.2.2 ADS-B

ADS-B is a well-established cooperative surveillance technology and data broadcast standard which has been used for surveillance for more than ten years primarily overland masses. Space-based ADS-B will enable global surveillance, including oceanic flight operations, when it becomes operational in 2018. Appendix 2 summarizes the existing or planned ADS-B equipage mandates which will enable maximum operational benefit to be obtained.

The projected performance of space-based ADS-B is consistent with that of terrestrial ADS-B and fully supports the flight tracking recommendations made by the IATA Aircraft Tracking Task Force (ATTF) in December 2014 and ICAO's GADSS.

10.2.3 Future air navigation systems (FANS)

The FANS messages are sent over the ACARS data links and networks. FANS applications include:

- ADS-C: Automatic dependent surveillance-contract (ADS-C) is an existing technology with regulatory approval globally and already provides a two-way communication function between ATC ground systems and aircraft which can be transmitted automatically without pilot action. This is important as it maximizes the utilization of existing certified aircraft tracking. ADS-C is an important building block as it currently fully supports the conclusions of the Aircraft Tracking Task Force (ATTF) that a near-term goal of global tracking of airline flights should be pursued as a matter of priority. It is also consistent with the findings from the draft ICAO global aeronautical distress and safety system (GADSS) concept of operation.

11. On-board data link infrastructure

11.1 Current

11.1.1 Introduction

This section describes existing data link avionics system infrastructure available on aircraft today. Appendix 3 provides more details. On-board data link systems are typically divided according to the following categories. Systems that are a part of and support:

i) The flight deck – The aircraft control domain (ACD);

ii) The aircraft information services (AIS) data domain.

iii) Data link systems that are a part of and support the cabin or the passenger information and entertainment services (PIES) data domain.

iv) Data link systems that are limited to ground use only. Also known as airport surface data communications systems that include Wi-Fi (GateLink) and cellular technologies; these systems are not considered further in this Report since they are never used inflight and therefore cannot support flight tracking or real-time in-flight data streaming.

Data link systems that are required for critical required data communications between air crew and air traffic control and airline operations control are described as supporting safety services. For example, aircraft separation through the use of ADS-C is described as a data link safety service.

For a data link system to be accepted and qualified as suitable for safety services, the communications avionics and the associated data link services must meet stringent performance requirements. These avionics systems typically take years to specify, develop and then qualify before they undergo months of flight trials in order to demonstrate the required level of dependability needed for safety services. Aeronautical mobile-satellite (route) service (AMS(R)S) is designated by ICAO and ITU for a two-way communication via satellite(s) pertaining to the safety and regularity of the flight along national or international civil air routes. To date, Inmarsat I-3 (Classic Aero) and 1-4 Classic Aero service are approved for safety services. Iridium is now being used for safety services and Inmarsat I-4 (SwiftBroadband) is also now undergoing FANS over SwiftBroadband evaluation for safety services.

Aeronautical mobile (route) service (AM(R)S) is designated by ITU for a two-way communication pertaining to the safety and regularity of the flight. To date, VHF data link including VDL Mode 2 is the only terrestrial data link approved and used for safety services.

Air-to-ground (ATG) cellular, Ku-band and Ka-band data link systems are not approved for safety services.

11.1.2 On-board data link systems infrastructure – AIS domain/flight deck systems

Most data link systems for flight deck and avionics use are associated with the ACARS system which is available and used on-board most aircraft today, especially for long haul trans-oceanic aircraft. There is some use of other airborne data links for flight deck use but this is rather limited compared to the use of data links associated with ACARS. ACARS systems and associated data links shall be considered first followed by a discussion on other data links utilized for the flight deck.

11.1.2.1 ACARS – Aircraft communications addressing and reporting system (ACARS)

ACARS character-oriented protocol has been in use since the late 1970s, having been designed for transmission over narrow bandwidth pipes such as VHF radios. Linked to this are ground networks hosted by Rockwell Collins Information Systems (ARINC) and SITA, allowing aircraft to send reports of up to 220 characters in length either automatically or upon request. This allows aircraft and airline operation centers to exchange information such as equipment health and maintenance data, flight relevant events such as out, off, on, in (OOOI) status, or other en-route flight data such as engine performance, speed, altitude, flight plans, and numbers and city pair destinations.

The ACARS unit or function is not a data link system in itself that processes the character-oriented messages on board the aircraft, but rather a short text message router that uses available data link systems that may be installed and connected. These links include:

i) VHF data link or VHF digital link (VDL Mode 2);

ii) HF data link;

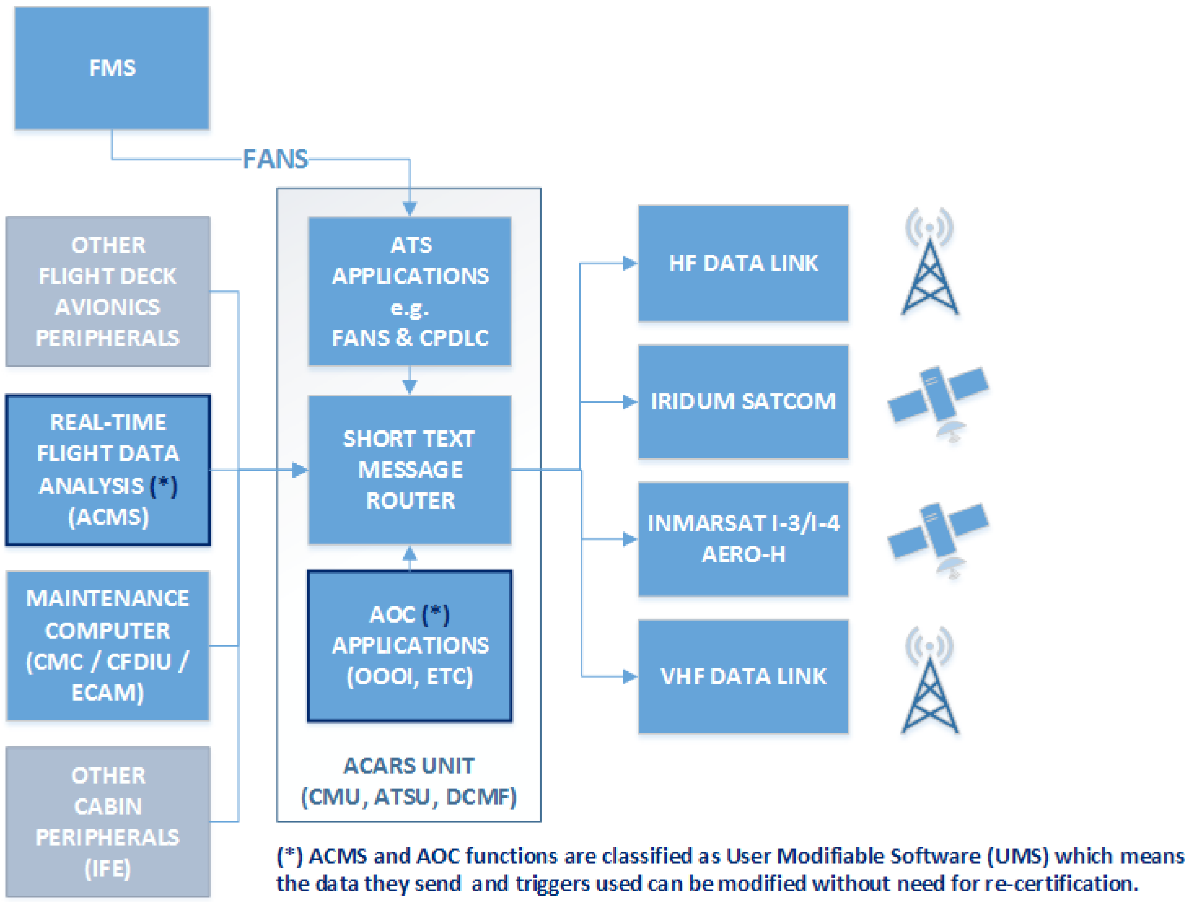
iii) Inmarsat Classic Aero SatCom systems;

iv) Iridium SatCom.

These links all are narrowband. HF provides 600 bps, while VDL Mode 2 provides 31.5 kbps and Analog VHF Data and SatCom links are limited to only 2.4 kbps when used for ACARS. The actual throughput data rate for VDL Mode 2 is less than 20 kbps. This means these ACARS data links are suited to sending short character oriented messages as they were designed for, but they are not suited for, streaming full black box data from modern aircraft generating over 5 MB per flight hour. It is feasible and it has been demonstrated that flight data parameters can be streamed over VDL Mode 2 and Iridium at a lesser rate that matches older black box data standard recording rates.

VHF or VDL Mode 2 is the most widely used overland, while Classic Aero SatCom is the most widely used on oceanic routes. HF data link is used to a much lesser extent and Iridium is increasingly being used too. Typically, airline's will configure their ACARS systems to utilize the lowest cost link when available which is usually VDL Mode 2, then SatCom, then HF data link but the airline preferences may vary based on their negotiated data services costs.

The diagram below also illustrates that many avionics systems are connected to the ACARS router as clients or "end-system" peripherals on board the aircraft. Systems such as the flight management system (FMS), aircraft condition monitoring system (ACMS) and maintenance and fault monitoring (CMC) as well as many other avionics are connected. The ACARS unit itself also includes an airline operational communication (AOC) application and the ACARS system is the core messaging protocol for FANS, controller-pilot data link communication (CPDLC) and ADS-C air traffic applications.



11.1.2.2 Other Data link systems used for flight deck applications

There are several systems which are designed for flight deck and avionics data communications that utilize Iridium that are not linked with the ACARS system. These include the following systems:

i) Panasonic (formerly Airdat) FlightLink weather data link system;

ii) STAR Navigation's in-flight safety monitoring system (Star-ISMS);

iii) FLYHT's automated flight information and reporting system (AFIRS).

11.1.3 On-board data link systems infrastructure – PIES domain/cabin systems

Over the last five years, there has been more and more broadband data link systems installed in the cabin on many airlines aircraft. In the USA, there have been a large number of air-to-ground (ATG) cellular systems installed by GoGo. Elsewhere in the world, airlines have installed SITA OnAir and Aeromobile systems which mostly use Inmarsat SwiftBroadband to bring connectivity to passengers on a global basis. Panasonic, Global Eagle Entertainment (formerly Row44) and Thales (formerly LiveTV) have collectively installed Ku and Ka-band SatCom systems on a significant numbers of aircraft.

11.1.4 Data rates

The data rates of the cabin broadband links are high compared to flight deck ACARS links (see Appendix 3):

i) SwiftBroadband data link supports up to 432 kbps per channel;

ii) GoGo's ATG-3 can provide 1.8 Mbps off the aircraft and 3.1 Mbps to the aircraft;

iii) GoGo's ATG-4 can provide 3.6 Mbps off the aircraft and 9.8 Mbps to the aircraft;

iv) Ku-band offers 1 Mbps off the aircraft and 50 Mbps or more to the aircraft;

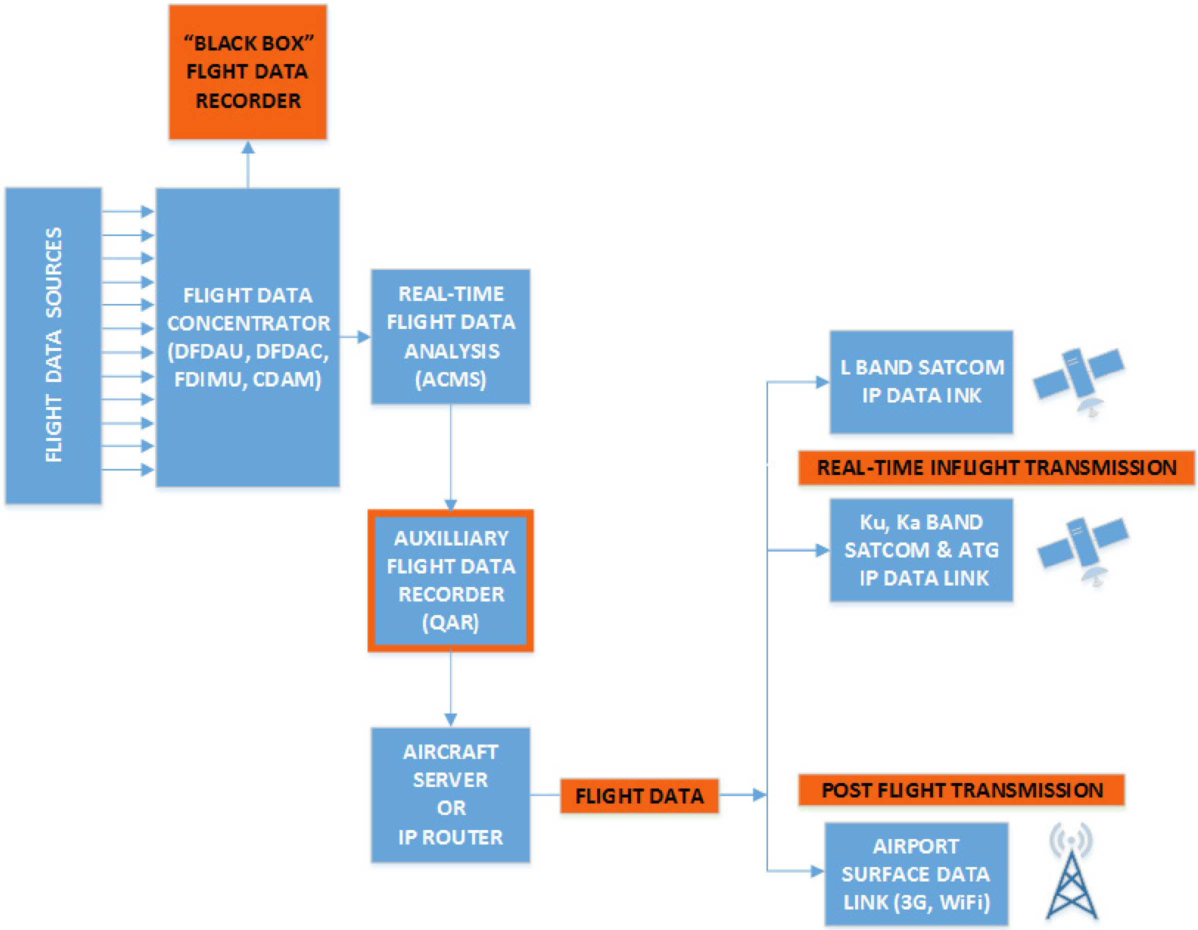
v) Ka-band offers 5 Mbps off the aircraft and 50 Mbps or more to the aircraft.

All of these systems provide relatively fast data rates off the aircraft compared to ACARS data links, i.e. between 432 kbps and 5 Mbps which is many times more than what would be needed to support black box flight data streaming. These cabin links are also much less expensive per MB to use and are also well suited to transfer non-safety service, non-ATC ACARS traffic.

Iridium has been installed by some airlines supporting cabin operations but due to the narrow bandwidth (2.4 kbps) the applications are relatively limited, for example, to live credit card validation or telemedicine.

11.1.5 Conclusion – On-board data link infrastructure (Current)

- Flight deck ACARS data link systems are already used to perform flight tracking. Together with FMS, ACARS enables ADS-C. Since FMS, ACMS and AOC capabilities are all integrated with ACARS, these may be used to expand flight tracking without installing additional equipment on the aircraft. With ACMS and AOC being user modifiable software (UMS), they are particularly well suited to hosting trigger algorithms that could be used to implement abnormal and autonomous distress tracking. With the fullest access to flight data parameters, ACMS is most likely the best suited and could be used for abnormal and autonomous distress tracking. The probable downside of using ACARS data links is their high transmission cost, but depending on the type of transmission/streaming/function, this should be expected to be low; this may not be a major concern.
- Current flight deck data link systems are not suited to full flight data streaming due to the narrow bandwidth and high transmission costs of these data links, and due to the fact that flight deck communications are not IP-based today but are really designed around messaging using special ARINC protocols.
- Cabin data link systems such as Ku-band, Ka-band and L-band Inmarsat SwiftBroadband where approved do provide very high bandwidth and low cost data transfer that supports routine tracking, distress tracking and even full flight black box streaming. ATG links, since they operate only overland, are not suited for trans-oceanic operations. Cabin broadband SatCom data link systems, although they do not have the same current equipage rates as flight deck data link systems, are increasingly being installed to provide passenger Internet access and this is forecasted to continue at a high installation growth rate.
- An apparent limitation of cabin data links is that they do not have native access to flight data system sources on board. There are network enabled IP data routing systems that have access to flight data that could be connected with the cabin broadband data link systems, and with time most of the Ku-band and Ka-band services will cover more and more of flight routes. Cabin data links also have an issue of being within the PIES domain on the aircraft, which means there are additional security measures that may be needed to protect AIS domain systems from potential attacks from the cabin. However, the industry is already working on security solutions to enable AIS and PIES domains to be connected.
- The diagram below illustrates how on-board information systems as described in section 10.1 may be connected with broadband data link systems to enable real-time data transmission.



- If cabin data link systems can be securely connected to AIS domain flight data information infrastructure on board such as IP data routers that already have access to flight data, then this combination would be very well suited to performing flight data streaming in support of GADSS flight data recovery requirements. Airlines are already downloading aircraft flight data post-flight over airport surface data links. Reuse of these systems to redirect the data transmission over broadband links is logical. Only after ICAO establishes performance standards can it be ascertained which data links can be used to meet the requirements.
- Since ICAO guidelines are that the solution for data streaming shall be performance based and be the responsibility of air carriers, and shall not be prescriptive, it will be possible for airlines and/or aircraft manufacturers to select from the combinations of available data acquisition, processing and routing systems and available data link systems to build a solution that meets SARPs.
- In view of the above, further considerations on frequency spectrum allocations and bandwidth requirements may be envisaged in order to properly examine the feasibility of reusing existing infrastructure to support real-time flight data streaming, which covers the various existing aviation satellite technologies and services (safety and non-safety purposes) as currently being provided to the aviation community throughout the world.

11.2 On-board data link infrastructure – Future

11.2.1 Introduction

This section explores the feasibility of using recent developments in on-board data link infrastructure. Future on-board data link systems may also be divided into three categories:

i) Data link systems that are a part of and support the aircraft control domain (ACD) or the aircraft information services (AIS) aircraft data domain. Planned developments here include the approval of Inmarsat SwiftBroadband for safety services use and the introduction of a new Internet protocol suite (IPS) that will utilize SwiftBroadband, VDL Mode 2 as well as new data links such as L-band digital aeronautical communications system (LDACS) terrestrial data link, Iridium Certus and other "Future SatCom" technologies for flight deck use.

ii) New data link systems that are a part of and support the cabin or the passenger information and entertainment services (PIES) data domain. Future developments include the introduction of Ku-band and Ka-band systems using high throughput satellites (HTS) and dual channel Ku-band systems such as GoGo's 2KU system. In addition, there are new ATG networks and systems planned including an LTE-based ATG planned by Inmarsat for the European region.

iii) Data link systems that are limited to ground use only. Future airport surface data communications systems developments are an introduction of equipment utilizing commercial LTE as well as AeroMACS which uses a dedicated 5.1 GHz band allocated for aviation use by ITU. These airport surface data systems are not considered further in this Report since they will not be used inflight and therefore cannot support flight tracking or real-time in-flight data streaming.

11.2.2 Internet protocol suite and new links for future DataComm

New network infrastructure for safety services based on the modern Internet protocol suite (IPS) is planned to meet future SESAR/FAA NextGen future DataComm needs. The airline and manufacturer industry body SAE-ITC Airlines Electronics Engineering Committee (AEEC) is considering beginning work to create a detailed technical definition of IPS for aeronautical safety services in a new ARINC Standard. This specification is to be based on the ICAO Doc 9896 IPS definition and on prevalent commercial IP network technology (e.g. IETF RFC 2460 for IPv6) with the modifications necessary to support aeronautical safety services. It is anticipated that IPS will use multiple line-of-sight and beyond-line-of-sight subnetworks that operate in 'protected' spectrum allocated by ITU and ICAO for safety services, including Inmarsat SwiftBroadband, Iridium Certus, AeroMACS, future SatCom and LDACS systems, and possibly VDL Mode 2.

11.2.3 Iridium NEXT/Certus

Iridium will begin the replacement of the entire Iridium satellite constellation of 66 low Earth Orbit satellites including 6 in-orbit spares. This replacement network is called Iridium NEXT and will begin in 2016 and will be completed by late 2017. The first aircraft equipage and regulatory operational assessments will take place in early 2017 for inclusion in testing and development of the ICAO GADSS program. With the increased capacity and much greater bandwidth (up to 1.4 Mbps), Iridium will continue to provide safety voice and data communications in addition to an entire new capability of safety and non-safety services including flight data recorder (FDR) download and other services utilizing secure IP streaming capability.

11.2.4 Conclusion – On-board data link infrastructure (Future)

Due to the long-time scales involved in developing new avionics data link systems and equipping a significant number of aircraft already in service, the future on-board data link systems described above may not be suitable in the near term. In the long term for 2020 and beyond, use of these data links systems could be considered.

In view of the above, further considerations on frequency spectrum allocations and bandwidth requirements may be envisaged in order to properly examine the feasibility of using future data link systems and recent developments in commercial aeronautical data link services, which covers the latest developments from various commercial broadband technologies and services for the aeronautical environment throughout the world.

12. Issues and limitations

12.1 Introduction

There are a range of strategic and technical issues which must be explored across the work of the entire sub working groups. To ensure that these issues are documented, the following have been identified to date.

12.2 Future data stream solutions

Given the limited time devoted to this Report, it has not been possible to define or develop future solutions for data streaming which could reduce the consequences associated with aircraft operating in abnormal circumstances. There is an opportunity to progress this future design work using this Report as the baseline of existing capabilities.

12.3 Data compression

This involves encoding information using fewer bits than the original representation. It is useful because it helps reduce resource usage, such as data storage space or transmission capacity. Lossless (no information is lost) compression reduces bits by identifying and eliminating statistical redundancy and involves trade-offs among various factors, including the degree of compression, space-time complexity and the computational resources required.

In order to make an efficient use of the frequency spectrum and to make best use of available bandwidth, data compression is a must. There are plenty of mechanisms already developed and tested that might be ready to implement, for example, Recommendation ITU-T V.44 (11/2000) offers a compression ratio of 6:1 (for pure text).

12.4 Cybersecurity

Cybersecurity is the process of applying security measures to ensure confidentiality, integrity, and availability of data by which digital equipment, information and services are protected from unintended or unauthorized access, change or destruction. The goal is to protect data both in transit and at rest and includes, but not limited to, encryption, integrity and authentication methods. Countermeasures can be put in place in order to ensure security of data. Some of these measures include, but are not limited to, access control, awareness training, audit and accountability, risk assessment, penetration testing, vulnerability management, and security assessment and authorization.

13. Recommendations and conclusions

13.1 Recommendations

The following recommendations are proposed for ITU consideration:

- That there are a range of existing technologies and infrastructure which can support the establishment of real-time data streaming capabilities from operating aircraft.
- Note that this Report contains a significant amount of material that can be considered under the responsibility of the Radiocommunication Sector (ITU-R) and is indeed currently being studied in ITU-R Study Groups 4 and 5.
- Note that this Report represents a valuable baseline of real-time data streaming capabilities and the content is relevant to many aspects of current safety improvements associated with flight tracking and real-time data streaming.
- Ensure that the various related working group committees are supplied with a copy of this Report to support the various aspects related to improving aviation safety.
- Once GADSS performance based requirements are defined for flight data streaming, further work will be required regarding the assessment of aircraft types and current equipage levels, which level of global service coverage is needed, which data volumes may be sent and which bandwidth is needed – and assess worst case needs (i.e. the bandwidth needed).
- Explore the significant range of operational, regulatory, technology and commercial aspects of the findings documented. This is work which could be conducted subject to the views of ITU.
- Commence work to define or develop future solutions for data streaming which could reduce the consequences associated with aircraft operating in abnormal circumstances, using this Report as the baseline of existing capabilities.
- Consider the material contained in this Report in further developing related activities and relevant Reports/Recommendations under the scope of concerned ITU study groups.
- Further work is required to establish real-time data streaming performance parameters or standards, and these values or parameters are likely to be selected based on the anticipated ICAO SARPs for GADSS.

13.2 Conclusions

This Report examines the feasibility of using recent developments in commercial aeronautical data link services, as well as reusing existing infrastructure, for real-time flight data streaming where appropriate.

The findings are that there are a range of existing technology capabilities that can be utilized which have existing avionic and regulatory approval and are consistent with the findings of the Aircraft Tracking Task Force (ATTF) and GADSS. In addition, there is a commercial evolution path with new technologies that are being progressed which also are consistent with the ATTF and GADSS concepts.

The analysis conducted also suggests that the original concept of black box in the cloud is a limiting term in that real-time streaming has a broader relevance and meaning, as there are a variety of technology solutions that could be implemented.

This Report also concludes that while this is a valuable source document, there are a number of actions which could be progressed and these are outlined in the recommendations section above.

14. Acronyms and abbreviations

This Report uses the following acronyms and abbreviations:

Code	Description
2G	Second Generation mobile network
3G	Third Generation mobile network
4G	Fourth Generation mobile network
AAC	Airline Administrative Communications
AAtS	Aircraft Access to SWIM
ACARS	Aircraft Communications Addressing and Reporting System
ACD	Aircraft Control Domain
ACMS	Aircraft Condition Monitoring System
ADIF	Aircraft Data Interface Function
ADS-B	Automatic Dependent Surveillance-Broadcast
ADS-C	Automatic Dependent Surveillance-Contract
AFIRS	Automated Flight Information and Reporting System
AID	Aircraft Interface Device
AIS	Aircraft Information Services
AISD	Aircraft Information Services Domain
AM(R)S	Aeronautical Mobile (Route) Service
AMS(R)S	Aeronautical Mobile-Satellite (Route) Service
AOC	Airline Operational Communication
APC	Airline Passenger Correspondence
ARINC	Aeronautical Radio, Incorporated
ASDI	Aeronautical Situational Display to Industry
ASIAS	Aviation Safety Information Analysis and Sharing
ATC	Air Traffic Control
ATFCM	Air Traffic Flow and Capacity Management
ATG	Air-to-Ground
ATM	Air Traffic Management
ATS	Air Traffic Services
ATSU	Air Traffic Service Unit
ATTF	Aircraft Tracking Task Force

Code	Description
CFDIU	Centralized Fault Display Interface Unit
CIWS	Corridor Integrated Weather System
CMC	Central Maintenance Computer
CMU	Communications Management Unit
CPDLC	Controller-Pilot Data Link Communication
CSP	Communication Service Provider
DAR	Digital ACMS Recorder
DCMF	Data Communications Management Function
DFDAC	Digital Flight Data Acquisition Card
DFDAU	Digital Flight Data Acquisition Unit
DHS	Department of Homeland Security
DL	Data Link
ECAM	Electronic Centralized Aircraft Monitor
EFB	Electronic Flight Bag
EGT	Engineering Technology
EOO	Extended Overwater Operations
ES	Extended Squitter
EvDO	Evolution-Data Optimized
EWD	Enhanced WINS Dissemination
FAA	Federal Aviation Administration
FANS	Future Air Navigation System
FDIMU	Flight Data Interface Management Unit
FDM	Flight Data Monitoring
FDP	Flight Data Processing
FDR	Flight Data Recorder
FDSL	Flight Data Services
FDX	Flight Data eXchange
FMS	Flight Management System
FTI	Flight Test Instrument
GADM	Global Aviation Data Management
GADSS	Global Aeronautical Distress and Safety System

Code	Description
GBAS	Ground-Based Augmentation System
GDDB	Ground Damage DataBase
GEO	Geosynchronous satellite
GRAS	Ground-based Regional Augmentation System
GSIC	Global Safety Information Centre
HF	High Frequency
HLSC	High Level Safety Conference
HTS	High Throughput Satellites
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IOSA	IATA Operational Safety Audit
IP	Internet Protocol
IPS	Internet Protocol Suite
ISAGO	IATA Safety Audit for Ground Operations
ISMS	In-flight Safety Monitoring System
ITWS	Integrated Terminal Weather System
LDACS	L-band Digital Aeronautical Communications System
LEO	Low Earth Orbit
LRU	Line Replaceable Unit
LTE	Long Term Evolution
NDS	NOTAM Distribution Service
NESG	Enterprise Security Gateway
NOTAM	Notice to Airmen
NTSB	National Transportation Safety Board
NWS	National Weather Service
OEM	Original Equipment Manufacturer
OOOI	Out, Off, On, In
PCMCIA	Personal Computer Memory Card International Association
PIES	Passenger Information and Entertainment Services
PIESD	Passenger Information and Entertainment Services Domain
PODD	Passenger Owned Devices Domain

Code	Description
QAR	Quick Access Recorder
R&D	Research and Development
RCP	Required Communication Performance
SAA	Special Activity Airspace
SAR	Search and Rescue
SARP	Standards and Recommended Practices
SatCom	Satellite Communication
SFDPS	SWIM Flight Data Publication Service
SITA	*Société Internationale de Télécommunications Aéronautiques*
SSR	Secondary Surveillance Radar
STDDS	SWIM Terminal Data Distribution System
STEADES	Safety Trend Evaluation Analysis and Data Exchange System
SWIM	System Wide Information Management
TBFM	Time-Based Flow Management
TFMS	Traffic Flow Management System
TTFD	Triggered Transmission of Flight Data
UAT	User Acceptance Test
UMS	User Modifiable Software
VDB	VHF Data Broadcast
VDL	VHF Data Link or VHF Digital Link
VHF	Very High Frequency
WARP	Weather and Radar Processor
WG	Working Group
WiFi	Wireless Fidelity
WINS	Weather Information Network Server
WMSCR	Weather Message Switching Centre Replacement
wps	Word per second

15. References

– Recommendation ITU-T V.44 (2000), Data compression procedures.

– ARINC 834 (2015), *Aircraft Data Interface Function*.

– IEEE 802.11 (2011), *IEEE Standard for Information technology – Local and metropolitan area networks – Specific requirements – Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications Amendment 8: IEEE 802.11 Wireless Network Management*.

– IETF RFC 2460 (1998), *Internet Protocol, Version 6 (IPv6) Specification*.

Appendix 1: Summary of ground-based infrastructure capabilities

The following table provides a brief overview of different communication service providers (CSPs) that could potentially provide or support the development of real-time flight data transmission.

NOTE – It is important to note that the content in the table is limited to those organizations who participated or contributed to the work of the Working Group.

Service provider	Firms	Data link provider	Downstream data from the flight deck	Send messages and control flight deck	Is the data link certified for safety communications?	Experience with "event-triggered" systems	Current safety connectivity products	Equipage rates
Legacy cockpit CSPs	SITA On Air	Inmarsat & Iridium						
	ARINC Rockwell Collins, SatCom Direct			Yes	Yes	Yes	- Electronic flight bags.	
							- Electronic flight instruments.	- 80% of wide bodies are equipped.
				ARINC and SITA are the leading CSPs for safety critical communications. Their services (from on board the aircraft to the ground infrastructure to the software programs) are certified to transmit safety critical data between aircraft and air traffic controllers.	ARINC and SITA both use Inmarsat L-band and a series of VHF/HF ground networks.	ARINC and SITA specialize in software employed by ATC/AOC ground units, which includes programs designed to interpret aircraft flight data in real time.	- Flight data computer systems.	

Service provider	Firms	Data link provider	Downstream data from the flight deck	Send messages and control flight deck	Is the data link certified for safety communications?	Experience with "event-triggered" systems	Current safety connectivity products	Equipage rates
							- Cockpit communications hardware/interfaces.	- 4,200 satellite connected aircraft (20% of global fleet).
			Yes, as data link providers.	This allows their on-board network technologies full access to communicate with flight computers.		They are safety certified for bidirectional communication with the aircraft flight computers, and can run an event identification/alert system outside of the aircraft.	- Data link and SatCom System services.	
							- Large scale global AOC/ATC service capabilities.	- Extensive communications technology infrastructure on the ground.
								- Extensive product range dealing with ATC/AOC software programs.
								- Satellite over remote areas/VHF over major land mass areas.

Service provider	Firms	Data link provider	Downstream data from the flight deck	Send messages and control flight deck	Is the data link certified for safety communications?	Experience with "event-triggered" systems	Current safety connectivity products	Equipage rates
	Flyht, STAR Navigation, Blue Sky Navigation, Spidertracks	Iridium				Yes		
			Yes	Yes, but are not approved for safety services as per the ICAO GOLD manual.	Not all		- Electronic flight bags.	- Only data link provider with polar coverage.
							- Electronic flight instruments.	
			Just as ARINC and SITA, these companies tend to provide a bundled service that includes flight deck applications, data link provisioning, air-to-ground and software to access and manipulate flight data on the ground.		For example, Iridium L-band is certified for safety operations.		- Flight data computer systems.	- Extensive experience, certification in safety and cockpit communications.
							- Cockpit communications hardware/interfaces.	
			Flyht in particular has developed extensive ability to harvest, package, and transmit different types of data.				- Data link and SatCom System services.	

Service provider	Firms	Data link provider	Downstream data from the flight deck	Send messages and control flight deck	Is the data link certified for safety communications?	Experience with "event-triggered" systems	Current safety connectivity products	Equipage rates
							- AOC/ATC tailored products.	
Cabin oriented CSPs	Gogo, Panasonic, Global Eagle, Viasat, Global Xpress (Inmarsat)	Ku- and Ka-band satellite operators						
			Yes	No	No	No		- Over 4,000 aircraft online today, at least 12,000 by 2023.
			While unable to send commands to the flight computer, the on-board equipment can stream flight data off of the flight computers. This could then be transmitted off the aircraft to 3rd parties.	Cabin oriented CSPs currently use on-board network technology that is not certified to send communications to cockpit flight computers.	The Ku- and Ka-bands are not approved for safety communications due to risk of link failure (rain fade, skew angle degradation, etc.).	Cabin oriented CSPs would be obliged to incorporate AIDs to merge their on-board networks with flight deck avionics.	- Some EFB and limited cockpit/crew applications.	- Increased throughput.
							- Limited data streaming to airline operations.	
					Today, only the L-band is approved under the ARINC standards.			- Reduced cost per MB.

Service provider	Firms	Data link provider	Downstream data from the flight deck	Send messages and control flight deck	Is the data link certified for safety communications?	Experience with "event-triggered" systems	Current safety connectivity products	Equipage rates
Equipment/airborne infrastructure providers	Teledyne Controls, Arconics, Lufthansa Systems, UTC Aerospace, DAC International, navAreo, Astronautics, CMC Electronics, Flyht, Cobham	Access to multiple data links.	Yes	Unknown, but will likely be subject to strict regulations once BBiC standards are established.	N/A	Yes		- Ability to aggregate data from various parts of aircraft, including different software platforms, into one format.
							- Electronic flight bags.	
						The majority of these companies have "smart data" capability, as well as the ability to access specific data types from the flight deck.	- Aircraft interface devices.	- AIDs allow non SOS-certified hardware (i.e. EFBs) to have bidirectional communications with safety avionics.
							- Electronic flight instruments.	
							- Various AOC services such as flight tracking, terrestrial data streaming, etc.	- Ability to convert ACARS messages into IP data packets to be sent over broadband links.
Flight data monitoring	FDSL, Teledyne, Sagem, Aerobytes, Airbus, GE Aviation	N/A	N/A	N/A	N/A	N/A	N/A	Performed by virtually all airlines.

Service provider	Firms	Data link provider	Downstream data from the flight deck	Send messages and control flight deck	Is the data link certified for safety communications?	Experience with "event-triggered" systems	Current safety connectivity products	Equipage rates
Air traffic service tracking providers	Multiple ATC service providers such as FAA, Air services Australia, Airways New Zealand, NAMA Nigeria, ATNS South Africa, Euro control.	No	Yes	Yes, depending on type of technology.	Yes, subject to type of technology.	Yes, subject to type of technology.	N/A	Unknown and subject to type of technology.

Appendix 2: ADS-B mandates

The following table summarizes planned or existing ADS-B mandates globally.

Region	Published material and equipage mandates
Europe	• The European Commission has enacted an Implementing Regulation laying down requirements for the performance and the interoperability of surveillance for the Single European Sky ((EU) No 1207/2011). This was recently updated by the Commission Implementing Regulation (EU) No 1028/2014 of 26 September 2014 amending Implementing Regulation (EU) No 1207/2011 which mandates specific ADS-B equipage after 7 June 2020.
United States	• In 2010, the FAA issued a new rule contained in Title 14 of the Code of Federal Regulations (14 CFR) part 91, §§ 91.225 and 91.227. This rule requires ADS-B (Out) performance when operating in designated classes of airspace within the NAS after 1 January 2020.
Canada	• Transport Canada Advisory Circular (AC) No. 700-009. • Issue 2 EASA AMC 20-24.
Australia	• Guidance material: CAO 20.18, Amend Order No. 3, dated December 2009. • Mandates ADS-B Out for upper airspace (≥ FL290) in December 2013.
Hong Kong	• After 31 December 2014 for aircraft flying within Hong Kong FIR between FL290 and FL410. • Must meet DO-260 (Version 0) requirements of ICAO Annex 10 and ICAO Doc 9871 Chapter 2, or DO-260A (Version 1) requirements of ICAO Doc 9871 Chapter 3. • Means of compliance per EASA AMC 20-24 or CASA CAO 20.18 Appendix XI.
Singapore	• Guidance material: CAAS AIC 14, 28 December 2010. • Implement the use of ADS-B Out after 12 December 2013 within certain parts of the Singapore FIR (≥ FL290). • EASA AMC 20-24 or CASA CAO 20.18 Appendix XI, otherwise must fly at < FL290.
Other Asia Pacific countries	• Expected to follow ADS-B Avionics Requirements template per APANPIRG Conclusion 21/39. • EASA AMC 20-24 or CASA CAO 20.18 Appendix XI.

Appendix 3: Summary of data link systems profiles and performance

These tables are largely based on information collected by RTCA SC-206 and published on March 18th, 2014 in Appendix C of RTCA DO-349.

The vendors listed in the tables are representative examples for each data link technology listed.

Some of the vendors listed provided data points to RTCA SC-206 and these were included in the table for their respective links.

Additional data points in the DO-349 Appendix C tables were provided by either subject matter expects or research performed by the authors of RTCA DO-349.

Further data points in these tables were provided by either subject matter expects or research performed by the authors of the FG-AC report.

Regardless of its origins, the information contained in these tables does not represent vendor-specific implementation values, but rather is intended to represent the defined data link technology.

Note: The absence of information in some rows in these tables is a result of appropriate information being unavailable to FG-AC Working Group 4 at the time of writing.

(continued)

Table 1 Technology profiles for Terrestrial Data Link Technologies

Technology		VDL Mode 0/A	VDL Mode 2		HFDL	VDL Mode 4	UAT/978	1090ES	GBAS/GRAS VDB	EvDO Rev.A	EvDO Rev.B	LTE
			ACARS	ATN								
Example Provider		ARINC, SITA	ARINC, SITA		ARINC	LFV	ITT	ITT	Institute for Air Navigation Services (IANS)/ Spectrum	GoGo	GoGo	Inmarsat
Link Use (1)	Air-to-Air (Crosslink)	N	N	N	N	Y	Y	Y	N	Y	Y	
	Ground-to-Air (Uplink)	Y	Y	Y	Y	Y	Y (Automatic Dependent Surveillance – Rebroadcast (ADS-R)/Traffic Information Services – Broadcast (TIS-B)/FIS-B)	Y (ADS-R/TIS-B)	Y	Y	Y	Y
	Air-to-Ground (Downlink)	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y
Altitude Coverage/ Restrictions		No technical restrictions line of sight (LOS)	No technical restrictions LOS	No technical restrictions LOS	No technical restrictions LOS	No technical restrictions LOS	No technical restrictions LOS	No technical restrictions LOS	No technical restrictions LOS	No technical restrictions, but legally can only be used >10,000 ft AGL	No technical restrictions, but legally can only be used >10,000 ft AGL	

(continued)

Technology	VDL Mode 0/A	VDL Mode 2		HFDL	VDL Mode 4	UAT/978	1090ES	GBAS/GRAS VDB	EvDO Rev.A	EvDO Rev.B	LTE
		ACARS	ATN								
Example Provider	ARINC, SITA	ARINC, SITA		ARINC	LFV	ITT	ITT	Institute for Air Navigation Services (IANS)/ Spectrum	GoGo	GoGo	Inmarsat
Geographic Coverage	Within 200 nm of a ground station	Within 200 nm of a ground station	Within 200 nm of a ground station	Global	Sweden: Russia: Moscow, Tuymen region, part coverage elsewhere. Small pockets of coverage elsewhere in Europe, Middle East, and Asia. Nationwide.	U.S. by 2013	U.S. Air-to-air: 90 nm Air-to-ground 150 nm	Within 200 nm of a ground station in U.S., Asia, and Russia	Now: Contiguous U.S., portion of Alaska, up to 250 miles offshore Future: Canada, Mexico	Now: Contiguous U.S., portion of Alaska, up to 250 miles off-shore Future: Canada, Mexico	Europe
Frequency Band	118.000-136.975 Megahertz (MHz) Depends on DLSP and Region	136.975 MHz Common Freq Multi Freq Ops in Development	117.975-137 MHz	2.85-22 MHz Depends on DLSP and Region	112.000-136.975 MHz	978 MHz	1090 MHz	108.000-117.975 MHz	849-851 MHz (Rx) 894-896 MHz (Tx)	849-851 MHz (Rx) 894-896 MHz (Tx)	

(continued)

Technology	VDL Mode 0/A	VDL Mode 2		HFDL	VDL Mode 4	UAT/978	1090ES	GBAS/GRAS VDB	EvDO Rev.A	EvDO Rev.B	LTE
		ACARS	ATN								
Example Provider	ARINC, SITA	ARINC, SITA		ARINC	LFV	ITT	ITT	Institute for Air Navigation Services (IANS)/ Spectrum	GoGo	GoGo	Inmarsat
Data Rate	2.4 kilobits per second (kbps)	31.5 kbps	31.5 kbps	300-1800 bps	19200 bps	1 Megabits per second (Mbps)	695 bps (burst) 4x with	31.5 kbps (uplink only)	Peak 3.1 Mbps (uplink) 1.8 Mbps (downlink) per modem; 1 modem per aircraft	Peak 4.9 Mbps (uplink) 1.8 Mbps (downlink) per modem; 2 modems per aircraft	
Safety Classification and Approval	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No
Latency	> 5 s (ARINC)	< 3.5 s 95% (ARINC)	<3.5 s 95% — (RTCA DO-224C)	Highly dependent on atmospheric conditions		1.2 ms at 200 nm	1.2 ms at 200 nm	937.5 ms	<50 ms node-to-node ping	<35 ms node-to-node ping (Avg <50 ms)	
Multi-Critical Application Capability/ Prioritization	No	No		No	Yes	No	No	No	DiffServ IETF	DiffServ IETF	

(1) The answers provided in the Link Use row are dependent upon the Altitude Coverage/Restrictions row in this table

(continued)

Table 2 Technology profiles for Satellite Data Link Technologies

Technology		L-band GEO Equatorial I-3 I-4 Classic Aero H/H+	L-band GEO Equatorial I-3 Swift64	L-band GEO Equatorial I-4 Swift Broadband	L-band LEO	Ku-Band GEO	Ka-Band GEO
Example Provider or Information Request Response Provider		**Inmarsat**			**Iridium**	**GoGo, Global Eagle Entertainment, Panasonic (PAC), ViaSat**	**ViaSat, EutelSat, Inmarsat, GoGo**
Link Use (1)	Air-to-Air (Crosslink)	N	N	N	N	N	N
	Ground-to-Air (Uplink)	Y	Y	Y	Y	Y	Y
	Air-to-Ground (Downlink)	Y	Y	Y	Y	Y	Y
Altitude Coverage/ Restrictions		No technical restrictions	No technical restrictions	No technical restrictions	No technical restrictions	No technical restrictions, but legally can only be used >10,000 ft AGL in some countries (e.g., Germany, USA, Malta, Switzerland, Philippines, Italy, Belgium)	No technical restrictions, susceptible to rain fade
Geographic Coverage		< 80° |Latitude|	< 80° |Latitude|	< 80°|Latitude|	Global	< 80° |Latitude| and beam dependent	< 80° |Latitude| and beam dependent

(continued)

Technology	L-band GEO Equatorial			L-band LEO	Ku-Band GEO	Ka-Band GEO
	I-3 I-4 Classic Aero H/H+	I-3 Swift64	I-4 Swift Broadband			
Example Provider or Information Request Response Provider	**Inmarsat**			**Iridium**	**GoGo, Global Eagle Entertainment, Panasonic (PAC), ViaSat**	**ViaSat, EutelSat, Inmarsat, GoGo**
Frequency Band	1530-1559 MHz (Rx) 1626.5-1660.5 MHz (Tx)	1530-1559 MHz (Rx) 1626.5-1660.5 MHz (Tx)	1525-1559 MHz (Rx) 1626.5-1660.5 MHz (Tx)	1618.725-1626.5 MHz	10.2-12.2 GHz (Rx) 14.0-14.5 GHz (Tx)	29 GHz band (Rx) 19 GHz band (Tx)
Data Rate	0.6-10.5 kbps	64 kbps 4x with channel bonding	432 kbps (not all will be assigned to safety service)	2.4 kbps	50 Mbps (uplink) 1 Mbps (downlink)	50 Mbps (uplink) 5 Mbps (downlink)
Safety Classification and Approval	Yes	No	In work / planned	Yes	No	No
Latency	50 s 95%; meet RCP240D	Meet RCP240	10 s 95%; meet RCP240D	< 2 s 95% (RTCA DO- 270 Change 1)	800 ms; satellite accounts for the biggest part	800 ms; satellite accounts for the biggest part
Multi-Critical Application Capability/ Prioritization	Yes	Yes, only for lease services	Yes, under development		Yes	Yes

(1) The answers provided in the Link Use row are dependent upon the Altitude Coverage/Restrictions row in this table.

Appendix 4: Analysis of global bandwidth and cloud storage required to support black box streaming

Worst case scenarios for continuous streaming and triggered streaming are provided in the spreadsheet below. The triggered streaming are for various word per second with associated kbps from 64 wps – 1024 wps.

Continuous data streaming analysis

This analysis illustrates the total global bandwidth and data storage needs for a given quantitiy of aircraft that might be in flight simultaneously.

Three tables provide three sets of analysis for streaming:

a) 1024wps flight data recorder (black box) data which is the most common recording rate on new aircraft in 2015

b) 64wps flight data recorder (black box) data which was the standard recording rate for many aircraft in the late 1980s and early 1990s.

c) streaming only aircraft position information

<u>Assumptions for this analysis</u>

Black Box Data Recording Rate = 1024 ARINC 717 words per second (wps) (New aircraft are increasingly using this data rate)
One ARINC 717 word = 12 bits
Data Recorded in One Hour by One Aircraft = 5.4 MB
Transmission rate to send 5.4 MB / Hour continuously without including overhead = 12.3 Kbps
This rate would be 16x less if only 64wps data is sent (768 bps); or 170x less if only lat/long/alt is sent (72 bps).
These bandwidth needs assume continuous transmission and not transmission of an accumulated amount of flight recording.

	1024wps		64wps		Lat / Long / alt only	
No. of Aircraft in Flight instantaneously	Total Global Bandwidth Required (Mbps) for 1024wps data frame	Total Global Data Volume per Month (TB) for 1024wps data frame (*)	Total Global Bandwidth Required (Mbps) for 64wps data frame	Total Global Data Volume per Month (GB) for 64wps data frame (*)	Total Global Bandwidth Required (Mbps) for lat/long/alt only	Total Global Data Volume per Month (GB) for lat/long/alt only (*)
10	0.12	0.022	0.0073	1.4	0.0007	0.13
100	1.2	0.22	0.07	14	0.007	1
1,000	12	2	0.73	138	0.07	13
2,000	23	4	1.46	277	0.14	26
3,000	35	6	2.20	415	0.21	39
4,000	47	9	2.93	554	0.27	52
5,000	59	11	3.66	692	0.34	65
6,000	70	13	4.39	831	0.41	78
7,000	82	15	5.13	969	0.48	91
8,000	94	17	5.86	1,107	0.55	104
9,000	105	19	6.59	1,246	0.62	117
10,000	117	22	7.32	1,384	0.69	130
11,000	129	24	8.06	1,523	0.76	143
12,000	141	26	8.79	1,661	0.82	156
13,000	152	28	9.52	1,800	0.89	169
14,000	164	30	10.25	1,938	0.96	182
15,000	176	32	10.99	2,076	1.03	195
16,000	188	35	11.72	2,215	1.10	208
17,000	199	37	12.45	2,353	1.17	221
18,000	211	39	13.18	2,492	1.24	234
19,000	223	41	13.92	2,630	1.30	247
20,000	234	43	14.65	2,769	1.37	260

(*) Assumed average Flight Hours per aircraft per month = 420 Hours (this only affects data volumes collected over time and not bandwidth requirements)

<u>Notes:</u>

Data may be compressed before transmission which will reduce bandwidth requirements while transmission protocols used may introduce overhead and increased bandwidth requirements.
The average black box frame size today is more realistically 512wps or less, which could cut the above global data volume and bandwidth requirements at least in half

Data rates 12,288 Kbps (1024wps), 768 bps (64wps) and 72 bps (lat/long/alt) are consistent with BEA "Flight Data Recovery" Paper published in December 2009

TRIGGERED TRANSMISSION FLIGHT DATA STREAMING ANALYSIS

The tables below illustrate the bandwidth requirements required for a single aircraft to stream accumulated black box data based on airborne or ground triggering of the transmission.
Each table shows for a given flight recorder standard (1024, 512, 256, 64 wps) what bandwidth would be required to transmit between 1 and 24 hours of accumulated data assuming the trigger to stream data occurrs between 1
Assumptions: 1) the data volumes are raw with no compression 2) transmission rate is raw with no overhead added (in practise some compression may be possible and there will be some overhead)
3) some additional bandwidth is needed to account for sending data recording during the minutes from time of trigger to time of crash. This is 12 Kbps for 1024wps, 6 Kbps for 512wps, 3 Kbps for 256wps and 0.7
The green area represents scenarios where 432 Kbps bandwidth may be adequate to send all the accumulated flight data. The red area represents scenarios where more than 432 Kbps may be needed.

Bandwidth (Kbps) Needed for Crash Scenario (1024 wps recording)

The values shown in the table represent the required bandwidth needed to send the accumulated flight data (1024 wps recording) from an aircraft within the time remaining before recording stops (time of crash)

Minutes before crash / Accumulated Data (Hours)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Data Volume to be sent (MB)
1	737	369	246	184	147	123	105	92	82	74	67	61	57	53	49	5.4
2	1475	737	492	369	295	246	211	184	164	147	134	123	113	105	98	11
3	2212	1106	737	553	442	369	316	276	246	221	201	184	170	158	147	16
4	2949	1475	983	737	590	492	421	369	328	295	268	246	227	211	197	22
5	3686	1843	1229	922	737	614	527	461	410	369	335	307	284	263	246	27
6	4424	2212	1475	1106	885	737	632	553	492	442	402	369	340	316	295	32
7	5161	2580	1720	1290	1032	860	737	645	573	516	469	430	397	369	344	38
8	5898	2949	1966	1475	1180	983	843	737	655	590	536	492	454	421	393	43
9	6636	3318	2212	1659	1327	1106	948	829	737	664	603	553	510	474	442	49
10	7373	3686	2458	1843	1475	1229	1053	922	819	737	670	614	567	527	492	54
11	8110	4055	2703	2028	1622	1352	1159	1014	901	811	737	676	624	579	541	59
12	8847	4424	2949	2212	1769	1475	1264	1106	983	885	804	737	681	632	590	65
13	9585	4792	3195	2396	1917	1597	1369	1198	1065	958	871	799	737	685	639	70
14	10322	5161	3441	2580	2064	1720	1475	1290	1147	1032	938	860	794	737	688	76
15	11059	5530	3686	2765	2212	1843	1580	1382	1229	1106	1005	922	851	790	737	81
16	11796	5898	3932	2949	2359	1966	1685	1475	1311	1180	1072	983	907	843	786	86
17	12534	6267	4178	3133	2507	2089	1791	1567	1393	1253	1139	1044	964	895	836	92
18	13271	6636	4424	3318	2654	2212	1896	1659	1475	1327	1206	1106	1021	948	885	97
19	14008	7004	4669	3502	2802	2335	2001	1751	1556	1401	1273	1167	1078	1001	934	103
20	14746	7373	4915	3686	2949	2458	2107	1843	1638	1475	1341	1229	1134	1053	983	108
21	15483	7741	5161	3871	3097	2580	2212	1935	1720	1548	1408	1290	1191	1106	1032	113
22	16220	8110	5407	4055	3244	2703	2317	2028	1802	1622	1475	1352	1248	1159	1081	119
23	16957	8479	5652	4239	3391	2826	2422	2120	1884	1696	1542	1413	1304	1211	1130	124
24	17695	8847	5898	4424	3539	2949	2528	2212	1966	1769	1609	1475	1361	1264	1180	130

Bandwidth (Kbps) Needed for Crash Scenario (512 wps recording)

The values shown in the table represent the required bandwidth needed to send the accumulated flight data (512 wps recording) from an aircraft within the time remaining before recording stops (time of crash)

Minutes before crash / Accumulated Data (Hours)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Data Volume to be sent (MB)
1	369	184	123	92	74	61	53	46	41	37	34	31	28	26	25	2.7
2	737	369	246	184	147	123	105	92	82	74	67	61	57	53	49	5.4
3	1106	553	369	276	221	184	158	138	123	111	101	92	85	79	74	8.1
4	1475	737	492	369	295	246	211	184	164	147	134	123	113	105	98	11
5	1843	922	614	461	369	307	263	230	205	184	168	154	142	132	123	14
6	2212	1106	737	553	442	369	316	276	246	221	201	184	170	158	147	16
7	2580	1290	860	645	516	430	369	323	287	258	235	215	198	184	172	19
8	2949	1475	983	737	590	492	421	369	328	295	268	246	227	211	197	22
9	3318	1659	1106	829	664	553	474	415	369	332	302	276	255	237	221	24
10	3686	1843	1229	922	737	614	527	461	410	369	335	307	284	263	246	27
11	4055	2028	1352	1014	811	676	579	507	451	406	369	338	312	290	270	30
12	4424	2212	1475	1106	885	737	632	553	492	442	402	369	340	316	295	32
13	4792	2396	1597	1198	958	799	685	599	532	479	436	399	369	342	319	35
14	5161	2580	1720	1290	1032	860	737	645	573	516	469	430	397	369	344	38
15	5530	2765	1843	1382	1106	922	790	691	614	553	503	461	425	395	369	41
16	5898	2949	1966	1475	1180	983	843	737	655	590	536	492	454	421	393	43
17	6267	3133	2089	1567	1253	1044	895	783	696	627	570	522	482	448	418	46
18	6636	3318	2212	1659	1327	1106	948	829	737	664	603	553	510	474	442	49
19	7004	3502	2335	1751	1401	1167	1001	876	778	700	637	584	539	500	467	51
20	7373	3686	2458	1843	1475	1229	1053	922	819	737	670	614	567	527	492	54
21	7741	3871	2580	1935	1548	1290	1106	968	860	774	704	645	595	553	516	57
22	8110	4055	2703	2028	1622	1352	1159	1014	901	811	737	676	624	579	541	59
23	8479	4239	2826	2120	1696	1413	1211	1060	942	848	771	707	652	606	565	62
24	8847	4424	2949	2212	1769	1475	1264	1106	983	885	804	737	681	632	590	65

Bandwidth (Kbps) Needed for Crash Scenario (256 wps recording)

The values shown in the table represent the required bandwidth needed to send the accumulated flight data (256 wps recording) from an aircraft within the time remaining before recording stops (time of crash)

Minutes before crash / Accumulated Data (Hours)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Data Volume to be sent (MB)
1	184	92	61	46	37	31	26	23	20	18	17	15	14	13	12	1.4
2	369	184	123	92	74	61	53	46	41	37	34	31	28	26	25	2.7
3	553	276	184	138	111	92	79	69	61	55	50	46	43	39	37	4.1
4	737	369	246	184	147	123	105	92	82	74	67	61	57	53	49	5.4
5	922	461	307	230	184	154	132	115	102	92	84	77	71	66	61	6.8
6	1106	553	369	276	221	184	158	138	123	111	101	92	85	79	74	8.1
7	1290	645	430	323	258	215	184	161	143	129	117	108	99	92	86	9.5
8	1475	737	492	369	295	246	211	184	164	147	134	123	113	105	98	11
9	1659	829	553	415	332	276	237	207	184	166	151	138	128	118	111	12
10	1843	922	614	461	369	307	263	230	205	184	168	154	142	132	123	14
11	2028	1014	676	507	406	338	290	253	225	203	184	169	156	145	135	15
12	2212	1106	737	553	442	369	316	276	246	221	201	184	170	158	147	16
13	2396	1198	799	599	479	399	342	300	266	240	218	200	184	171	160	18
14	2580	1290	860	645	516	430	369	323	287	258	235	215	198	184	172	19
15	2765	1382	922	691	553	461	395	346	307	276	251	230	213	197	184	20
16	2949	1475	983	737	590	492	421	369	328	295	268	246	227	211	197	22
17	3133	1567	1044	783	627	522	448	392	348	313	285	261	241	224	209	23
18	3318	1659	1106	829	664	553	474	415	369	332	302	276	255	237	221	24
19	3502	1751	1167	876	700	584	500	438	389	350	318	292	269	250	233	26
20	3686	1843	1229	922	737	614	527	461	410	369	335	307	284	263	246	27
21	3871	1935	1290	968	774	645	553	484	430	387	352	323	298	276	258	28
22	4055	2028	1352	1014	811	676	579	507	451	406	369	338	312	290	270	30
23	4239	2120	1413	1060	848	707	606	530	471	424	385	353	326	303	283	31
24	4424	2212	1475	1106	885	737	632	553	492	442	402	369	340	316	295	32

Bandwidth (Kbps) Needed for Crash Scenario (64 wps recording)

The values shown in the table represent the required bandwidth needed to send the accumulated flight data (64 wps recording) from an aircraft within the time remaining before recording stops (time of crash)

Accumulated Data (Hours) \ Minutes before crash	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Data Volume to be sent (MB)
1	46	23	15	12	9	8	7	6	5	5	4	4	4	3	3	0.3
2	92	46	31	23	18	15	13	12	10	9	8	8	7	7	6	0.7
3	138	69	46	35	28	23	20	17	15	14	13	12	11	10	9	1.0
4	184	92	61	46	37	31	26	23	20	18	17	15	14	13	12	1.4
5	230	115	77	58	46	38	33	29	26	23	21	19	18	16	15	1.7
6	276	138	92	69	55	46	39	35	31	28	25	23	21	20	18	2.0
7	323	161	108	81	65	54	46	40	36	32	29	27	25	23	22	2.4
8	369	184	123	92	74	61	53	46	41	37	34	31	28	26	25	2.7
9	415	207	138	104	83	69	59	52	46	41	38	35	32	30	28	3.0
10	461	230	154	115	92	77	66	58	51	46	42	38	35	33	31	3.4
11	507	253	169	127	101	84	72	63	56	51	46	42	39	36	34	3.7
12	553	276	184	138	111	92	79	69	61	55	50	46	43	39	37	4.1
13	599	300	200	150	120	100	86	75	67	60	54	50	46	43	40	4.4
14	645	323	215	161	129	108	92	81	72	65	59	54	50	46	43	4.7
15	691	346	230	173	138	115	99	86	77	69	63	58	53	49	46	5.1
16	737	369	246	184	147	123	105	92	82	74	67	61	57	53	49	5.4
17	783	392	261	196	157	131	112	98	87	78	71	65	60	56	52	5.7
18	829	415	276	207	166	138	118	104	92	83	75	69	64	59	55	6.1
19	876	438	292	219	175	146	125	109	97	88	80	73	67	63	58	6.4
20	922	461	307	230	184	154	132	115	102	92	84	77	71	66	61	6.8
21	968	484	323	242	194	161	138	121	108	97	88	81	74	69	65	7.1
22	1014	507	338	253	203	169	145	127	113	101	92	84	78	72	68	7.4
23	1060	530	353	265	212	177	151	132	118	106	96	88	82	76	71	7.8
24	1106	553	369	276	221	184	158	138	123	111	101	92	85	79	74	8.1

Appendix 5: WG4 composition

i) Ifeanyi Frank Ogochukwu – Debbie Mishael Consulting, Nigeria (Group Leader)

ii) Stephen Angus – Inmarsat, UK

iii) Matt De Ris – Panasonic Avionics Corporation, USA

iv) William Cecil – Teledyne Controls, USA

v) Hannes-Stephan Griebel – Thales Alenia Space, Germany

vi) Juan Pablo Martin – Universidad Tecnológica Nacional, Argentina

vii) Nelson Malaguti – International Telecommunication Union, Switzerland

viii) Maiwada Abdulaziz – Nigerian Airspace Management Agency, Nigeria

ix) Olumuyiwa Adegorite – Nigerian Airspace Management Agency, Nigeria

x) Rachel Donald – Inmarsat Aviation, Switzerland

xi) Carlos Flores – Federal Communications Commission, USA

xii) Loftur Jonasson – International Civil Aviation Organization, Canada

xiii) Paul Najarian – Department of State, USA

xiv) Ken McLean – Aireon LCC, Australia

xv) Michael Hooper – Iridium, USA

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