ITU-T

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

Key findings, recommendations for next steps and future work

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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 Introduction

The final Focus Group Report is presented in this document, with recommendations for next steps and future work for the consideration of the ITU Telecommunication Standardization Advisory Group (TSAG).

FG AC has structured its work into four working groups developing three reports/deliverables. The output of these groups is interdependent. Definitions, terms and references can be found as an annex to this document.

This document was the result of compilation of Deliverables 1 to 4 from ITU-T FG AC working groups. The development was built on the concept of the current knowledge and available technologies that were discussed and deliberated within the period of the study group.

2 Objective

Based on the findings laid out in the Focus Group deliverables, the objective of this final Report is to make recommendations for next steps and future work for the consideration of the ITU Telecommunication Standardization Advisory Group (TSAG).

3 Key findings and recommendation by each deliverable

3.1 Deliverable 1: Existing and emerging technologies of cloud computing and data analytics

The approach of Deliverable 1 is based on the evaluation of current technologies and then discussions on the consideration of emerging technologies applicable to real-time flight data monitoring (FDM). It also identifies current cloud computing and data analytics technology such as available technology and solutions, and acceptable to stakeholders such as airlines, industry operators and regulators. Please refer to Deliverable 1 for details.

3.1.1 Contributions

A total of eight contributions[1] related to Deliverable 1 were received, as follows:

i. AC-I-009: Existing Recommendations and Standards Relating to Cloud Computing by MCMC Malaysia.

ii. AC-I-011: Technology for Cloud and Big Data Analytics by MIMOS Malaysia.

iii. AC-I-020: Update on ISO/IEC JTC 1/SC27 relating to security for cloud computing by Telekom Malaysia.

iv. AC-I-026: Draft progress report Deliverable 1.

v. AC-I-037: Draft progress report Deliverable 1.

vi. AC-I-041: Aviation Cloud for Real-time Flight Data Processing: A globally distributed Architecture.

vii. AC-I-050: Draft progress report Deliverable 1.

viii. AC-I-058: Draft progress report Deliverable 1.

[1] All FG AC contributions are available at https://extranet.itu.int/ITU-T/focusgroups/fgac/Input%20Documents/Forms/AllItems.aspx – Requires TIES or Guest account (https://www.itu.int/net/iwm/public/frmUserRegistration.aspx).

3.1.2 Key findings

A cloud service provider can provide reliable, secure and affordable infrastructure in which to host the applications needed to support flight data monitoring (FDM) and other types of data analytics. A cloud services partner may provide additional data analytics tools and services to drive additional benefit from the data and information that has been generated by standard FDM techniques and other data sources such as the weather, the aircraft communications addressing and reporting system (ACARS), electronic flight bags (EFBs), etc. The use of the cloud as a repository for sensitive data and information requires an assurance of security and privacy such as ISO/IEC 27001 and ISO/IEC 27000 family to protect the applicable airline as the cloud service customer (CSC).

3.1.2.1 Data analytics

The Internet of things (IoT) is driving exponential growth in sensors, networks and smart devices everywhere, providing a huge increase in streaming data, or 'Data in Motion'. Although this data has tremendous potential, much of it often retains its highest value for only a short period of time. 'Data in Motion' capabilities aim to extract data "on the fly" before it is stored – specific for aviation – before the data is sent to the ground, rather than 'Data at Rest' which refers to data that has been collected from various sources, stored and is then analysed after the event occurs.

The key advantage provided by 'Data in Motion' analytics is the ability to identify potential problems and initiate a rapid response while the aircraft is in flight. Data analytics offer significant improvement over today's capabilities for several use cases, particularly related to FDM. For example, before each flight, the on-board 'Data in Motion' analytics function is set as per the normal aircraft systems operating parameters for the flight such as the flight plan data. When on-board sensors or systems detect an 'out of bounds' parameter or a deviation from the flight plan, the built-in logic can determine the most appropriate action (based on the event or combination of events). This functionality can be provided simply as an alert to the ground with contextual information. Ground support staff are quickly able to interpret these alerts and respond accordingly. A complex alert may trigger initial processing of other on-board systems to get a better understanding of the problem.

3.1.2.2 Fog computing

Fog computing is a paradigm that extends cloud computing and services to the edge of the network. Similar to cloud, fog provides data, compute, storage, and application services to CSCs. However, fog characteristics are more towards its proximity to CSC users or sensing objects, its dense geographical distribution, and its support for mobility, along with sensitivity to real-time problems identification, alerting and response.

By hosting services at the edge of the network, fog reduces service latency and improves quality of service (QoS). Fog computing supports emerging Internet of things (IoT) applications that demand real-time/predictable latency (industrial automation, transportation, networks of sensors and actuators). Due to its wide geographical distribution, fog computing is well positioned for real-time big data and real-time analytics. Fog supports densely distributed data collection points, hence adding a fourth axis to the often mentioned big data dimensions (volume, variety, and velocity).

The main and most important capability of fog computing is a smart and efficient use of available bandwidth, together with content security and privacy. Furthermore, both mobility and the wireless nature of flight data monitoring are covered by this paradigm in the same manner as superior quality of service, strong presence of streaming and edge analytics data mining. Hence, real-time, actionable analytics, and processes that filter the data and push it to the cloud are fundamental needs covered by fog computing.

Transmitting all that data to the cloud and transmitting response data back puts a great deal of demand on bandwidth, requires a considerable amount of time and can suffer from latency. In a fog computing environment, much of the processing would take place in a router, decreasing the data volume that must be moved, the consequent traffic, and the distance the data must go; thereby reduces transmission costs, shrinks latency, and improves QoS.

In addition, some information should only be transmitted upon certain triggering conditions, and in that case, vital information should be sent first. All the processing power and applications that are needed in order to accomplish the transmission, data acquisition and analysis must run in an on-board device.

3.1.2.3 Video analytics

Video analytics is defined as the collection and detection of abnormal behaviour, movement or events via video streaming. With the advancement of data analytics, the analysis and detection of abnormal behaviour or movement using real-time video analytics can provide a proactive source of data for FDM. For example, the typical abnormal behaviour or events includes falling, running, tussling, entering restricted zones, etc., unwanted events that are defined by the airline industry. The abnormal event detection is followed by the generation of a triggered signal data in real time. The transmission of the triggered event to the ground system or cloud services for air traffic management/operations serves as an emergency alert. The recordings made on the ground systems and the video analytics also provide digital evidence (digital forensics) in understanding the causes of accidents and for post-flight operation management. The timely and real-time availability of video data for any incidents that may result in an accident, crash or loss of aircraft can be designed for better and safer flight operation. For example, the discovery of human factors that compromises a flight can help provide clarity in accident investigations.

Thus, the benefits of video analytics are:

1) Make it easier to locate an aircraft in case of an emergency.
2) Improve accurate search and rescue response that would significantly reduce the search and rescue efforts and costs in determining the location of an accident site.

3.1.2.4 Machine learning and quantum computing

Machine learning is a subfield of computer science driven by computational thinking that evolved from the study of pattern recognition and computational learning theory in artificial intelligence. Machine learning explores the construction and study of algorithms that can learn from and make predictions on data. Such algorithms operate by building a model from example inputs in order to make data-driven predictions or decisions, rather than following strictly static program instructions.

When employed in the aviation industry, machine learning methods may be referred to as predictive analytics or predictive modelling.

Quantum computing studies theoretical computation systems (quantum computers) that make direct use of quantum-mechanical phenomena, such as superposition and entanglement, to perform operations on data. Quantum computers are different from digital computers based on transistors. Whereas digital computers require data to be encoded into binary digits (bits), each of which is always in one of two definite states (0 or 1), quantum computation uses quantum bits (qubits), which can be in superposition of states. Large-scale quantum computers will be able to solve certain problems much more quickly than any classical computers that use even the best currently known algorithms, like integer factorization using Shor's algorithm or the simulation of quantum many-body systems.

3.1.2.5 Digital asset profile system

Digital asset profile system enables applications to interact with physical objects by a unique identity for a physical object (e.g. an aircraft component) and associated information (e.g. performance, maintenance) and maintain a record of its lifetime in operation (e.g. usage, quality, value). The platform provides a simple way to access the asset information and interpret it in order to support the process or operation being executed. The profile information also enables early identification of problems, analysing situations and early detection of deviations from the expected operations.

3.1.3 Recommendations and next steps

Based on the above Working Group 1 findings, the following are the recommendations for ITU-T considerations.

1. For TSAG to recommend to the relevant ITU-T study groups to further study the requirements and capabilities needed to develop a specific real-time aviation cloud of the following technologies identified in this deliverable:
   a. Inter-cloud computing (e.g. ITU-T Study Group 13);
   b. Audio and video analytics (e.g. ITU-T Study Group 16);
   c. Digital asset profile system (e.g. ITU-T Study Group 16 and 17);
   d. Machine learning (e.g. ITU-T Study Group 16);
   e. Fog computing (e.g. ITU-T Study Group 13);
   f. Quantum computing (e.g. ITU-T Study Group 13 and 16).
2. For the International Civil Aviation Organization (ICAO) to determine further specifications to better limit and establish the scope and needs of the system to be developed with consideration of the technologies to implement the global aeronautical distress and safety system (GADSS).
3. For ISO/IEC SC27, ITU-T Study Group 17 and CEN TC 377 (EASA) to provide the guidelines for additional information security controls applicable to the aviation industry with reference to ISO/IEC 27002.
4. For IATA to consider the adoption of ISO/IEC 27001 and/or ISO 16495 family as the assurance methodology for security and privacy to protect airline operators as the cloud service customer (CSC).
5. For ITU-T, ICAO, IATA, SC27, ISO TC 20 and other relevant stakeholders to continue the collaboration works in reviewing the applicable technologies and the required capabilities to meet the requirements for the aviation applications of cloud computing for FDM.
6. Aviation authorities such as ICAO, the European Aviation Safety Agency (EASA) and the Federal Aviation Administration (FAA) to establish the appropriate definition of real-time FDM in terms of data types and data volume (parameters and recording frequencies).

3.2 Deliverable 2/3: Use cases and requirements

This deliverable describes existing sources of flight data; categorizes different user groups for flight data; identifies and describes 28 use cases, from high-priority use cases as those defined in the global aeronautical distress and safety system (GADSS) to lower priority use cases related to the monitoring of flight data. The deliverable also identifies high-level requirements all these use cases have in common, e.g. security, reliability, etc. Please refer to Deliverable 2/3 for details.

3.2.1 Contributions

A total of 17 contributions[2] related to Deliverable 2/3 were received, as follows:

i. AC-I-010: Use cases of real time flight data monitoring by NICT Japan.
ii. AC-I-012: Use cases and service parameters by Thales Alenia Space Deutschland – this contribution also covers some items in Deliverable 4.
iii. AC-I-014: Considerations on data conversion and global flight data sharing by Travia Air Indonesia.
iv. AC-I-016 (att1 & att 2): Real-time flight data streaming and flight tracking/following by Star Navigation Systems Group, Canada.

[2] All FG AC contributions are available at https://extranet.itu.int/ITU-T/focusgroups/fgac/Input%20Documents/Forms/AllItems.aspx- Requires TIES or Guest account (https://www.itu.int/net/iwm/public/frmUserRegistration.aspx).

v AC-I-021: System wide information management (SWIM) by Eurocontrol.

vi AC-I-015: Flight operation messaging and potential use cases by Lufthansa Airlines, Germany.

vii AC-I-022: Example use cases by Controls and Data Services, United Kingdom.

viii A C-I-023: ATI cloud by the *Société Internationale de Télécommunications Aéronautiques* (SITA), Switzerland.

ix AC-I-027: Draft progress report Deliverable 2.

x AC-I-028: Draft progress report Deliverable 2.

xi AC-I-030: Proposal for "on-flight quarantine" and "smart quarantine".

xii AC-I-031: HLSC 2015 presentation on Global Aircraft Tracking Initiative, ICAO, Canada.

xiii AC-I-038: Draft progress report Deliverable 2.

xiv AC-I-040: Draft progress report Deliverable 2.

xv AC-I-042 (att1 and att2): Abnormal movements' detection in flight.

xvi AC-I-051: Draft progress report Deliverable 2.

xvii AC-I-059: Draft progress report Deliverable 2.

3.2.2 Key findings

Working Group 2 has identified 28 use cases that utilize data aggregated from an aircraft and transmitted wirelessly in-flight to the ground for further processing and correlation.

The use cases can be categorized into two groups.

The first group contains those use cases that require that data be transmitted virtually in real time; this means that data has to be transmitted during the flight and as quickly as possible after it has been generated. Examples for this category are flight tracking/following, search and rescue operations or mission support with in-flight aircraft condition monitoring.

The second category deals with use cases that do not require a real-time transmission of data and where post-flight availability is sufficient. Two out of many examples are approach statistics and predictive maintenance. In this category the potential for innovation is limited. The use cases already exist in the aviation industry, by using post-flight downloads of the data. On some aircraft, the data is downloaded to rewritable compact discs (CDs) or universal serial buses (USB) sticks. Other aircraft uses cellular network data streaming on the ground. However, if a central data repository is being developed, because of the real-time use cases, then also the post-flight use cases can benefit from the repository. The airlines and maintenance, repair and operations (MROs) can use and process the data more efficiently, compared to today's many individual companies and manufacturers specific solutions. In addition, new applications might evolve if auto-correlation and automatic pattern recognition algorithms are applied to the collection of all data available from an aircraft and reveal previously unseen information.

3.2.3 Recommendations and next steps

Working Group 2 recommends:

- Regulatory authorities to mandate real-time flight data streaming. The list of use cases shows that the data can be used in many different ways. Without a clear mission, the industry will develop various products with different goals and certainly incompatibilities amongst each other.
- Regulatory authorities shall establish the appropriate detailed definition of real-time FDM in terms of data types and data volume (parameters and recording intervals).

- Once the required data sets are defined, then streaming technologies described in Deliverable 4 can be selected and applied to the flight data for optimum use.
- Operators, maintenance, repair and operations (MROs), original equipment manufacturers (OEMs), etc., shall continuously be involved in due course, so that they also understand what ITU/ICAO are doing in that regard and what is coming their way.
- The list of use cases should be enhanced to meet future requirements of stakeholders. ITU-T SG13 is to study the use cases and their applicability to Recommendation ITU-T Y.3600, *Big data – Cloud computing based requirements and capabilities*. The study should also include the aspects of real-time monitoring in cloud computing and big data environments.
- ITU-T SG16 to study on the 4D trajectory of predictive analysis.
- ITU-T SG17 and any other relevant SDO to study end-to-end (E2E) security for aviation applications.

3.3 Deliverable 4: Avionics and aviation communications systems

Deliverable 4 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). Please refer to Deliverable 4 for details.

3.3.1 Contributions

A total of seven contributions[3] related to Deliverable 4 were received, as follows:

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 Kingdom.

iii AC-I-013: Input to Deliverable 4 by Intelsat, Luxembourg.

iv AC-I-029: Draft progress report Deliverable 4.

v AC-I-039 (att1): Draft progress report Deliverable 4.

vi AC-I-052: Draft progress report Deliverable 4.

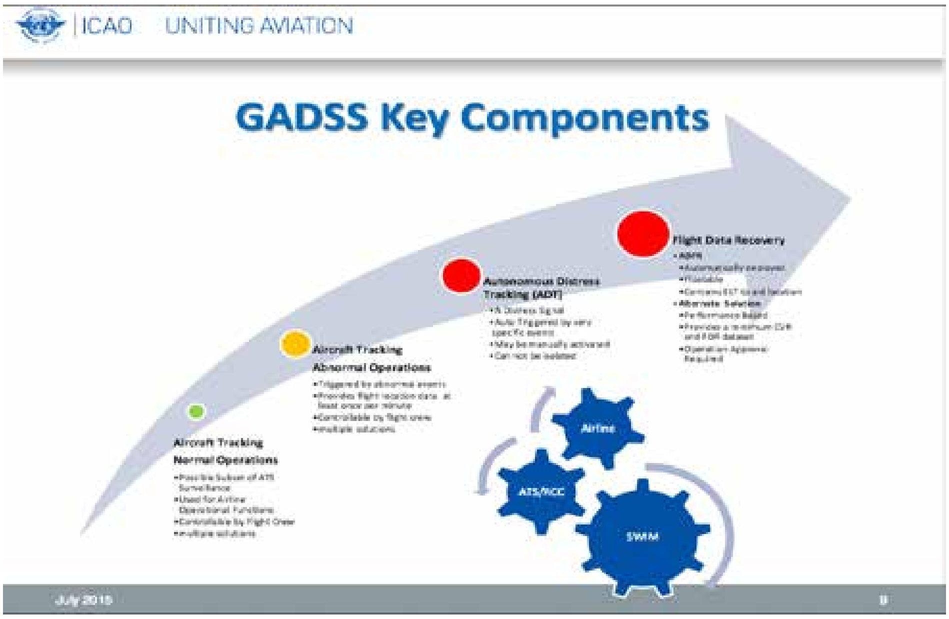
vii AC-I-060: Draft progress report Deliverable 4.

3.3.2 Key findings

3.3.2.1 Real-time data

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 ICAO Standards and Recommended Practices (SARPs).

[3] All FG AC contributions are available at https://extranet.itu.int/ITU-T/focusgroups/fgac/Input%20Documents/Forms/AllItems.aspx – Requires TIES or Guest account (https://www.itu.int/net/iwm/public/frmUserRegistration.aspx).



3.3.2.2 Current technology

3.3.2.2.1 Ground-based infrastructure

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

3.3.2.2.2 Airborne data links

- If cabin data link systems can be securely connected to aircraft information services (AIS) domain flight data information infrastructure on board such as Internet protocol (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 performing black box transmission 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 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.

3.3.2.2.3 Flight data sharing

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

3.3.2.2.4 Flight data monitoring

Every airline already has a flight data monitoring 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. There are also ground software solutions that may be cloud based, which are used for flight tracking that may also support real-time flight data monitoring, reporting and alerting.

3.3.2.2.5 Airborne infrastructure

These are the data link systems on board that may already support transmission of flight data or could easily be adapted to transmit flight data. There are numerous data links on board aircraft today each connected with different aircraft systems and each with a varying aircraft equipage, varying service coverage around the globe and each with a varying bandwidth.

3.3.2.2.5.1 On-board information systems infrastructure

- Aircraft flight data management and recording solutions are the systems on board today that are used to collect, process, analyse, store and forward flight data via available links that may include or may be connected with off-board data links.
- Aircraft interface devices (AID) 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 such as installed or portable electronic flight bags (EFBs).
- Aircraft condition monitoring system (ACMS) has real-time access to all the flight data parameters on the aircraft and is used to perform real-time analysis and reporting. ACMS is programmable by airlines or by ACMS vendors without need for recertification. This means it is relatively easy to modify ACMS on aircraft to include sending an increased number of reports in support of real-time flight data monitoring.
- 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 to aircraft servers and some quick access recorder (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 streaming. ACMS is user modifiable software (UMS) and can support triggering and sending anything from small amounts of data up to full black box data or more. Moreover, this can be easily changed without need for costly aircraft recertification.
- 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 airline operational communication (AOC) has a reprogrammable capability but it is very limited to aircraft flight data compared to ACMS.
- Flight deck ACARS data link systems are already used to perform flight tracking. Together with the flight management system (FMS), ACARS enables automatic dependent surveillance-contract (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 downside of using ACARS data links is their high transmission cost, but depending on the usage level which 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 is not IP based today but is really designed around messaging using special Aeronautical Radio Inc. (ARINC) protocols.

- Cabin data link systems such as Ku-band, Ka-band and L-band Inmarsat SwiftBroadband, although not approved for safety services, do provide very high bandwidth and low cost data transfer that supports routine tracking, distress tracking and even full flight black box streaming. Air-to-ground (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, and some cabin broadband SatCom data link systems may have more near global coverage. However, these limitations may be overcome naturally and easily. 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 and Ka services will cover more and more flight routes. Cabin data links also have the issue that they are within the passenger information and entertainment services (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.

3.3.2.2.5.2 On-board aircraft surveillance and tracking infrastructure

Future air navigation system (FANS) messages are sent over the ACARS data links and networks. FANS applications include: automatic dependent surveillance-contract (ADS-C), aircraft position reporting function and controller-pilot data link communication (CPDLC) application.

- Automatic dependent surveillance-broadcast (ADS-B) (cooperative surveillance technology) is a well-established data broadcast standard which is used for surveillance overland masses and the deployment of space-based ADS-B over the next two years.
- Space-based ADS-B enables global surveillance including over 70% of the earth's surface which is currently outside terrestrial surveillance areas. 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 global aeronautical distress and safety system (GADSS) concept of operations.
- Automatic dependent surveillance-contract (ADS-C) is an existing technology with regulatory approval globally and already provides a two-way communication function between air traffic control (ATC) ground systems and aircraft which can be transmitted automatically without pilot action. It is consistent with the findings of the ICAO global aeronautical distress and safety system (GADSS) concept of operation.

3.3.2.3 Future technology

3.3.2.3.1 Ground-based infrastructure

Currently, there is not an efficient or effective ground-air/air-ground mechanism for data management, exchange, and sharing of National Airspace System (NAS) originated information with aircraft or aircraft originated information with NAS. This reduces the flight crews' scope of planning and ability to collaborate with air traffic management (ATM) in making dynamic and strategic decisions during all phases of flight. Thus, flight crews rely heavily on voice and other legacy communications for in-flight aviation information which increases pilot workload on the flight deck. SWIM is currently being positioned to provide that ingrate suite of infrastructure and services.

3.3.2.3.2 Airborne data links

- Due to the long timescales 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 are not suitable in the near to medium term. In the long term for 2020 and beyond, use of these data link 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.
- No single system exists today that can satisfy all of the GADSS and other real-time data streaming requirements although the performance standards of space-based ADS-B, to be deployed over the next two years, will satisfy the near-term GADSS objectives of providing location data at least every one minute. This capability, along with others discussed in this Report, could be configured to meet the autonomous distress tracking (ADT) requirements of GADSS.
- The longer term objectives of GADSS flight data recovery, automatic deployable flight recorder (ADFR), will most likely be realized by developments in broadband capability. The requirements of this capability, and potential impact on SPECTRUM should be discussed further.
- While it is conceivable that a single system designed to satisfy all the GADSS concepts could be built, it would require a radical departure from all existing systems and therefore may not be practical or economical.
- That said, equipment existing today on board aircraft and on the ground offers several feasible ways of implementing real-time flight data streaming within a reasonable space of time.

3.3.2.3.3 On-board aircraft/ground-based surveillance and tracking infrastructure

Satellite-based ADS-B is a future technology that supports surveillance overland and sea. The deployment of space-based ADS-B capability over the near term enables global surveillance including over 70% of the earth's surface which is currently outside terrestrial surveillance areas. 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 global aeronautical distress and safety system (GADSS) concept of operations. See Thales Alenia Space (TAS-D) and Aireon LCC.

3.3.2.3.4 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 Deliverable 4, Appendices 4 and 3, respectively, and are summarized below.

a) 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 of Deliverable 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 three example flight data black box recording rates:

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

Deliverable 4 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
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

b) Data link systems performance

Information relating to the capabilities and bandwidth of various terrestrial and satellite data link technologies are defined in Deliverable 4 Appendix 3. Appendix 3 includes two tables: one with terrestrial data link characteristics for VHF digital link (VDL) Mode 0/A, VDL Mode 2, high frequency (HF) data link (DL), VDL

Mode 4, UAT/978, 1090ES, GBAS/GRAS VDB and ATG using evolution-data optimized (EvDO) and long term evolution (LTE) technologies and 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

c) Conclusion

- 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.

3.3.3 Recommendations and next steps

The following recommendations are proposed for ITU consideration:

- TSAG to submit final Deliverable 4 to relevant ITU-R Study Groups 4 and 5 (SG4 and SG5) for their perusal.

- 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, what level of global service coverage is needed, what data volumes may be sent and what 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 the 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 results of a defined outcome or an operational hazard assessment.

3.3.4 ICAO linkage

In accordance with the Terms of Reference of the FG AC, based on the operational requirements for real-time monitoring of flight data identified by ICAO, FG AC, in close collaboration with ICAO and other partners of the Focus Group, should identify the requirements for telecommunication standards for an aviation cloud for real-time monitoring of flight data.

At the Second High Level Safety Conference (HLSC) in Montreal, Canada, ICAO developed the following recommendation which is relevant to this Report:

Recommendation 1/2 3.1 – The conference agreed on the following recommendations:

Global flight tracking:

a) ICAO should expeditiously publish and use the global aeronautical distress and safety system (GADSS) for the implementation of normal, abnormal and distress flight tracking, search and rescue (SAR) activities and retrieval of cockpit voice recorders (CVRs) and flight data recorders (FDRs) data.

4 Conclusion

The Focus Group made important researches on the needs to develop an aviation cloud. Different technologies were studied including actual and future options. Besides that, studies still need to be done in order to have a complete description, requirements and design of a real-time system. In addition, general recommendations are presented below.

General recommendations

- To recommend to relevant ITU-T study groups to further study the requirements and capabilities identified in Deliverables 1 and 2&3 from this Focus Group.
- To submit Deliverable 4 to relevant ITU-R Working Parties for their perusal.
- The relevant ICAO working groups to take into consideration the findings of this Report and to determine further specifications of the system to be developed to implement GADSS.
- For ISO/IEC SC27 and CEN TC 377 (EASA) to provide the guidelines for additional applicable information security controls.
- To ask regulatory authorities to establish the appropriate detailed definition of real-time FDM in terms of data types and data volume (parameters and recording intervals).
- To consider the material contained in this Report in further developing related activities of the concerned ITU study groups.
- In addition, each working group presented its particular conclusion regarding their own scope which are presented below.

4.1 Deliverable 1

The cloud computing and data analytics capabilities offer scalability, reliability, security and affordability for real-time flight data monitoring, data streaming and aircraft tracking. The existing and emerging technologies described in this Report, such as inter-cloud computing, video analytics, digital asset profile system, machine learning, fog computing, quantum computing, shall be considered for the aviation applications for FDM and other applications.

Cloud computing and data analytics provide the enabling platform for accessing, processing and utilizing flight data for aviation applications and services as defined in Working Group 2&3 of FG AC. In addition, cloud computing and data analytics technologies have the capabilities to support real-time FDM and to manage data privacy and security requirements.

4.2 Deliverable 2&3

The deliverable of Working Group 2 describes use cases that make use of in-flight transmission of flight data. Known data sources that currently transmit or might transmit in the near future from an aircraft have been described. Most important is the data of the digital flight data recorder, also known as black box. However, also other data, such as aircraft condition monitoring system reports, often sent via very high frequency (VHF) data link is of high interest. Future systems can include video streaming for surveillance and analysis or health sensor data for health monitoring.

Twenty-eight use cases have been identified for the aviation cloud. These use cases are categorized in two groups: real-time data streaming, and on-demand or post-flight data collection.

The real-time aspect is a new quality that has never been available for ground flight data processing. It is an enabler for new techniques and processes in aviation. The use cases of this category contain high potential for innovation. Real-time processing of flight data will increase flight safety, dispatch reliability, efficiency and on-time performance. The processes, algorithms and information technology (IT)-systems for real-time flight data monitoring are currently not available and need to be developed.

4.3 Deliverable 4

This initial 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 initial findings are that there are a range of existing technology capabilities that can be utilized that 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 findings of ATTF and GADSS.

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.

The report also concludes that while this is a valuable source document, there are a number of actions which could be progressed and these are outlines in the recommendations section of Deliverable 4 report.

5 Acronyms and abbreviations

This Report uses the following acronyms and abbreviations:

AAC	Airline Administrative Communications
ABAP	Advanced Business Application Programming
ACARS	Aircraft Communications Addressing and Reporting System
ACD	Aircraft Control Domain
ACMS	Aircraft Condition Monitoring System
ADFR	Automatic Deployable Flight Recorder
ADS-B	Automatic Dependent Surveillance-Broadcast
ADS-C	Automatic Dependent Surveillance-Contract
ADT	Autonomous Distress Tracking
AID	Aircraft Interface Device
AIS	Aircraft Information Services
AISD	Aircraft Information Services Domain
AMS(R)S	Aeronautical Mobile-Satellite (Route) Service
ANN	Artificial Neural Network
ANS	Automated celestial Navigational System
AOC	Airline Operational Communication
APC	Airline Passenger Correspondence
ARINC	Aeronautical Radio, Inc.
ASIAS	Aviation Safety Information Analysis and Sharing
ATC	Air Traffic Control
ATG	Air-to-Ground
ATM	Air Traffic Management
ATS	Air Traffic Services
ATTF	Aircraft Tracking Task Force
CD	Compact Disc
CMC	Central Maintenance Computer
CPDLC	Controller-Pilot Data Link Communication
CPU	Central Processing Unit
CRM	Customer Relationship Management
CSC	Cloud Service Customer

CT	Computational Thinking
CVR	Cockpit Voice Recorder
DAG	Directed Acyclic Graph
DFDAU	Digital Flight Data Acquisition Unit
DFDR	Digital Flight Data Recorder
DL	Data Link
DR	Disaster Recovery
E2E	End-to-End
EASA	European Aviation Safety Agency
EFB	Electronic Flight Bag
ELT	Emergency Locator Transmitter
EOO	Extended Overwater Operations
EvDO	Evolution-Data Optimized
FAA	Federal Aviation Administration
FANS	Future Air Navigation System
FDM	Flight Data Monitoring
FDR	Flight Data Recorder
FDX	Flight Data eXchange
FIDS	Flight Information Display System
FMC	Flight Management Computer
FMS	Flight Management System
FOQA	Flight Operational Quality Assurance
GADSS	Global Aeronautical Distress and Safety System
GBAS	Ground-Based Augmentation System
GEO	Geosynchronous satellite
GRAS	Ground-based Regional Augmentation System
HF	High Frequency
HLSC	High Level Safety Conference
IaaS	Infrastructure as a Service
ICAO	International Civil Aviation Organization
ILP	Inductive Logic Programming
INS	Inertial Navigation System

IoT	Internet of Things
IP	Internet Protocol
IT	Information Technology
ITU-T	The ITU Telecommunication Standardization Sector
LEO	Low Earth Orbit
LTE	Long Term Evolution
MFA	Multi Factor Authentication
MRO	Maintenance, Repair and Operations
NAS	National Airspace System
NTSB	National Transportation Safety Board
OEM	Original Equipment Manufacturer
PCMCIA	Personal Computer Memory Card International Association
PFIS	Passenger Flight Information System
PHP	Hypertext Preprocessor
PIES	Passenger Information and Entertainment Services
PIESD	Passenger Information and Entertainment Services Domain
PODD	Passenger Owned Devices Domain
QAR	Quick Access Recorder
QoS	Quality of Service
RAM	Random Access Memory
SaaS	Software as a service
SAR	Search and Rescue
SARP	Standards and Recommended Practices
SatCom	Satellite Communication
SG	Study Group
SVM	Support Vector Machine
SWIM	System Wide Information Management
T-PED	Transmitting Portable Electronic Device
TTFD	Triggered Transmission of Flight Data
TSAG	Telecommunication Standardization Advisory Group
UMS	User Modifiable Software
USB	Universal Serial Bus

VDB	VHF Data Broadcast
VDL	VHF Digital Link
VHF	Very High Frequency
WLAN	Wireless Local Area Network
WPS	word per second

6 Acknowledgements

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Annex 1 Definitions used in the Focus Group Deliverables

1.1 adiabatic quantum computer (based on quantum annealing) (Deliverable 1): Computation decomposed into a slow continuous transformation of an initial Hamiltonian into a final Hamiltonian, whose ground states contains the solution.

1.2 aeronautical mobile-satellite (route) service (AMS(R)S) (Deliverable 4): An aeronautical mobile-satellite service reserved for communications relating to safety and regularity of flights, primarily along national or international civil air routes.

1.3 aircraft communications addressing and reporting system (ACARS) (Deliverable 2&3 and 4): A digital data link system for transmission of short messages between aircraft and ground stations via air band radio or satellite. The protocol was designed by Aeronautical Radio, Inc. (ARINC) and deployed in 1978, using the Telex format.

1.4 aircraft condition monitoring system (ACMS) (Deliverable 2&3 and 4): ACMS collects performance data of various systems in the aircraft. Most reports are related to the engines, with reports such as take-off report, engine stable report or sink rate report. The reports are typically transmitted via the aircraft communications addressing and reporting system (ACARS).

1.5 aircraft control domain (ACD) (Deliverable 4): ACD consists of systems and networks that support the safe operation of the aircraft, based on digital data networks. The justification for most of these systems is traceable to the safety of the flight. It may also provide services and connectivity between independent aircraft domains such as the aircraft information services domain (AISD), and the passenger information and entertainment services domain (PIESD), cabin distribution network and any connected off-board networks. In general, systems within ACD should always protect themselves. A complicating factor for ACD is that, while all air transport aircraft may be assumed to have ACD, there is a tremendous variety of systems and network architectures used in avionics. This means that characteristics internal to the domain can only be described in general terms.

1.6 aircraft information services domain (AISD) (Deliverable 4): AISD may provide services and connectivity between independent aircraft domains such as avionics, in-flight entertainment, cabin distribution and any connected off-board networks. It provides general purpose routing, computing, data storage and a security perimeter between AISD and less critical domains and any connected wireless networks. It may be comprised of one or more computing platforms for third-party applications and content and may be used to support applications and content for either cabin or flight crew use.

1.7 aircraft interface device (AID) (Deliverable 4): 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 such as installed or portable electronic flight bags (EFBs).

1.8 aircraft surveillance (Deliverable 4): Provides the aircraft position and other related information to air traffic management and/or airborne users for the purpose of aircraft separation.

1.9 aircraft tracking (Deliverable 4): A ground-based process that maintains and updates, at standardized intervals, a record of the four dimensional position of individual aircraft in flight. Aircraft tracking may be used for progress monitoring of the flight, to provide immediate notification when an aircraft experiences an abnormal event, and in case of an accident, to enhance the ability to rescue survivors.

1.10 airline administrative communications (AAC) (Deliverable 4): AAC includes information regarding administrative aspects of the airline business such as crew scheduling and cabin provisioning. Examples are passenger lists, catering requirements and baggage handling. Non-safety related communications include AAC and airline passenger correspondence (APC).

1.11 airline operational communication (AOC) (Deliverable 2&3 and 4): The AOC communications encompass all aircraft flight operations, maintenance and engineering. It involves the information exchange between the aircraft and the airline operational centre or operational staff at the airport associated with the safety and regularity of flights. Communication required for the exercise of authority over the initiation, continuation, diversion or termination of flight for safety, regularity and efficiency reasons.

1.12 airline passenger correspondence (APC) (Deliverable 4): Airline passenger correspondence (APC) includes communication services that are offered to passengers, both for data and voice. It mainly consists of the traffic connecting to the Internet and placing phone calls. Bandwidth required for air traffic control (ATC), airline operational communication (AOC) (and airline administrative communications (AAC)) is negligible compared to APC.

1.13 air traffic control (ATC) (Deliverable 1, 2&3 and 4): ATC is a service provided by ground-based controllers who direct aircraft on the ground and through controlled airspace. The primary purpose of ATC worldwide is to prevent collisions, organize and expedite the flow of traffic, initiate search and rescue procedures, and provide information and other support for pilots. Many technologies are used in air traffic control systems. Primary and secondary radar are used to enhance a controller's situation awareness within his assigned airspace. These inputs, added to data from other radars, are correlated to build the air situation. Usually, a flight data processing system manages all the flight plan related data, incorporating the information of the track once the correlation between them (flight plan and track) is established.

1.15 association rule learning (Deliverable 1): Method for discovering interesting relations between variables in large databases.

1.16 automated celestial navigational system (ANS) (Deliverable 2&3): Automated position fixing that enables a navigator to transition through a space without having to rely on estimated calculations, or dead reckoning, to know his or her position.

1.17 automatic dependent surveillance-broadcast (ADS-B) (Deliverable 1, 2&3 and 4): A cooperative surveillance technology in which an aircraft determines its position via satellite navigation and periodically broadcasts it, enabling it to be tracked. The information can be received by air traffic control ground stations as a replacement for secondary radar. It can also be received by other aircraft to provide situational awareness and allow self-separation.

1.18 automatic dependent surveillance-contract (ADS-C) (Deliverable 1, 2&3 and 4): A method of surveillance that relies on (is dependent on) downlink reports from an aircraft's avionics that occur automatically in accordance with contracts established between the air traffic control (ATC) ground system and the aircraft's avionics. Reports can be sent whenever specific events occur, or specific time intervals are reached. ADS-C provides accurate surveillance reports in remote and oceanic areas. The reports are converted by more advanced data link equipped ground stations into a track and presented on the controller's air situation display to provide enhanced situational awareness and the potential for reduced separation standards.

1.19 Bayesian network (Deliverable 1): A Bayesian network, belief network or directed acyclic graphical model is a probabilistic graphical model that represents a set of random variables and their conditional independencies via a directed acyclic graph (DAG).

1.20 central maintenance computer (CMC) (Deliverable 2&3 and 4): CMC is used to facilitate maintenance tasks by directly indicating the fault messages in the cockpit, and allowing some specific tests.

1.21 cloud-based disaster recovery (DR) (Deliverable 1): Use of connectivity to compute and to store hosted resources on remote, elastic, multi-tenancy clouds to enable more cost-effective and flexible protection of data at a distance.

1.22 cluster analysis (clustering) (Deliverable 1): Assignment of a set of observations into subsets (called clusters) so that observations within the same cluster are similar according to some predesignated criterion or criteria, while observations drawn from different clusters are dissimilar.

1.23 controller-pilot data link communication (CPDLC) (Deliverable 2&3 and 4): A method by which air traffic controllers can communicate with pilots over a data link system.

1.24 data analytics (Deliverable 1): Process of examining data to uncover hidden patterns, unknown correlations and other useful information that can be used to make better decisions.

1.25 data in motion (Deliverable 1): Data as it is in transit.

1.26 data at rest (Deliverable 1): Data stored in persistent storage (disk, tape).

1.27 data in use (Deliverable 1): Active data which is stored in a non-persistent digital state typically in computer random access memory (RAM), central processing unit (CPU) caches, or CPU registers.

1.28 decision tree learning (Deliverable 1): Uses a decision tree as a predictive model, which maps observations about an item to conclusions about the item's target value.

1.29 digital asset profile system (Deliverable 1): Enable applications to interact with physical objects by a unique identity for a physical object (e.g. an aircraft component) and associated information (e.g. performance, maintenance) and maintain a record of its lifetime in operation (e.g. usage, quality, and value).

1.30 digital flight data acquisition unit (DFDAU) (Deliverable 4): An integrated system that combines the functions of mandatory data acquisition and recording with a sophisticated aircraft condition monitoring system (ACMS). This comprehensive system provides aircraft operators with a standardized hardware and software solution for high-power data acquisition, management and recording to an internal Personal Computer Memory Card International Association (PCMCIA) or magneto optical disk recorder.

1.31 digital flight data recorder (DFDR) (Deliverable 2&3): Device that preserves the recent history of the flight through the recording of dozens of parameters collected several times per second. DFDR records a large number of aircraft parameters in a highly robust unit. DFDR data is often called flight data.

1.32 flight data monitoring (FDM) (Deliverable 1, 2&3 and 4): General flight data analysis using various data sources and technology solutions to solve the issues.

1.33 flight data streaming (Deliverable 2&3 and 4): Real-time transmission of various data from the aircraft, some of which may be used for a variety of purposes including aircraft tracking, flight data recovery and analysis in the event of an accident.

1.34 flight information display system (FIDS) (Deliverable 2&3): A computer system used in airports to display flight information to passengers, in which a computer system controls mechanical or electronic display boards or television (TV) screens in order to display arrival and departure flight information in real time.

1.35 flight management computer (FMC) (Deliverable 1, and 2&3): FMC is a specialized computer system that automates a wide variety of in-flight tasks, reducing the workload on the flight crew. All FMSs contain a navigation database.

1.36 flight operational quality assurance (FOQA) (Deliverable 2&3): A voluntary safety program designed to improve aviation safety through the proactive use of flight recorded data. Operators will use these data to identify and correct deficiencies in all areas of flight operations. Properly used, FOQA data can reduce or eliminate safety risks, as well as minimize deviations from regulations.

1.37 flight tracking (Deliverable 1, 2&3 and 4): The task of tracking an aircraft for the purpose of determining its real-time spatial location or post-flight track flown.

1.38 fog computing (Deliverable 2&3): Architecture that uses one or a collaborative multitude of end-user clients or near-user edge devices to carry out a substantial amount of storage (rather than stored primarily in cloud data centres), communication (rather than routed over the Internet backbone), and control, configuration, measurement and management.

1.39 future air navigation system (FANS) (Deliverable 4): An avionics system which provides direct data link communication between the pilot and the air traffic controller. The communications include air traffic control clearances, pilot requests and position reporting. The FANS messages are sent over the aircraft communications addressing and reporting system (ACARS) data links and networks. FANS applications include automatic dependent surveillance-contract (ADS-C) and controller-pilot data link communication (CPDLC).

1.40 genetic algorithms (Deliverable 1): A search heuristic that mimics the process of natural selection, and uses methods such as mutation and crossover to generate new genotype in the hope of finding good solutions to a given problem.

1.42 inertial navigation system (INS) (Deliverable 2&3): A navigation aid that uses a computer, motion sensors (accelerometers) and rotation sensors (gyroscopes) to continuously calculate via dead reckoning the position, orientation, and velocity (direction and speed of movement) of a moving object without the need for external references.

1.43 infrastructure as a service (IaaS) (Deliverable 1): Provides hardware and basic software infrastructure on which an enterprise application can be deployed and executed. It offers computing, storage and network resources.

1.44 infrastructure for flight data streaming (Deliverable 4): The combination of airborne systems, ground systems and/or associated services that support the generation, collection, analysis, transmission, storage and sharing of flight data.

1.45 intercloud (Deliverable 1): Global interconnected cloud of clouds driving connection of multiple isolated clouds, applying same network security, quality of service (QoS), and access control policies of a public cloud.

1.46 machine learning (Deliverable 1): Subfield of computer science driven by computational thinking (CT) that evolved from the study of pattern recognition and computational learning theory in artificial intelligence.

1.47 multi-factor authentication (MFA) (Deliverable 1): Method of computer access control which a user can pass by successfully presenting several separate authentication stages.

1.48 one-way quantum computer (Deliverable 1): Computation decomposed into sequence of one-qubit measurements applied to a highly entangled initial state or cluster state.

1.49 passenger information and entertainment services domain (PIESD) (Deliverable 4): PIESD is defined to include any device or function of a device that provides entertainment and network services to passengers. It may contain multiple systems from different vendors which may or may not be interconnected to one another, and its borders may not necessarily follow physical device borders. It may also include passenger device connectivity systems, passenger flight information systems (PFIS), broadband television or connectivity systems, seat actuator or message system and controls.

1.50 passenger owned devices domain (PODD) (Deliverable 4): PODD is defined to include only those devices that passengers may bring on board. They may connect to the airplane network. Their connectivity to the airplane network is defined to be provided by the passenger information and entertainment services domain (PIESD). Until they connect via PIESD, the passenger owned devices (PODs) should be considered external to the airplane network.

1.51 platform as a service (PaaS) (Deliverable 1): Provide on top of an infrastructure as a service (IaaS) a predefined development environment, such as Java, advanced business application programming (ABAP) or Hypertext Preprocessor (PHP), with various additional services (e.g. database, analytics or authentication).

1.52 predictive maintenance (Deliverable 2&3 and 4): Tamper-proof collection of flight data for early detection of degradation.

1.53 quantum computing (Deliverable 1): Study of theoretical computation systems (quantum computers) that make direct use of quantum-mechanical phenomena, such as superposition and entanglement, to perform operations on data.

1.54 quantum gate array (Deliverable 1): Computation decomposed into sequence of few-qubit quantum gates.

1.55 Qubit (Qbit) (Deliverable 1): A unit of quantum information – the quantum analogue of the classical bit.

1.56 quick access recorder (QAR) (Deliverable 2&3 and 4): An airborne flight data recorder designed to provide quick and easy access to raw flight data, through means such as universal serial bus (USB) or cellular network connections and/or the use of standard flash memory cards. The data from QAR is used for flight operational quality assurance (FOQA), which is quality assurance process in the airline and often required by the authorities.

1.57 reinforcement learning (Deliverable 1): Concerned with how an agent ought to take actions in an environment so as to maximize some notion of long-term reward.

1.58 representation learning (Deliverable 1): Representation learning algorithms often attempt to preserve the information in their input but transform it in a way that makes it useful, often as a pre-processing step before performing classification or predictions, allowing to reconstruct the inputs coming from the unknown data generating distribution, while not being necessarily faithful for configurations that are implausible under that distribution.

1.59 safety service (Deliverable 4): Any radio communication service used permanently or temporarily for the safeguarding of human life and property.

1.60 similarity and metric learning (Deliverable 1): Learning machine is given pairs of examples that are considered similar and pairs of less similar objects. It then needs to learn a similarity function (or a distance metric function) that can predict if new objects are similar. It is sometimes used in Recommendation systems.

1.61 software as a service (SaaS) (Deliverable 1): Provides on top of an infrastructure as a service (IaaS) or a platform as a service (PaaS) a specific application over the Internet, such as a Customer Relationship Management (CRM) application.

1.62 sparse dictionary learning (Deliverable 1): A datum is represented as a linear combination of basic functions, and the coefficients are assumed to be sparse. Sparse dictionary learning has been applied in several contexts. In classification, the problem is to determine which classes a previously unseen datum belongs to. Suppose a dictionary for each class has already been built, then a new datum is associated with the class such that it is best sparsely represented by the corresponding dictionary.

1.63 support vector machines (SVMs) (Deliverable 1): A set of related supervised learning methods used for classification and regression. Given a set of training examples, each marked as belonging to one of two categories, an SVM training algorithm builds a model that predicts whether a new example falls into one category or the other.

1.64 topological quantum computer (Deliverable 1): Computation decomposed into the braiding of anions in a 2D lattice.

1.65 transmitting portable electronic device (T-PED) (Deliverable 2&3): Electronic devices, typically but not limited to consumer electronics, brought on board the aircraft by crew members, passengers, or as part of the cargo. T-PEDs radiate transmissions on specific frequencies as part of their intended function. T-PEDs include two-way radios, mobile phones of any type, satellite phones, and computers with mobile phone data connection, wireless local area network (WLAN) or Bluetooth capability.

1.66 video analytics (Deliverable 1): Collection and detection of abnormal behaviour, movement or events via video streaming.

Annex 2 References used in the Focus Group Deliverables

- Recommendation ITU-T V.44 (2000), *Data compression procedures*. ITU-T V series: Data communication over the telephone network.
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