ITU-T

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

Existing and Emerging Technologies of Cloud Computing and Data Analytics

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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 Overview

The deliverable for Working Group 1 is to establish the baseline information of the current technological developments of cloud computing and data analytics capabilities and review the opportunities that can be used for aviation applications using cloud computing for flight data monitoring (FDM).

The following guiding principles for the review and discussion on current cloud computing and data analytics technology were considered:

- available technology and solutions; and
- acceptable to stakeholders such as airlines, industry operators and regulators.

The approach for this documentation is based on the terms of reference, and by focusing first on the evaluation of the current technologies and then discussions on the consideration of emerging technologies applicable to real-time FDM.

Disclaimer: This document was the result of several meetings by the experts from ITU FG AC Working Group 1. 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. Further research and discussion on these topics are necessary to further review the application for real time FDM and to address issues in the technology adoption including security and privacy controls for flight operations.

2 Relevant technology

2.1 Cloud computing

2.1.1 Scope and definition

Cloud computing is defined in Recommendations ITU-T Y.3510 (2013), *Cloud computing infrastructure requirements* and ITU-T Y.3520 (2013), *Cloud computing framework for end to end resource management* as the paradigm for enabling network access to a scalable and elastic pool of shareable physical or virtual resources with self-service provisioning and administration on demand.

2.1.2 Capabilities

Recommendations ITU-T Y.3501 (2013), *Cloud computing framework and high-level requirements* and ITU-T Y.3510 (2013) *Cloud computing infrastructure requirements* include the essential capabilities for computing, storage and network resources, as well as the capabilities of resource abstraction and control. The essential capabilities for computing, storage and network resources and resource abstraction and control relevant for FDM are:

- compute resources;
- network resources;
- storage resources;
- resource abstraction and control.

2.1.3 Key challenges

The available technology is mostly on proprietary systems, and on private networks; this technology may not integrate easily into other ancillary/related applications and/or be available on a global access basis. Therefore, there is a need for a hybrid and integrated cloud for a common cloud service for existing and future FDM applications. The cloud platform should allow simple and flexible access to flight data and applications, minimizing and reducing cost associated with onboarding of new services, whilst maintaining uniform compliance with the aviation industry policies.

2.1.4 Applicability for the aviation industry

The main cloud characteristics defined in Recommendation ITU-T Y.3500 (2014), *Cloud computing – Overview and vocabulary* are also applicable in the aviation industry such as the following:

- Network-centric: Cloud infrastructure that consists of distributed resources including compute, storage and other hardware resources that are connected through the networks.
- On-demand resource provisioning: Cloud infrastructure that dynamically provides resources according to cloud service customer's (CSC's) needs.
- Elasticity: Cloud infrastructure that is capable of expanding or reducing its resources to accommodate heavier or lighter workloads.
- High availability: Cloud infrastructure that is capable of providing required resources under the conditions stated in a service level agreement (SLA) or emergency situation.
- Resources abstraction: Cloud infrastructure underlying resources (compute, storage, network, etc.) that is invisible to the user or CSC.

2.2 Inter-cloud computing

2.2.1 Scope and definition

Inter-cloud is defined (Recommendation ITU-T Y.3511 (2014), *Framework of inter-cloud computing*. ITU-T Y series: Global information infrastructure, Internet protocols aspect and next-generation networks.) as "A cloud model that, for the purpose of guaranteeing service quality, such as the performance and availability of each service, allows on-demand reassignment of resources and transfer of workload through an interworking of cloud systems of different cloud providers based on coordination of each consumers requirements for service quality with each providers SLA and use of standard interfaces".

2.2.2 Applicability for the aviation industry

Recommendation ITU-T Y.3511 (2014), *Framework of inter-cloud computing* defined inter-cloud as "Inter-cloud computing allows for flexibility of a computing between different data sources or types of data that would otherwise be unavailable via single cloud. For instance, flight data analysis, flight planning and maintenance management are three different cloud systems that require inter-cloud computing to collaborate information between each other."

The flexibility and resiliency of inter-cloud with multiple backup through cloud federation offer uninterrupted and high availability of cloud services. For example, in the event that a cloud service provider (CSP) experiences power outage and loss of data, inter-cloud resources in other CSPs are used to restore the affected CSP services. This is critical for any industry that requires real-time global services, and where CSP has limited communication coverage in a geographically dispersed area. The capability to monitor data and do backup at any instant protecting the data at all times require inter-cloud services, as indicated below, that are also relevant to other industries.

2.3 Cloud-based disaster recovery

2.3.1 Scope and definition

(Source: AC-I-037, Section 2.3)

Cloud-based disaster recovery (DR) is the 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.

2.3.2 Capabilities

The following set of capabilities provides assurance and choice for CSC to satisfy regulatory requirements for their key data and applications cloud-based DR.

- managed applications and managed DR;
- on premises cloud backup and restore;
- virtual cloud backup and restore;
- cloud replication to virtual machines (VMs).

2.3.3 Applicability for the aviation industry

Cloud-based DR can reduce better the cost than the traditional DR because the cloud is economically priced and has the ability to allocate capacity and performance on demand, enabling CSC to pay only for the resources consumed. Moving DR to the cloud will also increase the flexibility of DR configurations and practices, and the CSP remote management offers a higher speed of recovery.

2.4 Cloud security

2.4.1 Scope and definition

(Sources: Recommendation ITU-T X.1601 (2014), *Security framework for cloud computing*, and ISO/IEC 27002:2013, *Code of practice for information security controls*.

The distributed and multi-tenant nature of cloud computing, the prevalence of remote access to cloud computing services and the number of entities involved in each process make cloud computing inherently more vulnerable to both internal and external security threats than other paradigms. The security threats and challenges in adopting cloud computing and the security requirements vary to a great extent for different cloud computing service deployment models and service categories. However, many of the security threats can be mitigated with the right application of security processes, controls and mechanisms.

2.4.2 Applicability for the aviation industry

CSPs may include specific security platforms, platform as a service (PaaS), or applications, software as a service (SaaS), such as multifactor authentication (MFA) to enable customers and partners to control access to the cloud. Cloud security services may be configured as part of the service level agreement (SLA) and the service level guarantee (SLG) of cloud services provided by CSPs.

Cloud security controls need to respond to the defined security threats and security challenges. Security threats are those associated with attacks (both active and passive), and also environmental failures or disasters. Security challenges comprise of difficulties arising from the nature and operating environment of cloud services. When not properly addressed, security challenges may leave doors open for threats.

The technological advancement and commercial advantages of cloud computing make cloud computing services be in demand for other industries such as manufacturing, research and development (R&D), financial, maritime, etc.

2.5 Data analytics

2.5.1 Scope and definition

The Internet of things (IoT) is propelling an 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, which is specific to aviation, aim to extract data "on the fly" before it is stored and sent to the ground; whereas 'Data at Rest' refers to data that has been collected from various sources, stored and is then analyzed 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 those related to FDM. For example, before each flight, the onboard '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 onboard 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 will be quickly able to interpret these alerts and respond accordingly. A complex alert may trigger initial processing of other onboard systems to get a better understanding of the problem.

2.5.2 Key challenges

The challenge is how to manage and extract value from a constant stream of information and turn it into operational insight. Each manufactured aircraft has different operating parameters which need to be considered for the flight data being analyzed. This data also needs to be compared to the 100s or 1000s of previous flights to determine the variance from the normal operating windows. Ground support staff has to be sufficiently trained to understand these variables and then know how to respond accordingly.

2.5.3 Applicability for the aviation industry

Data analytics capabilities may also enable new possibilities for air traffic control (ATC) (e.g. airspace optimization, meteorological), airport operations (e.g. ground management) and flight operations and safety (e.g. fuel optimization, search and rescue, accident investigations, flight crew techniques), where:

- Data collection occurs with multiple on flight components that include aircraft communications addressing and reporting system (ACARS), automatic dependent surveillance-broadcast (ADS-B), automatic dependent surveillance-contract (ADS-C), etc. This data is collected and then sent to ground base stations and inflight service operations.
- Once this data is collected and processed by data analytic components of CSP, the relevant alerts or event correlation will take place. The analytic engines will determine the scope of variance of the data received for each aircraft being monitored. This will include aspects such as deviation from the registered flight plan.
- Using cloud-based technology capable of analyzing large volumes of real-time events on very fast throughput variance of acceptable operating parameters can be quickly identified. These data analytics can be performed on a single aircraft or across a fleet while in flight operations.
- Security is a key factor for FDM applications. These aspects include ensuring that data is being received from a single aircraft, data streams have not ceased, and data has not been corrupted or modified while in transit. It is necessary to have controls in place that will ensure that data, once received by CSP, has not been modified and is securely stored on storage media. CSP should have the means to detect these data anomalies and quickly respond to isolate these incidents.

Other relevant industry applications that require rapid and real-time notification of potential problems is 'Data in Motion' analytics which provides a useful capability that should also help accelerate the decision-making and response time for an incident and safety related operation.

3 Emerging technology

3.1 Fog computing

3.1.1 Scope and definition

(Input from CISCO, dkeely@cisco.com and further edited by faud.khan@twelvedot.com of TwelveDot Inc.)

Fog computing is a paradigm that extends cloud computing and services to the edge of the network. Similar to cloud, fog computing 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 problem identification, alerting and response.

CSP can host services at the edge of their network to reduce service latency and improves quality of service (QoS). 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). To accommodate this heterogeneity, fog services are abstracted inside a container for ease of orchestration.

3.1.2 Applicability for the aviation industry

Regulators will determine the key variables of flight operations that are required for FDM. While there will be a minimum set of data points, airlines and operators have the option to expand this to multiple datasets including engine monitoring. FDM with data analytics also detects impending failures and notifies both the crew and ground stations.

Fog computing can be leveraged by CSPs who want to provide a higher level of service quality by managing multiple live stream datasets. For small service providers, this might not be an issue; however, as aviation continues to grow with more people using airlines more data will result. It is important to consider that fog computing adds functionality to CSP and still requires a full cloud solution behind it to collect, store and analyse FDM data.

3.2 Digital asset profile system

3.2.1 Scope and definition

The 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.

3.2.2 Applicability for the aviation industry

The digital asset profile system is already operating in the cloud, managing the identities of millions of devices in industries such as consumer packaged goods. The digital asset profile system provides an easy and flexible means of managing the structure, relationships and access to large amounts of information that is generated by FDM. The digital asset profile system is expected to reduce time in maintenance/out of service, maintenance cost and backlog, while improving engine/aircraft performance/productivity and safety compliance. The new insights are likely to prove useful capabilities of identifying ways to improve future product design or flight crew technique modifications.

3.3 Audio and video analytics

3.3.1 Scope and definition

(Input from AirAsia Berhad, ahmadamirul@airasia.com and www.comparisonics.com)

Audio analytics is defined as a study of audio signatures represented by waveforms and frequency. Current technologies which are capable of segregating individual sounds in a large audio recording exist. These audio signatures can enable automation of audio-triggered real-time monitoring of flight data and cockpit audio from aircraft to ground. For example, a hijacking could be easily identified well before any deviation in the flight path.

Video analytics is defined by AC-I-042[1] and Doctor of Science thesis on "Abnormal Behaviour Detection in Surveillance Videos" (DISS.ETH No.201377)[2] as a collection and detection of abnormal behaviour, movement or events via video streaming.

With the advance of data analytics, the analysis and detection of abnormal behaviour or movement using real-time audio and video analytics can provide a proactive source of data for FDM. For example, typical abnormal behaviour or events includes falling, running, tussling, entering restricted zones, etc., or whatever unwanted events which 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. Audio and 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 audio and 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 audio and video analytics are:

- Make it easier to locate an aircraft in case of an emergency.
- 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.

The real-time transmission of a triggered signal on detection of abnormal movement in the aircraft is sent to a server on the ground via a communication network. A short five-second mpeg video clip record, both before and after the trigger, is sent as well. The triggered signal data as well as the video clips are recorded onto an on-board recorder that can be accessed in-flight or post-flight. The ground system stores the data to provide situational awareness. The industry is currently depending on specific implementations of cloud computing services and the audio and video analytics shall benefit the following users:

- air traffic management (ATM);
- airline operators;
- operational control centres;
- flight following centres;

[1] The document was prepared and presented at the third meeting of ITU-T FG AC in Geneva from 18-20 May 2015.
[2] Doctor of Science thesis on "Abnormal Behaviour Detection in Surveillance Videos", presented by Fabian Nater (DISS. ETH No.20377), examined by Prof. Luc Van Gool, ETH.

- airport ground operations;
- maintenance facilities (including maintenance, repair and operations (MRO));
- dispatch and mission control;
- automated flight following (AFF) for governmental organizations;
- military;
- flight schools;
- passengers and crew.

3.3.2 Capabilities – Audio analytics

The audio analytics emerging technology of sound matching where a computer algorithm measures the similarity of sounds. This unique technology is used in the applications to search audio based on sonic similarity. Given any sound, similar sounds can be located automatically. The audio signature can also be in waveform display that is coloured to represent frequency content. This visualization allows the flight operation control to see the sounds with automated data analytics capabilities for real-time FDM. The capabilities identified are as follows:

- creating signatures to characterize audio;
- comparing signatures to determine the similarity of sounds; and
- deriving colours from signatures for displaying audio.

3.3.3 Capabilities – Video analytics

Current video surveillance systems mainly use rather simple features and alarm criteria, like a scene not containing motion or trip lines not being crossed. However, the emerging technologies can generate stronger models of normality and raise alarms if scenes deviate, and the data can be used for human behavior analytics, process-based analytics and novelty detection. The capabilities identified are as follows:

Data requirements

Aircraft registration, aircraft hardware unit serial identification, date, time, position (latitude/longitude). Additional requirements are: altitude, speed, tracking, and heading.

Data source

Data source is from the video surveillance cameras on board the flight within the flight management computers (FMC). Trigger signals are typically less than 100 bytes. The video clip of five-second duration is 1 MB. In a normal flight, no triggers will be generated. In others, there may be triggers when abnormal movement takes place.

Transmission technologies

Technologies are available as of today. Current technologies have sufficient capabilities for tracking, sending alerts, and a few parameters. Global transmission technologies are limited to satellite-based technologies with global coverage. However, the current available technologies have sufficient capabilities for retrieving the position, time, data and either recording it or sending it via the current communication network channels such as satellite or radio. The transmission interval can be defined as the required performance criteria by regulators subject to the communication network limitations.

3.3.4 Key challenges – Video analytics

The 'semantic gap', i.e. the true understanding of the video scene is crucial for having the right intervention for a given situation. It can be expected that the substantial advances in object recognition that have been made during recent years will start to flow into surveillance systems, therefore reducing the high false alarm rates. In general, a better understanding of the technology and its use cases is required. Other key challenges are:

- Aircraft navigational capabilities – Many aircraft do not have modern navigational equipment. This may bring about the need to access traditional cockpit devices and calculate via dead-reckoning methods the aircraft's position in time and space. Accuracy and precision will be affected. Alternatively a global positioning system (GPS) (or other) antenna may need to be installed;
- Many aircraft do not have communication equipment capable of transferring any data to the ground in real time. A communication device capable of transferring data to the ground needs to be installed;
- Portable versus installed equipment and the supplemental type certificate (STC) considerations associated with it need to be installed;
- Satellite technologies for transmitting data in real time needs to be available globally (over poles, land and water);
- Access control to the data because it can reveal sensitive operational and economical details of the airlines;
- Security mechanisms, to avoid and detect misuse of the system or false data injection; and
- Privacy, false alarm and failures to detect abnormalities.

3.3.5 Applicability for the aviation industry

Visual surveillance analyses image streams of single or multiple cameras, and flags situations of interest or concern, typically for a human operator to determine the right action to be taken to manage the situation in a timely manner. The real-time transmission of a triggered signal on the detection of an abnormal movement in the aircraft can also be used in other transportation-related industry such as cars, public busses, railways, commercial trucks and heavy vehicles. The audio and video analytics can also provide situational awareness in security-related areas such as in maritime, banking, schools, building/airport management and restricted areas. Effective and efficient surveillance technology has many other related applications such as from the private home (e.g. avoiding burglaries, reporting falls by elderly people, providing dietary assistance, etc.), over safety in public places (e.g. left luggage, re-identification of suspects throughout premises) to enhancing quality and productivity in industry (e.g. wearing of safety helmets, and making sure the correct assembly cycles are followed).

3.4 Machine learning

3.4.1 Scope and definition

Machine learning is a subfield of computer science driven by computational thinking (CT) 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.

Integration across datasets requires a well-coordinated distributed network system to monitor multi processors and multiple network links. A computational future for big data that relies on this type of automation through well-coordinated armies of intelligent agents that track the movement of data from one point in the network to another, identifying bottlenecks and scheduling processing tasks, provide the capabilities of machine learning to simplify decision-making in cross industry applications.

3.4.2 Applicability for the aviation industry

The relevant industry applications for machine learning may include:

- adaptive web services and websites;
- affective computing and brain-machine interfaces;
- sentiment analysis (or opinion mining);
- speech and handwriting recognition;
- syntactic pattern recognition, natural language processing;
- aviation analytics and diagnostics.

3.5 Quantum computing

3.5.1 Scope and definition

"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 super positions of states."[3]

3.5.2 Applicability for the aviation industry

The relevant aviation industry applications for quantum computing may include:

- search engines;
- computer vision, including object recognition;
- sequence mining;
- software engineering;
- information retrieval and machine perception;
- optimization and metaheuristic;
- recommender systems and diagnostics.

4 Technology consideration

4.1 Barriers to adoption

4.1.1 Challenges for CSC

The following challenges are related with environmental difficulties or indirect threats that may give rise to more direct threats to CSC:

- ambiguity in responsibility;
- lack of trust;

[3] https://en.wikipedia.org/w/index.php?title=Quantum_computing&oldid=697906322

- lack of governance;
- lack of privacy protection;
- unavailability of services;
- cloud service provider lock-in;
- misappropriation of intellectual property;
- loss of software integrity;

4.1.2 Challenges for CSP

The challenges associated with environmental difficulties or indirect threats that may give rise to more direct threats to the interests of CSP are:

- ambiguity in responsibility;
- shared environment;
- inconsistency and conflict of protection mechanisms;
- jurisdictional conflict;
- evolutionary risks;
- bad migration and integration;
- business discontinuity;
- cloud service partner lock-in;
- supply chain vulnerability;
- software dependencies.

4.1.3 Challenges for cloud service partner (CSN)

The following considers challenges that directly affect CSNs. Such challenges might affect the ability of CSN to do business, to protect their intellectual property, and to avoid legal or regulatory difficulties. Security challenges to a given CSN will depend on their specific business and environments such as development, integration, audit, etc.

- ambiguity in responsibility;
- misappropriation of intellectual property;
- loss of software integrity.

4.2 Dependency

4.2.1 Dependency for CSC

The following dependencies are directly affecting CSC. They may affect the CSCs' business interests, privacy, lawfulness or safety. The risk will be depending on the nature of the cloud computing service being used. For example, a cloud service specific to the transcoding of commercial video files has no requirements to protect personally identifiable information (PII), but will have strong requirements around the protection of digital assets.

- data loss and leakage;
- insecure service access;
- insider threats.

4.2.2 Dependency for CSP

The dependencies that directly affect CSPs are such threats that might affect the ability of CSP to offer services and to void legal or regulatory difficulties. The risks to a given CSP will also depend on their specific service offerings and environments.

- unauthorized administration access;
- insider threats.

4.3 Technology and CSC readiness

Cloud computing technology and capabilities are already available and proven for the aviation industry. CSCs should identify their cloud computing services requirements and align them with the recommended industry best practices as identified by FG AC WG2/3.

Currently, cloud computing for flight information, processes, systems and services are available in specific instances provided by CSPs and CSNs. It is the responsibilities of the aviation industry, the International Civil Aviation Organization (ICAO) and stakeholders such as civil aviation authorities to specify the relevant standards and regulations over cloud computing requirements such as an aviation cloud for real-time monitoring of flight data. This will include protection and security, data ownership and access to flight data.

5 Conclusion and recommendation

5.1 Conclusion

The Working Group 1 document elaborates the existing and emerging technologies in the areas of *cloud computing* and *data analytics* that could be utilized for FDM in the aviation industry. 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 document, 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.

In conclusion, the 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.

5.2 Recommendation

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

1 For TSAG to recommend to 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 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 CSC.

5 For ITU-T, ICAO, IATA, ISO TC 20 and other relevant stakeholders to continue the collaboration work 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, EASA and FAA to establish the appropriate definition of real-time FDM in terms of data types and data volume (parameters and recording frequencies).

6 Acronyms and abbreviations

ACARS	Aircraft Communications Addressing and Reporting System
ADS-B	Automatic Dependent Surveillance-Broadcast
ADS-C	Automatic Dependent Surveillance-Contract
AFF	Automated Flight Following
ATC	Air Traffic Control
ATM	Air Traffic Management
CEN	*Comité Européen de Normalisation*- European Committee for Standardization
CSC	Cloud Service Customer
CSN	Cloud Service Partner
CSP	Cloud Service Provider
CT	Computational Thinking
DR	Disaster Recovery
EASA	European Aviation Safety Agency
FAA	Federal Aviation Administration
FDM	Flight Data Monitoring
FG AC	Focus Group on Aviation Applications of Cloud Computing for Flight Data Monitoring
FMC	Flight Management Computer
GADSS	Global Aeronautical Distress and Safety System
GPS	Global Positioning System
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IEC	International Electrotechnical Commission
IoT	Internet of Things
ISO	International Organization for Standardization
ITU	International Telecommunication Union
ITU-T	The ITU Telecommunication Standardization Sector
MFA	MultiFactor Authentication
MPEG	Moving Picture Experts Group
MRO	Maintenance, Repair and Operations
PaaS	Platform as a Service
PII	Personally Identifiable Information

QoS	Quality of Service
R&D	Research and Development
SaaS	Software as a Service
SLA	Service Level Agreement
SLG	Service Level Guarantee
STC	Supplemental Type Certificate
TSAG	Telecommunication Standardization Advisory Group
VM	Virtual Machine
WG	Working Group

7 References and further reading

[1] Recommendation ITU-T Y.3500 (2014) | ISO/IEC 17788:2014, *Information technology – Cloud computing – Overview and vocabulary*. ITU-T Y series: Global information infrastructure, Internet protocols aspect and next-generation networks.

[2] Recommendation ITU-T Y.3501 (2013), *Cloud computing framework and high-level requirements*. ITU-T Y series: Global information infrastructure, Internet protocols aspect and next-generation networks.

[3] Recommendation ITU-T Y.3502 (2014) | ISO/IEC 17789:2014, *Information technology – Cloud computing – Reference architecture*. ITU-T Y series: Global information infrastructure, Internet protocols aspect and next-generation networks.

[4] Recommendation ITU-T Y.3503 (2014), *Requirements for desktop as a service*. ITU-T Y series: Global information infrastructure, Internet protocols aspect and next-generation networks.

[5] Recommendation ITU-T Y.3510 (2013), *Cloud computing infrastructure requirements*. ITU-T Y series: Global information infrastructure, Internet protocols aspect and next-generation networks.

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