European Union Aviation Safety Agency

EASA.2012.FC02 SC.006

EUROCAE Study:

Analysis of the evolution of air/ground communication

Disclaimer

EASA – EUROCAE Framework contract N° EASA.2012.FC02

Special Contract N° 006

Analysis of the evolution of air/ground communication

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SARL au capital de 50 000 € - RCS Nanterre B 424 467 066
TVA intracommunautaire FR 51 424 467 066 - APE : 7490B
Code SIRET : 424 467 066 000 25

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Christian Schleifer	Director	03/08/2016

Document History

Edition	Date	Status	Author	Justification
00.00.06	29/06/2016	Draft	Luc Deneufchatel	
00.00.07	11/07/2016	Final	Luc Deneufchatel	Updated after internal review
00.01.00	03/08/2016	Approved	Christian Schleifer	Completed deliverable

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1. Introduction

Aviation air/ground communications are historically classified into four different categories, independently from the radio-communication system used:

- Air Traffic Services Communications (ATSC) with aircraft,
- Aeronautical Operational Control Communications (AOC),
- Airline Administrative communications (AAC)
- Aeronautical Passenger Communications (APC)

ATSC and AOC have been considered as categories of communications requiring protected spectrum (i.e. Aeronautical Mobile service En-route – AM(R)S - safety of life spectrum allocations) as they contribute either directly to the flight safety, or to flight regularity (which could also have an indirect impact on the flight safety). These categories are also generally covered by complete (i.e. ATSC) or specific and partial regulations (i.e. AOC) depending on their impact on flight safety.

The two other categories (AAC and APC) have been always excluded from aviation protected spectrum (ITU is designating these allocations as “off route”) and not requiring specific aviation regulation. Actually AAC communications were generally mixed with AOC without specific distinction and they were using de facto the same radio-communication resources than ATSC and AOC categories.

This study will concentrate only on the evolutions of ATSC and AOC categories and more specifically on AOC type.

Security threat is a growing concern potentially impacting all the categories of communications. But when the communications are associated with flight safety it needs to be seriously considered even if the services are provided by dedicated radio-communication system using protected aviation spectrum.

<u>ATSC communications:</u>

Regarding the ATSC class of communication, the evolutions are quite well defined for the next two or three decades in order to support the new ATM concepts developed by SESAR or NEXTGEN that could be summarised by the move from tactical to strategic air traffic management. The first paradigm shift consists in the usage of data-link services as the primary mean of ATSC communication, instead of voice that is becoming a service used only for the few remaining tactical interactions and for emergency situation.

The first step of this change was the introduction of ATN B1 data-link services (i.e. basic CPDLC transactions) in the whole European upper airspace (i.e. Regulation 2009/29[1]). This deployment has put in light the difficulty associated to such a big change that impacts

[1] Mandated through EC Regulation 29/2009 above FL 285

the key ATM ground system. During this first deployment of VDLM2[2] single frequency air/ground communication technology, several technical and operational issues has been detected leading to a decision to delay the implementation programme to allow the identification and validation of the appropriate mitigations (i.e. the so call "provider abort" characterised by a disconnection at transport level). Among the causes creating these defects, the sharing of the same communication channel for both commercial AOC traffic and mandated ATSC traffic and the non-coordinated VDLM2 ground infrastructure deployment (i.e. multiplication of ground stations to cover the same geographical area) has been clearly identified. This point is addressed especially in this study because it could lead to specific measures regarding aviation protected spectrum usage.

The second step will be the introduction of a new set of services (i.e. ATN B2 services) and a vertical extension of the initial data-link service volume (from FL 285 to TMA and airports). It should probably face new technical and operational problems that were not visible in the first step.

In terms of radio-communication technologies, the ATM Master Plan[3] foresees a two steps approach:

- Usage of VDLM2 to cover the current (ATN B1 services) and medium terms needs (ATN B2 services),
- Usage of new technologies with higher performances and increased capacity (without getting very high throughput) with a time horizon of 2035 subject to timely progress in R&D.

It is not the main topic addressed by this study simply because it is today well covered in terms of regulation and approval process.

<u>AOC communications:</u>

The very rapid progress of the technologies in mobile radio communication world and the growing needs to share more and more information between the mobile units is today the major driver for AOC communication evolutions.

As a first illustration of these growing data exchanges, the huge and quick growth of downlink flow of aircraft equipment and systems monitoring parameters for the last generation of aircraft (i.e. A350, B787) has been multiplied by 10 to 50 compare with the previous aircraft generation.

The operation model of airlines has also deeply evolved during the last decade, relying more and more on real time data exchanges between flying aircraft and Airline Operational Control Centres (or Operator's Operational Control Centres) and thus making such functionality an essential one for airlines operation efficiency (many example of "No go" decision in case of ACARS function unavailable before take-off). This evolution has resulted in a constant increase in capacity demand for AOC data traffic.

[2] Standardised by ICAO (i.e. VDLM2 associated with the ATN/OSI transport layer)

[3] The last update of the European ATM Master Plan was published in 2015

Associated with this evolution, the question of the availability of communication technologies suitable to cope with this demand has emerged. It has opened a debate on the need to move away AOC data communications from aviation protected spectrum, because the remaining capacity within the aviation communication spectrum has been seriously reduced during the last 10 to 15 years and it must be reserved for the future ATM data communication services.

The next move toward a SWIM net centric data sharing model, one of the key cooperative ATM evolution, will also drastically modify the traditional way of dealing with aviation air/ground communications. Depending upon the intended usage of these information on board, the services could be provided by new actors and not anymore by only ANSPs and Airline Operational Control Centres (also named CCOs) and not use anymore the aviation protected spectrum. These new data exchanges need to be analysed in terms of intended use in order to apply to each of them the appropriate regulation (when necessary).

In parallel and in the same logic, the development of specific applications using portable devices as human machine interface (i.e. tablets or IPAD like device), known as Electronic Flight Bag (EFB), has open the door de facto to non-regulated communication service utilised by aircraft crew or cockpit system.

Introduction of various EFB classes with dedicated regulatory approval process to apply to them has provided minimum guidance for the implementation and usage of these new functions.

During the last 5 years the growth of the data traffic using the EFB solutions (commercial of the shelf IP based communications using non protected aviation spectrum) has been much higher than the classical AOC traffic using ACARS over aviation communication links (i.e. using protected spectrum). For these applications communication standards are not required because they are either airline specific ones or directly covered by a service subscription to a service provider. Therefore there is a continuous development of AOC applications that are provided on commercial non-aviation communication networks by new services providers (not any more limited to the historical ones SITA or ARINC).

2. Scope of the study

The study results contained in this report remains high level and provides some preliminary ideas on how the regulatory framework should evolve to cope with the wide evolutions of the tele-communication domain.

The study object of this EASA special contract will cover the following elements:

- a global picture of the air/ground communication current context with the classical categorisation of air/ground communications, the ICAO

Required Communication Performance concept with the setup of the performance indicators

- an indication of the evolutions within the foreseeable future covering ATM needs and AOC needs
- the major differences between AOC and ATS needs in terms of performance
- an analysis of the implications of these evolutions in terms of spectrum usage (defining the usage of protected spectrum and recommendations to move out non relevant services due to the shortage of protected spectrum for aviation needs). This will highlight the need to secure the use of the limited aviation safety of life spectrum by moving AOC communications into non safety of life.
- the need to define a new approach to assess the potential safety impacts of new AOC air/ground communications based upon content and intended usage of exchanged information. Depending on the result of such assessment specific regulatory requirements could be recommended to cover these potential safety impacts taking also into account the possible usage of non-aviation protected spectrum.
- some recommendations and eventual complementary activities.

The study will not be an exhaustive analysis of all the above mentioned issues due to the limited amount of efforts devoted to it. It will remain synthetic and high level thus proposing some way forwards in terms of regulatory evolutions.

3. The current context of aviation air/ground communications.

3.1. The spectrum dimension

One of the major concern for the aviation world continuous development is the access to appropriate spectrum to support the foreseen traffic growing. In particular two key improvements of Air Traffic Management are fully dependent from data exchanges between ground ATM and airborne systems:

- the trajectory based operations relying upon an agreed flight profile (the “trajectory”) between the ATM stakeholders,
- the data sharing of information provided by the aircraft to the ground domain or provided by ground based server to the aircraft. This is part of the SWIM (System Wide Information Management) function that is not yet mature regarding these air/ground exchanges. This is in particular linked with the

available bandwidth within the Aeronautical spectrum to cope with such needs.

These two functions and the associated need for communication require appropriate spectrum that is to say in the part of the spectrum that does not suffer from too strong propagation losses (i.e. below 2 GHz), and the necessary band width to accommodate these new flow of communication traffic.

It is therefore essential to have a good perception of the current spectrum dedicated to aviation services (i.e. protected and reserved frequency bands) and of the constraints that are linked with the access to new spectrum.

The following sections are addressing these two specific points.

3.1.1 The spectrum regulatory framework

The current spectrum allocated to aviation relative services are governed by International Telecommunication Union (ITU).

The spectrum is not allocated to specific system or technologies but to so call "services". Today the ITU services are presented in Table 1. The relevant services for this study are in red color:

Service name	Aeronautical domain	Safety of life service
Aeronautical mobile (R)* service	X	Y
Aeronautical mobile (OR)** service	X	N
Aeronautical mobile-satellite (R)* service	X	Y
Aeronautical mobile-satellite (OR)** service	X	N
Aeronautical radio-navigation service	X	Y
Aeronautical radio-navigation-satellite service	X	Y
Mobile-satellite service	X	N
Fixed service		N
Fixed-satellite service		N
Land mobile service		N
Land mobile-satellite service		N
Maritime mobile service		N
Maritime mobile-satellite service		N
Port operations service		N
Ship movement service		N
Broadcasting service		N
Broadcasting-satellite service		N
Inter-satellite service		N
Space operation		N
Radio-location service:		N

Radio direction-finding service:		N
Coordinated Universal Time (UTC) service		N
Industrial, scientific and medical (ISM) applications service		N
Radio-determination service		N
Radio-determination-satellite service		N
Radio-navigation service		N
Meteorological aids service		N
Earth exploration-satellite service		N
Meteorological-satellite service		N
Standard frequency and time signal service		N
Standard frequency and time signal-satellite service		N
Amateur service		N
Amateur-satellite service		N
Radio astronomy service		N
Radionavigation-satellite service		N
Maritime radionavigation service		N
Maritime radionavigation-satellite service		N
Radiolocation service		N
Radiolocation-satellite service		N

Table 1: List of ITU recognised services

The Spectrum allocation process is organised through a lengthy mechanism to ensure that the request for new allocation is clearly understood by the spectrum user communities and is clearly justified. Taking into account the explosion of demand for new spectrum allocations, in particular from the land mobile communication service stakeholders (i.e. commercial telecommunication service providers), the new process is running through the World Radio Conference (WRC) milestones.

WRC is the major radio regulation meeting that takes place every 3 to 4 years (usually at the ITU headquarters in Geneva) with a significant agenda. It runs for four to five weeks of plenary and ad hoc meetings involving around 1500 delegates from the various member states and international organisations.

The agenda of a WRC meeting is frozen at the previous WRC due to the large demand for new discussion items. At these WRC not only new spectrum allocation request are investigated but also the current usage of allocated spectrum in order to detect potential re-allocation of some spectrum that is not used as intended. During the last 20 years the aviation community has lost a significant part of its historical allocated spectrum by lack of implementation of the relevant systems. The two major domains illustrating this point are the:

- Microwave Landing System (MLS) for which 2/3 of the initial allocated spectrum has been lost,

- The Satellite aeronautical mobile communication (En-Route) for which the complete historical allocation has disappear and been allocated to Satellite Mobile services (no more specifically aviation).

Due to the very tight pressure from the mobile telecommunication industry sector, there is still a significant risk to see the aeronautical spectrum allocation decreasing in the coming decade to face the high existing spectrum congestion. A significant part of the existing aviation allocated spectrum being in the best part of the spectrum regarding propagation performances, because it is highly coveted by the other community looking for new spectrum to develop their own business

One of the complex subject still open and on the agenda of the next WRC (2019) is the spectrum allocation required for the drone's operations (C2/C3 radio links) because the discussion were not finalised at the last WRC (November 2015). This debate could have a collateral impact on the current aviation spectrum.

3.1.2 The spectrum dedicated to aviation

Several services are attached to aviation and benefit from a dedicated protected spectrum allocation. For the purpose of this study only the Aeronautical Mobile Service (AMS) will be considered in the following paragraphs.

There are two Aeronautical Mobile Service:

- The so call En-Route service that is indeed associated with the safety usage of this spectrum (i.e. Safety of Life service). ICAO has developed some guidance on this type of allocations in the handbook on radio-frequency (RF) spectrum requirements[4]. ICAO has developed a rationale to justify the use of a safety margin on top of the normal service protection criteria against interference from other adjacent services. Such safety margin could range from 3 to 6 dB above the normal protection criteria level (Detailed information are provided in Annex 1),
- The so call Off Route service that is not associated with safety usage.

The Table 2 below presents the global picture of these allocations.

- Aeronautical Mobile Service (AMS) or Aeronautical Mobile "En-Route" Service AM(R)S
- Aeronautical Mobile Satellite Service (AMSS) or Aeronautical Mobile «En-Route» Satellite Service AMS(R)S

[4] Doc 9718 : Handbook on Radio Frequency Spectrum Requirements for Civil Aviation

These four types of services are today authorised to operate in the following aviation frequency bands:

Service	Frequency band	Lower frequency	Upper frequency	Voice	Data	Shared
AMS	HF[5]	2,85 MHz	22 MHz	X	X	X
AM(R)S	VHF	117.975 MHz	137 MHz	X	X	
AMS	UHF	235 MHz	267 MHz	X	X	X
AM(R)S	L band	960 MHz	1164 MHz		X	X
AMSS	L band			X	X	X
AMS(R)S[6]	C band	5030 MHz	5091 MHz	X	X	X
AM(R)S[7]	C band	5091 MHz	5150 MHz		X	X

Table 2: Current aviation spectrum allocation for aeronautical mobile services

3.1.3 The aviation spectrum limitations

The spectrum allocated to aviation is historically distributed within the most attractive part of the spectrum in terms of propagation performances (i.e. below 5 GHz for the CNS domain). This part of the spectrum is also highly coveted by the other communities due to these very good propagation characteristics.

The very rapid development of the mobile communication services has created a huge demand for appropriate spectrum with if possible very good propagation characteristics. In the meantime, due to the scarcity of appropriate available spectrum to satisfy the huge and increasing demand, multiple actions have been initiated to access and share aviation spectrum with the argument that the aviation technologies that are operating in the aviation protected spectrum are very old and not at all spectrum efficient. This creates a continuous pressure on the aviation community.

Today it is clear that there is no way by which the aviation spectrum could expand due to the permanent critics from the other communities regarding the poor spectrum efficiency of the aviation current technologies. Any new demand from the aviation community will result in a strong opposition from these communities to get new spectrum allocations but

5 HF spectrum allocations for En-Route services are indeed: 2850 – 3025, 3400 – 3500, 4650 – 4700, 5480 – 5680, 6525 – 6685, 8815 – 8965, 10005 – 10100, 11275 – 11400, 13260 – 13360, 17900 – 17970, 21924 – 22000 MHz
HF spectrum allocations for Off Route services are indeed 3025 – 3155, 3800 – 3950, 4700 – 4750, 4750 – 4850, 5450 – 5480, 5680 – 5730, 6685 – 6765, 8965-9040, 11175 – 11275, 13200 – 13260, 15010 – 15100, 17970 – 18030 MHz

6 ITU global allocation to AMS(R)S in all the frequency band 5000 MHz to 5150 MHz in sharing with other services

7 Frequency band allocated in sharing to Aeronautical mobile at airport surface (AeroMACS system)

rather inciting aviation to improve their technologies within the existing allocated spectrum.

Therefore in order to secure the remaining spectrum to serve the future needs it is essential to use it with caution. One of the key question is therefore: is it still the time to share the scarce aviation spectrum with the growing AOC needs and to take the risk to not be able to satisfy the ATS needs associated with the ATM changes as developed within the SESAR programme.

In such context it could be necessary to develop guidelines on the usage of aviation spectrum to ensure that the aviation spectrum is used efficiently. One of these guidelines could be to recommend that AOC communications migrate toward non-aviation commercial system operating outside the aviation spectrum.

3.2 Historical origin and rationale of the current ICAO communication classification.

The current ICAO classification relative to communications between aircraft and ground entities identifies four categories of communications:

- Air traffic services communications (ATSC) with aircraft
- Aeronautical operational control (AOC) communications
- Aeronautical administrative communications (AAC).
- Aeronautical passenger communication (APC)

3.2.1. - Air traffic services communications (ATSC) with aircraft

The ICAO definition of ATS Communication (ATSC) is *"Communication related to air traffic services including air traffic control, aeronautical and meteorological information, position reporting and services related to safety and regularity of flight. This communication involves one or more air traffic service administrations"*[8].

The content of ATSC is not ambiguous because it covers all air-ground communications supporting the Air Traffic Services as defined in Annex 11.

3.2.2. – Aeronautical operational control (AOC) communications

[8] ICAO Doc 9880 "Manual on Detailed Technical Specifications for the Aeronautical Telecommunication Network (ATN) using ISO/OSI Standards and Protocols" and ICAO Doc 9896 "Manual on the Aeronautical Telecommunication Network (ATN) using Internet Protocol Suite (IPS) Standards and Protocols"

Aeronautical operational control (AOC) represents the communications supporting Operational Control.

Up to 1980 the ICAO definition of Operational Control was*: "The exercise of authority over initiation, continuation, diversion or termination of a flight"*. In 1980 it has been added a reference to safety, regularity and efficiency: *"The exercise of authority over the initiation, continuation, diversion or termination of a flight in the interest of the safety of the aircraft, and the regularity and efficiency of a flight."*

Then the ICAO definition of AOC communications is directly derived from this definition of Operational Control: *"Communication required for the exercise of authority over the initiation, continuation, diversion or termination of flight for safety, regularity and efficiency reasons"*[9].

The aircraft operator duty for Operational Control:

- Can be delegated only to the pilot-in-command;
- Or can be shared between the pilot-in-command, and a flight operations officer/flight dispatcher[10].

In the second case the aircraft operator implements an Operational Control Centre with a flight operations officer/flight dispatcher.

The AOC communications are in support of the actions of the flight operations officer/flight dispatcher when the aircrew is in the aircraft on the ground or in flight. There are two main kinds of actions:

- the provision to the pilot-in-command during flight of information necessary for the safe and efficient conduct of the flight.
- monitoring of the progress of each flight and advising the pilot-in-command of company requirements for cancellation, re-routing or re-planning, should it not be possible to operate as originally planned[11].

ICAO Annex 6 Part I addresses the specific case of emergency:

> *In the event of an emergency, a flight operations officer/flight dispatcher shall:*
>
> *a) initiate such procedures as outlined in the operations manual while avoiding taking any action that would conflict with ATC procedures; and*
>
> *b) convey safety-related information to the pilot-in-command that may be necessary for the safe conduct of the flight, including information related to any amendments to the flight plan that become necessary in the course of the flight.*

[9] ICAO Annex 10 Volume III Part I, Chapter I, Definitions
[10] ICAO Annex 6 Part I §3.1.4
[11] ICAO Doc 8335 § 5.3.4

However the pilot-in-command is the person ultimately responsible for the safety of the flight.

In terms of spectrum usage historically speaking AOC and ATSC have always been sharing the same spectrum allocations:

- In the case of AMS(R)S they are provided by the same communication system
- In the AM(R)S spectrum historically AOC services have been using a dedicated sub band within the VHF spectrum with less stringent frequency protection criteria.

Note: « Aeronautical operational control (AOC) communications » are often named "Operational Control Communications ».

3.2.3. - Aeronautical administrative communications (AAC)

The ICAO definition of AAC is *"Communications necessary for the exchange of aeronautical administrative messages"* (ICAO AN10 Volume III)

More precisely: *"Communication used by aeronautical operating agencies related to the business aspects of operating their flights and transport services. This communication is used for a variety of purposes, such as flight and ground transportation, bookings, deployment of crew and aircraft or any other logistical purposes that maintain or enhance the efficiency of over-all flight operation"* (ICAO Doc 9896).

3.2.4. - Aeronautical passenger communication (APC)

The ICAO definition of APC is *"Communication relating to the non-safety voice and data services to passengers and crew members for personal communication"* (ICAO Doc 9880).

This kind of air-ground communications is normally not regulated by ICAO. It is mentioned by ICAO only because APC can share the data-link in AMSS

All the above air-ground communications may use either voice or data communication modes.

It must be noted that APC is not consider within the ICAO remit.

3.2.5. ICAO communication priority scheme.

ICAO follows the order of priority defined by the ITU regulation for Aeronautical Mobile Communications (ITU Radio Regulations Article 44 "Order of priority of communications", ICAO Annex 10 Vol II 5.1.8 "Categories of messages", future EASA SERA.14005):

a) Distress calls, distress messages and distress traffic

b) Urgency messages, including messages preceded by the medical transports signal

c) Communications relating to direction finding

d) Flight safety messages

e) Meteorological messages

f) Flight regularity messages

ICAO has specified the content of Flight safety messages and Flight regularity messages (for voice only) (ICAO Annex 10 Vol II 5.1.8.4 and 5.1.8.6):

- The Flight safety messages comprise:

  1) movement and control messages (ATS)

  2) messages originated by an aircraft operating agency[12] or by an aircraft, of immediate concern to an aircraft in flight;

  3) meteorological advice of immediate concern to an aircraft in flight or about to depart (individually communicated or for broadcast);

  4) other messages concerning aircraft in flight or about to depart.

  The first one is clearly related to ATS and the second to AOC. The last one is very vague.

- The Flight regularity messages comprise:

  1) messages regarding the operation or maintenance of facilities essential for the safety or regularity of aircraft operation;

  2) messages concerning the servicing of aircraft;

  3) instructions to aircraft operating agency representatives concerning changes in requirements for passengers and crew caused by unavoidable deviations from normal operating schedules. Individual requirements of passengers or crew shall not be admissible in this type of message;

  4) messages concerning non-routine landings to be made by the aircraft;

  5) messages concerning aircraft parts and materials urgently required;

  6) messages concerning changes in aircraft operating schedules.

  The first type seems relative to ATS only. The other types may be relevant to AOC.

[12] "Aircraft operating agency" is the term used by ICAO for Airline or Aircraft operator.

3.3 The communication performance criteria.

In the last 15 years, ICAO has developed a performance base approach to cover the future communication systems supporting ATS communications. This approach has been integrated these performance requirements in a document entitled “Manual on Required Communication Performance (RCP). ICAO Document 9869[13]”. It covers the required end to end communication performance for the system that supports voice and/or data communications between the pilots and air traffic controllers.

The ICAO RCP Manual defines four parameters that can be used to characterize the required communications performance of any communications system (i.e., wired or wireless, terrestrial LOS or satellite). It is basically only applicable to ATS communications.

These four parameters are defined below:

- *Availability*: The probability that an operational communication transaction can be initiated when needed.
- *Continuity*: The probability that an operational communication transaction can be completed within the transaction time.
- *Integrity*: The probability of one or more undetected errors in a completed communication transaction.
- *Transaction time*: The maximum time for the completion of the operational communication transaction after which the initiator should revert to an alternative procedure.

The RCP approach is applicable to all future communication applications when they are developed. In order to cope with the significant difference between the life cycle of an ATM mobile communication system (i.e. typically between 25 and 45 years) and the development of communication applications (i.e. 3 to 5 years), a new approach has been proposed within the SESAR framework (WP 15.4): this new approach consists in the development of a limited number of classes of service covering current services and also any future services. Each class is defined as a set of performance targets that the supporting communication technology should be able to match.

With such approach the design of a communication system able to support future applications takes into account the classes that are relevant for its intended use. As a

[13] ICAO is currently in the final stage of revision of Doc 9869 in view of publishing Edition 2 in the coming months

counterpart the future applications will have to fit within one of the possible classes of service.

A first attempt to define these classes was proposed in the SESAR programme. They can be summarised into the following classes[14]:

- ✓ The first class corresponds to the current performance requirements that appear in the IR 29/2009 for the CPDLC services in En-route European airspace,
- ✓ The second class corresponds to the future critical services that should enable the major ATM improvements (4D-TRAD covering the trajectory exchanges and negotiation). For this class the performance will lead to the need for a dual link capability,
- ✓ The third class corresponds to the "best effort" which means that the quality of the service will be directly affected adversely by a pic of traffic demand (this class was considered as suitable for AOC services and for strategic only ATS services).

These proposals have been submitted to ICAO to facilitate the future service development but so far it has not been really used by the relevant panel (i.e. COM Panel).

It must be noted that there is some difficulty to get agreement on performance definition between the aviation community and the commercial telecommunication community. These diverging views materialised at ITU during the discussions on guaranty of performances:

- ✓ in aviation the performances are defined to cover the worst case and thus leading to more stringent system requirements
- ✓ in the commercial competitive world the performances are defined using a statistical approach that leads to more flexible and less stringent requirements.

Some complementary information on these divergences are available in Annex 2.

In complement to these classical performance metrics applicable to the ATS communications (but also to a less extend to the AOC communications), a new metric is now emerging: the security. EUROCAE WG 72 has investigated the security issues from an aircraft centric point of view and has developed standards facilitating the security assessment within the airworthiness process.

In particular WG 72 has developed materials to provide basic methodology to address the security aspects within the global airworthiness process. The following text extracted from ED-203 defines the security perimeter to be considered by the methodology:

"Security Perimeter

The security perimeter catalogues the elements of the aircraft or system architecture that have an interface with external systems or persons. These are the elements by which an

[14] The intention is to limit this approach to data-link services and to not use it for voice communication outside

aircraft or system can be affected or interacted with. Of particular note are functional interfaces, software parts, configuration management, and data load processes, and any process which is used to operate or manage a system. External systems and persons are considered to be avenues for off-board threats, such as threats from airline business information systems.

The security perimeter description includes:

- *Physical interfaces, i.e. interfaces that require a physical presence in or near the aircraft, for example Ethernet ports, wireless transceivers, USB plugs,*
- *Logical connections, i.e. interfaces that can be used remotely, often without any distance restriction, for example network connections, serial links, application interfaces. Useful details include:*
    - *Network protocols (e.g., IP, ICMP, ARINC664P7, ARINC429),*
    - *Network services (e.g., DNS, webserver, monitoring/logging service, database server, IPSEC client), and*
    - *Information flows (e.g., unidirectional or bidirectional connection, data source/sink or forwarded data, connection endpoints).*
- *Intended accessibility:*
    - *Interfaces within the aircraft for use by passenger devices,*
    - *Interfaces within the aircraft for use by cabin and flight crew devices,*
    - *Interfaces within the aircraft for use by maintenance and product support devices.*
    - *Interfaces with ground systems,*
    - *Interfaces to other aircraft systems. “*

This extract clearly indicates that the air/ground communication system are fully in the security perimeter

Security issues could have the same causes for ATS or AOC services but the consequences are of very different nature:

- ✓ For ATS communication the main trigger will be the potential indirect impact of it on the flight safety
- ✓ For AOC communication the main trigger will be the flight efficiency and more generally the economical dimension (including the data protection issue)[15]

These differences will be developed in the next section focusing on the AOC domain.

[15] It should be noted that for historical reasons ICAO has always associated AOC exchanges also with safety concerns

The following section is providing some information regarding the future ATM data-link services. For these ATM services the performance criteria are essential to ensure that the associated safety requirements are met.

3.4. Examples of future ATS communications services

The Baseline 1 data-link services have been mandated for deployment within the European upper airspace (i.e. above FL 285) by the Data Link Services (DLS) Implementing Rule (EC 29/2009).

The data link services required by the SES DLS Implementing Rule are:

- ✓ Data Link Initiation Capability (DLIC);
- ✓ ATC Communications Management (ACM);
- ✓ ATC Clearances (ACL);
- ✓ ATC Microphone Check (AMC).

The Baseline 2 data-link services have been defined worldwide to cover the future needs of air/ground data exchanges to support the move of ATM from tactical operations towards strategical operations. These services have been defined and standardised in the following EUROCAE standards recently published:

- ✓ ED-228A (DO-350A) SPR
- ✓ ED-229A (DO-351A) ATS INTEROP

These documents cover the following data-link services[16] (some are just extension of existing B1 services and other are new):

- ✓ DATA LINK INITIATION (DLIC) SERVICE (compatible with B1)
- ✓ ATC COMMUNICATIONS MANAGEMENT (ACM) SERVICE (compatible with B1)
- ✓ CLEARANCE REQUEST AND DELIVERY (CRD) SERVICE (extension of B1)
- ✓ ATC MICROPHONE CHECK (AMC) SERVICE (compatible with B1)
- ✓ DEPARTURE CLEARANCE (DCL) SERVICE (provided over ACARS at major airports in Europe)
- ✓ DATA LINK TAXI (D-TAXI) SERVICE
- ✓ POSITION REPORTING (PR) SERVICE
- ✓ 4-DIMENSIONAL TRAJECTORY DATA LINK (4DTRAD) SERVICE
- ✓ IN-TRAIL PROCEDURE (ITP) SERVICE

[16] **Green highlighted** services are new services on top of the existing B1 services already mandated in all European airspace above FL 275. For some of these new services (i.e. the 4DTRAD service), the performance requirements could lead to the need to operate the service on a dual link infrastructure allowing a high level of service availability.

- ✓ INTERVAL MANAGEMENT (IM) SERVICE
- ✓ OCEANIC CLEARANCE DELIVERY (OCL) SERVICE (provided over ACARS in Europe)
- ✓ DYNAMIC REQUIRED NAVIGATION PERFORMANCE (DRNP) SERVICE

4. Current AOC evolution trends

4.1. Current AOC – From ACARS to EFB

Initially AOC communications were supported by the ACARS system defined by AEEC. At the beginning, only VHF frequencies were used (some channels in the VHF band). Then HF and SATCOM in the AMSS band were added.

The applications were very dependent upon the aircraft operators. Examples:

- ✓ Departure and arrival reports (Out, Off, On, In times)
- ✓ Fuel/position /weather reports
- ✓ Crew pay accounting (cockpit and cabin)
- ✓ Delay/ETA/diversion/return to gate reports
- ✓ Gate assignments
- ✓ Security messages
- ✓ ATIS messages
- ✓ Aircraft performance monitoring
- ✓ Aircraft engine/APU monitoring
- ✓ Flight management system initialization
- ✓ Maintenance reports
- ✓ Operational messages (free text/formatted)

They don't strictly correspond to the ICAO definition of AOC given in 3.2.2. Most of them are AOC but some others could be considered as ATS or AAC.

From this time AOC has seen considerable developments in two directions: supporting communication means and applications.

The Table 7 in Annex 3 is providing the current picture of the AOC services that are used by the major airlines. This Table 7 provides some details regarding the specific requirements associated with each of them.

4.1.1. Communication means

For AOC, 3 types of air-ground data communications networks may be considered:

- ✓ The ACARS legacy networks
- ✓ The ATN/OSI network

- ✓ Other commercial networks

Each of these solutions are detailed in the following sections.

4.1.1.1 ACARS legacy solutions

ACARS is a very old communication protocol developed by the AEEC in the 70's based upon character oriented technology implemented in the old telex system (i.e. the system exchanges only characters and not data bit stream). These basic protocols have been improved in the meantime to support bit oriented applications (i.e. FANS 1/A services using ARINC 622 specification).

ACARS protocols and services uses a growing number of subnetworks. In addition to the legacy networks:

- ✓ - VHF (basic AM DSB[17] voice radio capability);
- ✓ - High Frequency Data Link (HFDL);
- ✓ - Inmarsat Classic Aero;

new subnetworks are now available:

- ✓ - VDLM2 (with the AOA[18] interface);
- ✓ - Iridium Short Burst Data (SBD);
- ✓ - Inmarsat Swift-Broadband (SBB).

It should be noted that all those networks are composed of a radio-communication segment and of a ground network.

They could use separate ground networks distinct from those defined by ICAO to support ATS or AOC communications, but they historically share the usage of radio-communication segment within protected spectrum allocated to aviation for safety of life services. The most recent evolutions in this AOC domain show an increase usage of "non-aviation" communication segment from the commercial competitive market.

These radio communication segments are under the responsibility of a variety of operators:

- ✓ - VHF and HFDL subnetworks are operated by the ACARS service providers, mainly ARINC and SITA;
- ✓ - Inmarsat satellite service is operated by Inmarsat and the ground segment is operated by ground telecommunication providers.
- ✓ - Iridium Satellite service is operated by the Iridium consortium.

[17] Amplitude Modulation Double Side Band

[18] ACARS over AVLC (the link layer of VDLM2)

- ✓ - VDLM2 is operated either by ANSPs or by ARINC or SITA as service providers.

ACARS has been developed and promoted by the airline community for AOC communications to improve the operations. Using the good progress of ACARS deployment for AOC needs, it has been also used for AAC (up to now the distinction between AOC and AAC is not clearly respected) and for some ATS applications.

The main ATS applications supported by ACARS are

For the airport and TMA domains:

- ✓ Departure Clearance via Data Communications over ACARS (DCL),
- ✓ Digital ATIS via Data Link over ACARS (D-ATIS)

For the En route domains[19]:

- ✓ Oceanic Clearance via Data Communications over ACARS (OCL),
- ✓ CPDCL and ADS-C (FANS 1/A service package).

To be noted that in order to address basic security issues AEEC has developed an additional layer covering authentication, integrity and confidentiality requirements (ACARS Message Security standard).

4.1.1.2 ATN

Aeronautical Telecommunications Network (ATN) is the sole data network (in fact a network of networks) defined by ICAO. Two options are possible: based on the OSI protocols (ATN/OSI) or based on the Internet Protocol (ATN/IPS). In principle it is dedicated to communication services both to air traffic providers and aircraft operating agencies and then in principle to ATSC, AOC and AAC communications. Practically ICAO only requires ATN to support ATSC applications: ADS-C, CPDLC and FIS for Air-Ground and some ground-ground ATS applications (ICAO Annexe 10 Vol III, 3.5). There is no plan to use the option ATN/OSI for AOC, AAC or APC.

Therefore it is clear today that the choice made in Europe to deploy ATN/OSI is not intended to be used for AOC needs.

ATN/OSI is supported by design by VDLM2 or SATCOM radio-communication means in protected bands. The future technologies recognised and standardised or to be standardised by ICAO (i.e. AeroMACS, LDACS and SATCOM next generations) will be compatible with the two ATN options (OSI and IPS) in order to facilitate the transition toward ATN/IPS in the very long terms (2035 +)

[19] To be noted that the FAA intend to implement ATN B1 & B2 services using ACARS protocols thus delaying the implementation of ATN/OSI as it is the case in Europe

There is today a significant divergence between the European and US communication strategy regarding the core technologies to be used.

In Europe the deployment of VDLM2 and ATN/OSI have been mandated through the IR 29/2009, the result being that despite the technical issues discovered during the start of large scale deployment, the major part of the investment has been made for both the ground and the air part. This leads to a strategy that must avoid to force the migration toward a new technology before the normal life duration of the current technology (i.e. typically 30 to 40 years). The convergence toward a new technology will be a long process during which a double capability will be required with the obvious negative economic impact.

In the USA the current strategy seems to be a clear continuation of ACARS usage toward a direct migration to ATN/IPS, thus skipping the ATN/OSI step.

This strong diverging views are now leading to strong discussion that will take place at EUROACE/RTCA level during the second part of 2016.

4.1.1.3 Other commercial networks

A number of existing or future mobile ground networks could and will support AOC needs. Today the main trend is to use commercial networks and services (as a basic customer) to get more attractive communication costs and to break the de facto captive market of SITA and ARINC ; this is mainly applied for the communication that take place at the gate or even during taxi operations. Table 3 below is presenting the technologies that could be used to support some AOC traffic at the airport surface.

COMMUNICATION TECHNOLOGIES: THEORETICAL AND PRACTICAL BIT RATES, AND SECURITY EVALUATION			
Technology	**Theoretical bit rate**	**Practical bit rate**	**Security**
GSM	14.4 Kbps	N/A	Insecure
GPRS	170 Kbps	40 – 50 Kbps	Relatively secure, however it is likely to lose this status in the future
EDGE	473 Kbps	270 Kbps	Same as GPRS
UMTS	2.0 Mbps	384 Kbps	Secure
HSPDA	1.8 – 84.4 Mbps (Depending on the HS-DSCH category)	1 – 6 Mbps (HS-DSCH category 8, and depending on the transmission conditions)	same as UMTS
HSUPA	0.71 – 17.25 Mbps (Depending on the E-DCH category)	1 – 1.5 Mbps (E-DCH category 6, and depending on the transmission conditions)	same as UMTS
LTE (DL)	10 – 300 Mbps (Depending on the device category)	N/A	More secure than UMTS. However the flat-IP based architecture results in more security risks.
LTE (UL)	5 – 75 Mbps (Depending on the device category)	N/A	More secure than UMTS. However the flat-IP based architecture results in more security risks.
802.11b	11 Mbps	5.8 Mbps	Accordingly to the security standard (WEP, WPA, WPA2, or IEEE 802.11i) being used can be considered from insecure to highly secure
802.11a	54 Mbps	24.7 Mbps	Accordingly to the security standard (WEP, WPA, WPA2, or IEEE 802.11i) being used can be considered from insecure to highly secure
802.11g	54 Mbps	24.7 Mbps	Accordingly to the security standard (WEP, WPA, WPA2, or IEEE 802.11i) being used can be considered from insecure to highly secure

Table 3: Accessible commercial communication networks

Besides these technologies that are mainly available for the AOC communications at airport surface (or at low altitude), there are other technologies potentially used in the other phases of flight (i.e. En-Route cruise). These technologies are IP based, satisfying the market requirements to be IP compatible:

- The technologies that are not aviation communication systems operating within the aviation protected spectrum[20].

Regarding the second set of technologies, we can note the last satellite system and associated service launched by Inmarsat: Global Xpress. This technology that operates in non-aviation spectrum provides very high capacity and throughput; thus it could become one technical answer to the AOC traffic expansion and the increase of communication demand for APC (in-flight entertainment) and aircraft operator need to exchange digital data with aircraft (AAC).

To be noted that for the business aviation sector some light applications (for weather information) are based on radio-broadcasting satellites (XM).

Except the networks using L-Band frequency or the future AeroMACS that will be restricted to airport surface communications, none of these networks use a Safety of life frequency band.

Generally speaking the commercial networks based upon non “aviation” technologies (i.e. non recognised by ICAO) offer a throughput significantly more important than the aviation technologies.

Note: the trend is the continuous development of data communication for AOC but AOC voice still exists. It uses specific frequencies within the VHF AM(R)S frequency band.

4.1.2. Applications

AOC applications are directly linked to the different aspects of aircraft operations. Besides the basics applications at the beginning of AOC listed above (4.1), a number of customized applications are introduced. They vary from advisory information given to the crew to applications integrated in the avionics. For business aviation there are a number of off-the-shelf products, providing for example meteorological information (sometimes directly broadcast by satellites).

They are highly dependent upon the throughput of the air-ground communication means, the interfaces and the airline Operational Control Centre infrastructure on the ground. Interfaces can range from very deterministic dialog supported by avionics (specific display or shared with Flight Management System) to more interactive dialog for example on EFB (see below).

SESAR studies have also shown that AOC services (with a wide scope) will continue to grow in the near future and require additional communication resources that could be only found outside the protected aeronautical spectrum. The current trend regarding the growth of the data flow in the downlink to support the technical follow up of flight operations (i.e. the technical monitoring of aircraft function and equipment) indicates a

[20] Among these technologies we can mention: AeroMobile, Panasonic eXConnect, Thales TopConnect, Row 44, “Direct-Air-to-Ground” (ATG), Aircell …

huge growth of such traffic that is not safety critical but rather a key for flight operation efficiency (anticipation and planning of defect fixing activity at the next aircraft stop-over). It is clear that such growth cannot be absorb only by the protected aviation spectrum and a migration toward commercial non-specifically aviation communication providers is needed.

The evolution of applications is linked to the throughput offered by the new communication means (mainly commercial networks) with the protocols moving from the current deterministic protocols to more powerful exchanges like client-server model based on API (Application Programming Interface) as web services.

The Table 7 in Annex 3 provides a sample of AOC applications (main source: COCR 2.0 document). The list contains current applications and some potential future applications but it is difficult to consider it as exhaustive.

Applications may be categorized according to different criteria:

- As the basis of the definition of AOC applications is the support of “Operational Control” a first criterion is the involvement of the aircraft operator through is operational control infrastructure. On the opposite ATSC is exclusively in relation with ATS infrastructure. Involvement of other stakeholders should be also identified.
- The second criterion is whether it contributes to “the exercise of authority over initiation, continuation, diversion or termination of a flight”. If not it can be considered as AAC or APC. For example applications relative to maintenance are outside this criterion.
- The third criterion is the level of impact on “safety, regularity or efficiency” as this feature has been added to the ICAO definition.

4.1.2.1 Applications brought by EFB

With the introduction of EFB in the 2000’ a number of applications related to air-ground communications have been installed. Initially the goal of EFB was a stand-alone equipment in the cockpit providing long-term data to the crew (aircraft documentation, maintenance manuals, flight plans, meteorological information, NOTAMS, charts, and aircraft performance data). EFBs primarily rely on data stored on-board before the flight. Due to the flexible Pilot interface of EFB, the idea emerged to host real-time applications in relation with Air-Ground datalink.

For now the regulation (ICAO, EASA, FAA) has considerably limited the role of applications concerning the control of aircraft. The applications dealing with aircraft navigation (except on the ground), aircraft real-time status or communication with ATS are prohibited (ref 4.2).

4.1.3. Application categorization

4.1.3.1 Categorization according to the involved stakeholders

The three main types of stakeholders/actors are ANSPs, Airline Operational Control Centres and Aircraft. They are regulated by different regulations (respectively: ATM/ANS regulation, Flight Ops regulation and Airworthiness regulations). They are potentially approved by different national approval authorities. Other kind of actors can be involved: communication service providers, MTO service providers and various service providers. When they act as subcontractors of one of the three main families of stakeholders/actors it can be considered as fully covered by them. In the Figure 1 below service providers that are not subcontracted are only considered.

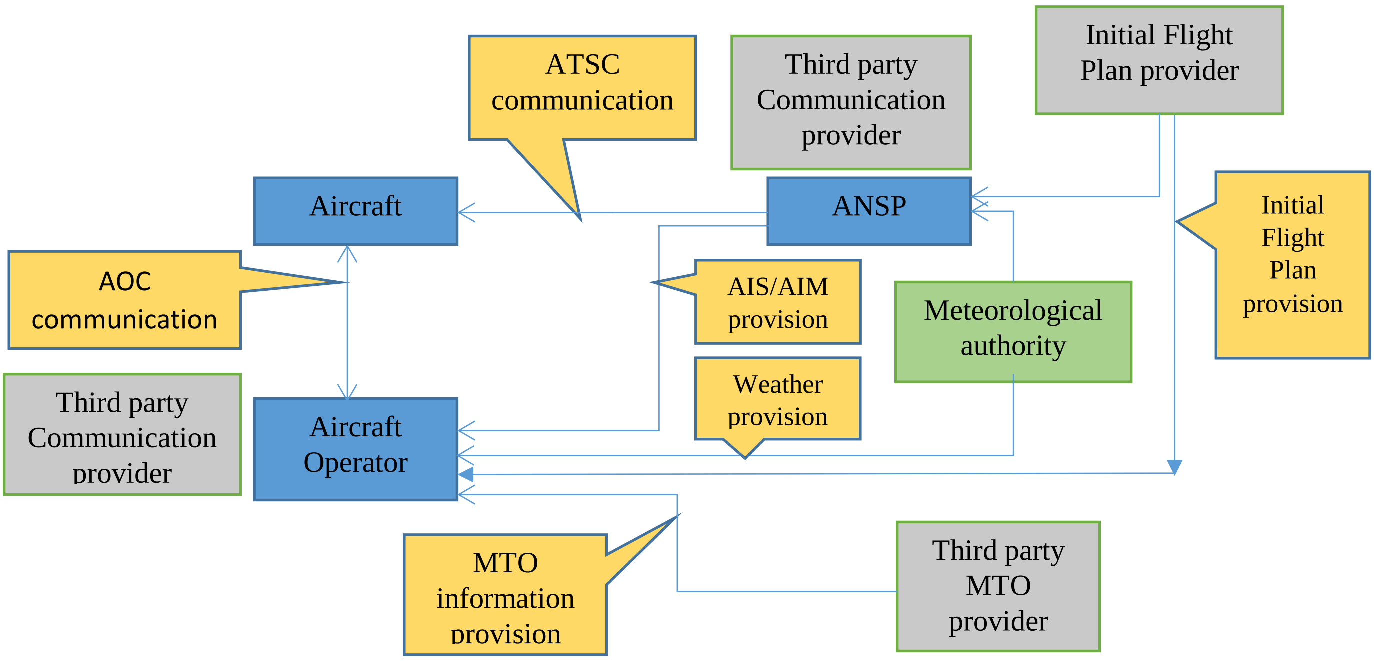

Figure 1 Actors involved in the data sharing with aircraft

Figure 1 shows the three main stakeholders/actors (in blue) and their respective service providers (in grey). The nature of exchanged data is specified in the yellow boxes.

It shows that most of the AOC applications involve two of the main stakeholders/actors: the Aircraft Operator with potentially some subcontracted third party service providers (Weather information, flight plan information, AIS providers, handling partners like fuel suppliers or de-icing companies…) and the Aircraft.

The Table 7 in Annex 3 indicates for some AOC applications what the associated ground end system is: it could be an Airline Operational Control Centre itself or an entity not directly associated with operations: Maintenance, Administrative (AAC), Fuel, Passenger information. Most of the current applications are not directly linked to operations.

4.1.3.2 Categorization according to the exercise of authority over the flight

The Table 7 in Annex 3 contains for each identified AOC service, details regarding the “exercise of authority on the flight“: it indicates whether the AOC application has some form of authority on the flight. Amongst the AOC application there is no application with a real direct authority on the flight in the sense of initiation, continuation, diversion or termination of a flight. Application relative to weather could have an indirect impact but ultimately it is the decision of the crew. For now most of them are advisory. Concerning EFB (Electronic Library) applications it depends upon the role on-board.

Table 7 provides also information regarding the objective of the AOC service: Safety or Regularity/Efficiency. Effect on Safety is rare and is always indirect. It can be considered that applications which improve the level of awareness of the crew or the Airline Operational Control Centre have a role on regularity/Efficiency but, once again, it is generally indirect.

4.1.3.2.1 Categorization according their role on-board aircraft

The airlines association “Airlines Electronic Engineering Committee” (AEEC) has published the ARINC Report 811 (“”Commercial Aircraft information security concepts of operation and process framework” December 2005). The primary goal of this document was to provide a generic and formalized description of the on-board architecture related to external communications. The goal was to provide segregation between domains having different levels of safety and security constraints. But it provides also an interesting classification of the different on-board functions related to Air-Ground communication according to their role during the flight.

It defines 4 main domains (Figure 2): Aircraft Control Domain (ACD), Airline Information Services Domain (AISD), Passenger Information and Entertainment Services Domain (PIESD) and Passenger Owned Devices Domain (PODD). The ACD can be divided into the ACD and the ACD IS (Aircraft Control Domain – Information System). The two last domains, PIESD and PODD, are dedicated to passenger’s connectivity, thus they are outside the scope of this work.

The Aircraft Control Domain has the highest level of safety requirements. The ACD consists of systems and networks whose primary functions are to support the safe operation of the aircraft such as air traffic control (ATC) and some high-priority aircraft operational control (AOC) communication with authority on the flight. They are part of the Flight and Embedded Control System Sub-domain. The functions in the Cabin Core Sub-domain (environmental functions dedicated to cabin operations, such as environmental control, passenger address, smoke detection...) have no authority on the flight (probably AAC functions).

The Airline Information Services Domain (AISD) provides general purpose routing, computing, data storage and communications services for non-essential applications. They support Administrative functions, Flight support, Maintenance...They normally have no authority on the flight (probably AAC functions).

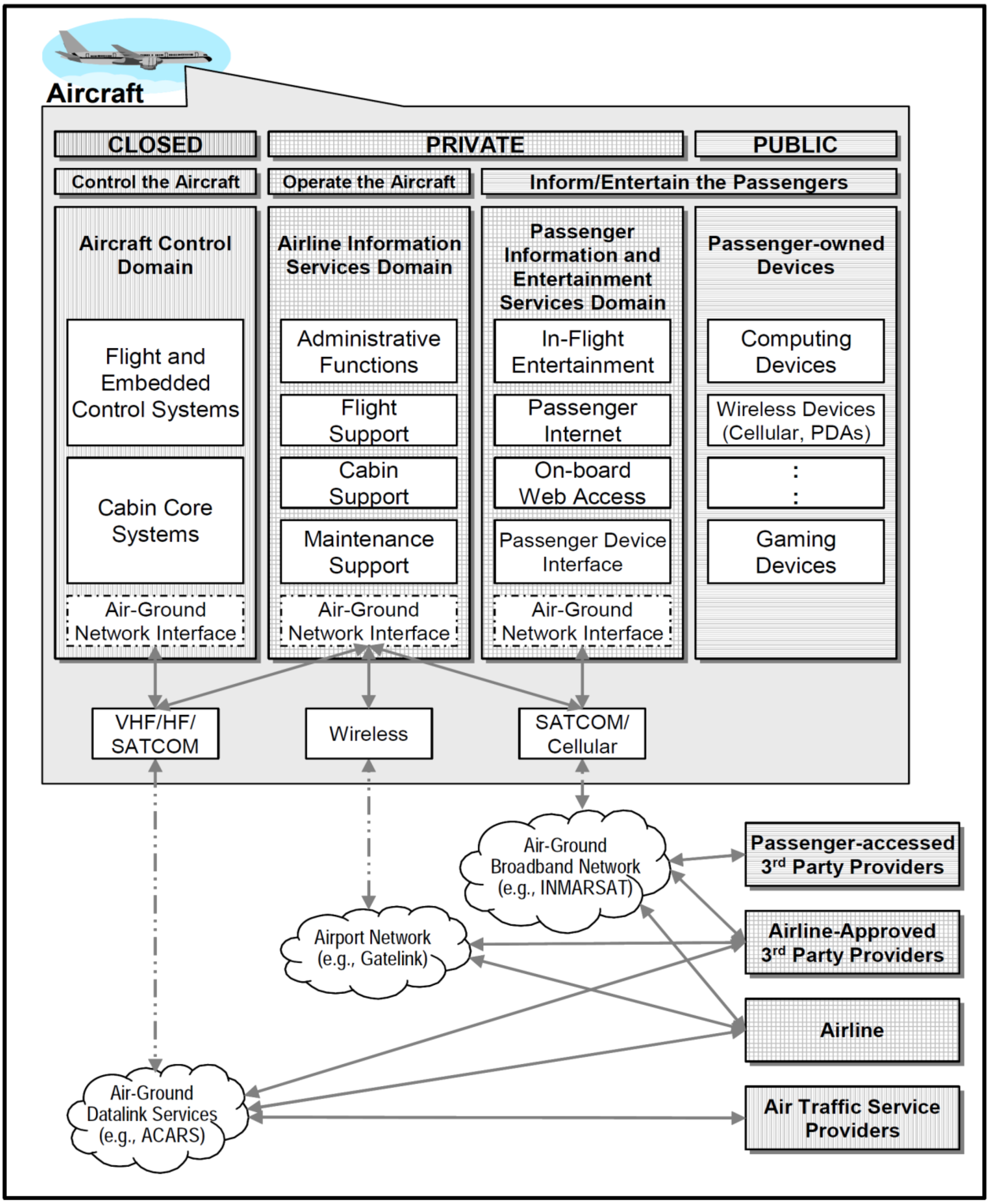

Figure 2 Intended usage of the exchanged data

Table 7 in Annex 3 identifies in column "On-board role" amongst the reviewed applications whether they concern ACD (Aircraft Control Domain), AISD (Airline Information Services Domain) or Passengers (Passenger Information and Entertainment Services Domain).

The majority of applications concern AISD (e.g. maintenance) and passenger information.

Some applications dealing with weather, aircraft loading, NOTAMS, aircraft performances calculation concern ACD but their significance depend upon the status (advisory or not).

4.1.3.2.2 Categorization according to the impact on safety

When communications are in support of aircraft trajectory control (like communications in support of ATS) the "transaction time" often plays a crucial role. It is obvious for the ANS separation service. As explain above the ICAO "Manual on Required Communication Performance (RCP)" (ICAO Document 9869) characterizes the performance of communications according to the following criteria:

- Availability: The probability that an operational communication transaction can be initiated when needed.
- Continuity: The probability that an operational communication transaction can be completed within the transaction time.
- Integrity: The probability of one or more undetected errors in a completed communication transaction.
- Transaction time: The maximum time for the completion of the operational communication transaction after which the initiator should revert to an alternative procedure.

Integrity is not a major issue for data communication because there are some technics to solve it. The three other criteria are globally relative to the Time critically. It shows it is the paramount criteria. It can be related to the fact that ITU and ICAO regulations give an important role to the priority order of communications (ref § 3.2.5). The priority is directly linked to the safety pressure.

In Table 7 in Annex 3 a column identifies qualitatively the weight of the Time criticality. It is generally Low (the column is then empty). Some applications have been considered Medium. No application has High requirements as ATS applications could have to ensure aircraft separation.

Security is not explicitly mentioned by the ITU and ICAO regulations but it is necessary to consider this criteria. Security threats may impact integrity (malicious modification of the content) and availability (Denial of service, interferences...).

In Table 7 in Annex 3 the requirements in terms of security criteria are identified qualitatively (derived from COCR 2.0):

- Confidentiality: Preserving authorised restrictions on information access and disclosure, including means for protecting personal privacy and proprietary information.
- Integrity: Guarding against improper information modification or destruction, and includes ensuring information non-repudiation and authenticity.

Many AOC applications have confidentiality constraints in order to protect the airline business data.

Applications having an impact on the cockpit have integrity constraints (whatever is the origin, safety or security).

Regarding communication throughput it is expected that the need for more AOC services will continue to increase and thus the overall requirement for communication bandwidth also. According to a survey of future AOC requirements initiated within the SESAR programme in 2011 with several major commercial airlines (as part of WP 15.2.4 activities), the following statements were made:

> "It is the Airspace User feeling that in general, total bandwidth requirements for a single aircraft in 2020 will be a significantly higher than today (ATS and AOC combined):
>
> – From legacy character- based to XML based, Web.
> – From messages to "messages and files"
> – Standardization of equipage with EFB/Aircraft infrastructure.
> – 70% - 80% of the increase will be "On Ground", but percentage is driven by Cost-Δ between Surface datalink and airborne datalink."

4.2. The relevant airworthiness and operational regulations

There is a complete set of regulations to approve ANSPs, aircraft and aircraft operators. For example EASA has implemented:

- The ATM/ANS regulation for ANSPs and the Aerodrome Regulation,
- The Air Operations regulation for aircraft operators
- The Airworthiness regulation for aircraft.

The paramount criteria is Safety.

There is a complete coverage inside each of the three domains (ANSP, Aircraft Operator, and Aircraft). When one or more domains are involved (multi-institutional applications) there are means to address the complete issue:

- When a given domain needs inputs from another domain under the responsibility of a different applicant a number of gateways are defined to transmit information from the Aircraft approval to Aircraft operators: AFM or Operational Suitability Data (OSD);
- When a closer cooperation is required, specific cooperation's between domains can be established (e.g. FOSA for RNP-AR approaches).

Specific procedures have been developed for ATS applications. They are generally multi-institutional, involving the ANSP in charge of the Airspace, the Aircraft and the Aircraft operator with an ATS data-link between ANSP and Aircraft:

- EUROCAE has established a methodology (EUROCAE ED-78A "Guidelines for Approval of the Provision and Use of Air Traffic Services Supported by Data Communications") to develop requirements of multi-institutional ATS applications in a coordinated manner amongst the different domains/institutions.
- For ATS operations within a given Airspace, ICAO and EASA require the ANSP responsible for this Airspace to perform a safety assessment after any significant safety-related change to the ATS system. Indeed this ANSP has a complete view and responsibility on the regulations and procedures Aircraft and Aircraft operators are compliant with in this Airspace (published AIP...)

AOC applications enter totally within the EASA regulatory framework. For example the airborne parts of AOC applications are approved through the Airworthiness regulation and the Aircraft Operator is approved against the Air Operations regulation (with the AFM and OSD links between both).

As seen in section 4.1.3.1, AOC applications involve generally two domains: Aircraft and Aircraft Operator. It is a classical situation. For example the ATS applications involve ANSPs, Aircraft, Aircraft Operator (crew) and a communication between ANSP and Aircraft but in this case the Aircraft Operator infrastructure on the ground is not in the loop. The specificity of AOC applications is that the ground infrastructure of the Aircraft Operator is involved and that the communication link is between Aircraft and the Operational Control centre of the Aircraft Operator.

A consequence is that AOC data link services are standardised in a very limited way: the protocols and some content of exchanges are defined by industry standards (AEEC). The reason is that AOC applications are highly dependent upon the Aircraft Operator context and because they require a degree of flexibility and scalability. In addition the communication means is also less standardized and regulated than communications used for ATS applications even if there is a slight trend to improve standardisation[21].

[21] In order to ease interoperability, AEEC maintains the ARINC specification 633 which standardizes a subset of messages that Aircraft Operators cannot modify. As the number of potential users is growing (fuel suppliers, de-

Globally the AOC datalinks and the AOC applications being standardized in a very limited way, it is an obstacle to the development of more valuable AOC applications when they impact safety which is generally linked. Another obstacle is the lack of precise knowledge about the origin of data transmitted by the ground specifically when they are provided by subcontractors.

EFBs represent a specific situation because the wish of Airline Operators is to have very flexible systems which could be customized according to the operator procedures, could evolve with them and also with the available technologies. It is why EASA and FAA have developed a specific process for EFB (mainly EASA AMC 20-25) which do not require a full airworthiness certification process (i.e. EFB being part of the aircraft configuration and certified as such). This specific process is only applicable under the condition that failures have no safety effects or minor safety effects at aircraft level.

Note about the principle for standardisation and approbation of ATS applications:

> ATS applications using data link between ANSPs and Aircraft rely on very stringent standards (communication link, applications, procedures...). Before publishing those standards aviation establish groups with representatives of the stakeholders. They define the standards (SPR, INTEROP) and perform a safety assessment on a typical environment to validate them and be sure they will be able to ensure safety in a variety of environments (ref the EUROCAE ED-78A process).
> Then when stakeholders seek for approval, each of them demonstrates the compliance of its part with the relevant regulation and, as explained above, the ANSP in charge of the Airspace perform a Safety Assessment for its specific environment.

4.3. Future ATM applications based on air-ground communication.

ATN B1 & ATN B2 services are already standardised but deployment will spread over the next 15 years. These services belong to the ATSC domain.

To be noted that there are still discussions ongoing concerning some of the applications included within the ATN B2 package: the wind and temperature profiles upload service that provides the basic updated input to the FMS to update the flight profile predictions. This is today considered as an AOC service that is not provided by ANSP. It is very likely that this new service will be provided in the near future by either the Airline Operational Control Centres or by new service providers that will focus their business on some new AOC services including potentially the wind and temperature profiles.

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icing, anti-icing, and ground handling companies...) it appears also a need to standardize the AOC messages relative to these users.

Most advanced deployment of some ATN B2 services (i.e. 4DTRAD service[22]) will probably require the implementation of new data-link technologies (i.e. LDACS and new SATCOM system) at the stage of very wide deployment in order to capture all the expected benefits (i.e. very high availability of the data-link services leading to the usage of two diversified radio technologies).

LDACS system should be restricted to ATS services and open to a limited sub set of AOC existing services that could still make usage of these protected communication resources.

In the same logic it is very unlikely that AOC services will make use of the ATN/OSI transport layer as it is the case for ATSC services (at least in Europe today through the EC mandate 29/2009). It is therefore quite clear that the communication architecture (in terms of protocols) will continue to differentiate between ATSC and the other types of communication in the coming years.

It must also be noted that the deployment of the ATN B2 package in Europe will probably not be effective until the current technical issues on VDLM2 and ATN/OSI are fully solved. This probably means that the ATN B2 service will only be provided at significant scale after 2025.

To be also noted that following the last European Master Plan update only a small application subset of the ATN B2 service will be implemented in Europe (i.e. 4D TRAD, Flight Interval Management, D-TAXI) while other sub set could be selected only for the US airspace (i.e. Advanced FIM, dynamic RNP). Regarding the US side there is today no clear plan regarding the effective implementation of the ATN B2 services but they will be operating using the ACARS protocols and not the ATN/OSI protocols.

5. The recent issue regarding VDLM2 and the impact of mix regulated and non-regulated traffic on its performances

Deployment of VDLM2 in Europe has highlighted technical problems at service level known as “provider abort”: it is a disconnection at the transport layer level creating the need for logical reconnection at application level (i.e. logon service) that is an event that can only be accepted by exception.

Investigations of the technical causes are on-going through the ELSA study supervised by the SESAR Joint Undertaking. The report of this study should be issued by mid-2016 and should recommend the necessary actions to make the service operational and acceptable.

Investigation of these issues is ongoing under SESAR Joint Undertaking leadership (ELSA study) with the expectation to get a technical and operational solution coping with them. On the basis of these findings and depending on complementary validation

[22] 4DTRAJ is a service to coordinate the agreed trajectory between the aircraft and the relevant ATS units

activities, the EC regulation could be revised accordingly. In any case these events have postpone the real usage of data-link significantly.

One potential mitigation could be to move to multi-frequency VDLM2, but this move will require extra investment for ground infrastructure (radio sites) for ANSP and potential upgrade for airspace users.

Other technologies have been also identified (i.e. Inmarsat “Precursor”) as potential mitigation of these VDLM2 defects, but it requires new significant investment at airspace users level.

A segregation of traffic AOC and ATSC traffic on separate radio links could be a necessary step forward to ensure a stable behaviour of the ATSC data link services in the near future.

Among the various causes for such dysfunction of the VDLM2 system, one concerns the fact that the same radio channel resource is share between several services:

- the AOC commercial services based upon ACARS technology provided by SITA and ARINC, each of these providers having their own VDLM2 ground station network,
- the ATS regulated services based upon ATN technology (as standardised by ICAO) provided by ANSPs in compliance with the EC Regulation 29/2009, the ANSP having the obligation to “deploy” a specific network for SITA contracted aircraft and another specific network for the ARINC contracted aircraft

This deployment leads in practice at the co-existence of four networks of VDLM2 stations without any capacity of sharing the resource of a given ground station. This situation clearly highlight the fact that the commercial services and the regulated services have not the same objectives and cannot be simply rationalised.

It is essential to recall that historically the requirement for commonality of system to support ATM and AOC data-link services was considered as an economical constraint.

As a consequence, VDLM2 is today sharing the VHF aeronautical mobile spectrum with the voice services (ATS and AOC) and also the ACARS services. This spectrum is today still congested due to the long transition cycle between the usage of 25 kHz spaced channels to 8.33 kHz for ATS and AOC voice services. Regulation to enforce this migration is still under negotiation and could result in the migration to 8.33 kHz channels of 60% of the total frequency assignments in this frequency band in Europe.

As a consequence, the spectrum dedicated to VDLM2 is today limited to four 25 kHz channels. These four channels being adjacent one to the others, the parallel usage of these channels in the same airspace is today very limited (only two channels among four).

Further re-allocation of VDLM2 channels is possible but will require a number of frequency shifts in order to create the free spectrum to implement new VDL channels.

Therefore the current situation in the VHF band clearly require a migration of the majority of the AOC traffic toward commercial links that are not regulated. As mentioned above only a small subset of AOC existing applications seems legitimate to be kept over the protected VDLM2 channels.

6. First conclusions and identification of the main challenges.

6.1. ATS communications:

As already discussed in the previous sections, the situation regarding ATS data exchanges is clear:

1. Use of aviation dedicated and protected spectrum with the specific safety of life characteristics
2. Use of ICAO compliant communication systems that satisfy the performance requirements associated with the data-communication services

These two requirements are directly linked to the fact that the safety objective attached to the ATS data communication is the high probability of completing an exchange transaction within a maximum time duration. Therefore the performances of the service (that could be mapped to a class of service for the ATS services) induce a direct performance requirement on the data communication system.

In summary the time constraint associated with an ATS data communication service is the key driver to impose the use of ICAO compliant data communication system that operate into protected and dedicated spectrum.

There is also a clear growth for data communications to replace voice exchanges in the standard case: this is accompanying the ATM paradigm shift from tactical to strategic traffic management.

The foundation of the future ATM management will be the sharing of a trajectory (with much more parameters than the current flight plan) that is agreed by the ATC unit and the aircraft in order to rely on strategic and reliable flight profile predictions.

To support this paradigm shift, more advanced data communication services will be deployed (i.e. 4D TRAD service in particular) according to the last published standards (i.e. EUROCAE ED-228a and ED-229a).

This move could also be accompanied by new performance based regulation that could lead to the need to deploy and operated two parallel data communication system to ensure the trajectory management between ATC and the aircraft. Such requirement will imply to secure the appropriate spectrum to accommodate the data traffic with the required performances on two different technologies operating in different spectrum allocations.

The additional growing issue to be addressed in the future regulations dealing with ATS service is the “security” issue. This is in particular relevant when several communications networks are operating in parallel to ensure connectivity at aircraft level with various ground based service providers (e.g. ANSP for ATS, commercial providers for AOC, AAC and also public correspondence providers for the cabin needs). EUROCAE WG 72 has already developed some guidelines and methodology to cover these issues at the level of aircraft design and to provide the required evidences for airworthiness approval.

Further security requirements could become necessary in the near future to cope with the growing criticality increase of the communication system compare with the current ATM context.

6.2. AOC communications:

The definition of AOC communications within the ICAO standards is less straightforward than the definition of ATS communication. The first criterion is that AOC communications involve Airlines Operation Control Centres and Aircraft. Then the definition adds it has a form of authority on the flight linked to safety and efficiency constraints while it has been shown above that it is not always the case for the existing “AOC” communications: not all the so-call AOC applications are in relation with the Airline Operational Control Center (under the responsibility of a “flight operations officer/flight dispatcher”) and not all the applications have a safety or efficiency impact.

By analogy with ATS communications (often supporting aircraft separation), it has been considered that safety implies urgency or time pressure then requirements in terms of transaction time and as a consequence managed as Safety of Life communications in protected spectrum.

Due to the spectrum constraints explained in the document an effort should be made to separate the AOC communications which really require protected spectrum from communications which could use non protected spectrum and probably in term of communication capability a “best effort” class.

Of course we have seen that an a priori determination of the safety criticality of an AOC application is not always obvious and could depend of specific situations. The current trend is to reclassify as ATS the AOC communications which have a direct impact on the trajectory but is unlikely that all the AOC applications could be considered as non safety critical or at least not time-critical so not requiring protected spectrum.

The economical aspect has also to be considered: in the past, Airlines tend to host the new non-critical AOC applications in the existing on-board equipage. VDR, SATCOM, Router... were already installed. It was less expensive than the installation of new avionics. In the future the non-safety critical AOC applications could be hosted by the Airline information Services Domain (AISD) more suitable for flexible applications.

AOC applications raise standardisation and approval issues because they relate two main domains: Aircraft domain and Aircraft operator domain (only the ground part: Airline Operational Control Centres and Flight Operations Officer) with a communication link between both. There are no official standards because exchanges between aircraft and airlines could be considered as entirely under the responsibility of Airlines without major need for interoperability. Concerning the approval, aviation has developed standardisation and approval process for ATS applications involving ANSPs, Aircraft and Aircraft operator (crew and procedures) but AOC applications are different. The new aspect of AOC applications is that the ground part of Aircraft operators is involved with Aircraft. Up to now, the lack of standards and methodology has probably restricted the AOC applications to those with low safety impact limiting the interest of AOC.

There is a need to first understand the role and responsibilities of the different stakeholders (Aircraft Manufacturers, Aircraft operators and their different providers), Then, if necessary, develop a method to establish typical interoperability standards and requirements on which the applicants could rely when they seek approval. Finally, define the way the recognitions obtained by Aircraft manufacturer for the Aircraft and by the potential providers are transferred to the Aircraft operator, which is the final applicant.

7. Recommendations

The following recommendations are proposed as a result of the analysis developed within the previous sections of this report:

1. Security aspects for all data exchanges with aircraft become a serious challenge that must be addressed urgently through new activities.

2. The existing categorisation of the aeronautical communication services is not any more totally appropriate to face with the current development of these services. It needs to be revisited in particular regarding the overall AOC category. AOC type applications should respect the principle of communication in support of *"The exercise of authority over initiation, continuation, diversion or termination of a flight".* New AOC applications that are dealing with the trajectory management and that could have impact on the execution of the flight must be considered as ATS applications and must developed in the same way than other ATS applications, whatever is the provider of such service (e.g. ANSP or Aircraft Operation Control Center). Appropriate safety assessment methodology (i.e. ED 78a or equivalent alternative methods) must be used to define these new services in the same way it has been done for the last ATN B2 service package.

3. It is recommended to undertake an action toward ICAO in order to revisit the current definition of AOC communications and to identify new sub categories that could better fit with the current and foreseeable situation. But at ITU level it could be not wise to revisit the classical communication classification in order to keep open the capability to operate AOC new services within aviation protected spectrum.

4. The development of new services within the classical AOC domain could have a direct or indirect impact on the trajectory and induce safety consequences. It is recommended to proceed through a systematic approval process for any new AOC applications independently from the way the service is provided (i.e. using aviation specific communication links or any other commercial links). A safety assessment should be provided to the airworthiness authorities in order to fix the conditions for operational approval. Security aspects must also be considered.

5. The mandatory approval of the new AOC applications should be facilitated by the development of a new process standard by EUROCAE. This process should become the framework for developing the safety assessment of any new AOC applications. This approach will provide more flexibility and clarity regarding the new EFB services approval with appropriate mitigations measures when required to go away from the simple advisory only status

6. The severe congestion of dedicated protected aviation spectrum and the fact that there is very limited (if any) opportunities to get new dedicated to aviation spectrum allocations require urgent action to master the usage of the current spectrum. Such action could be to develop accurate guidelines regarding the usage of this scarce spectrum, in particular regarding its usage by new AOC services. These guidelines could limit the usage of this dedicated protected spectrum mainly to ATM services and to a more limited extend to AOC services that could justify a protected spectrum due to safety or fight conduct requirements. Applications that are not within the Operational Control domain (exercise of authority over initiation, continuation, diversion or termination of a flight) should migrate progressively towards commercial communication spectrum.

These recommendations could lead to complementary activities in order to undertake the associated actions that could be undertaken under the responsibility of EASA.

8. Potential follow up supporting activities

Taking into account the set of recommendations presented in section 7, the following activities are suggested:

1. to define the main criteria to be used for the future safety assessment of new AOC services. This activity could be undertaken in order to provide a key input for the new EUROCAE activity on the AOC services dedicated safety assessment methodology or be directly addressed by the new working group as a first step including a first deliverable covering these criteria.

2. to initiate the launching of a new EUROACE working group to develop this ad hoc safety assessment methodology with the objective to get an appropriate tool much less complex that the existing safety assessment methodologies used today for ATM services assessment (i.e. EUROCAE ED-78A or SESAR Safety Reference Material –SRM-). Such task could be undertaken by the EUROCAE secretariat in support of EASA request.

3. to develop some clear guidelines regarding the aviation protected spectrum usage in order to avoid the consumption of a very scarce spectrum by AOC services and to put at risk the deployment of the future ATM data-link services (i.e. ATN B2 services). This could be a new activity for a future framework contract between EUROCAE and EASA.

4. to initiate a review of the current ICAO material regarding the historical communication classification in order to get a more appropriate definition of AOC services and possibly new sub classes for AOC to facilitate the understanding of regulatory requirements associated to each of them.

9. Conclusions

The main conclusions of this study cover different domains:

The first one is the spectrum congestion aspect and the fact that the trend of usage of aviation spectrum is de facto mainly linked with AOC service deployment that ATM service deployment (simply because it is less regulated). This is also supported by the current experience around the VDLM2 deployment and the current observed quality of service that it is not at the expected level and for which the AOC traffic is probably a major cause. There is very few expectation to get any new aviation spectrum while the trend of the last two decades has been a significant loss of the historical aviation protected spectrum, therefore it is urgent to undertake action to secure the scare spectrum primarily to allow the implementation of future ATM evolutions.

The second domain concerns the AOC communication class that is not any more in line with the reality of today’s operations. There is a need to revisit the whole AOC domain and to define AOC sub classes associated with appropriate regulatory requirement when required. As a consequence to this redefinition of AOC, the need for a systematic safety assessment of new AOC services is needed and an appropriate methodology is probably needed and could be developed as a process standard by EUROCAE. Such methodology could provide more accurate guidelines for the new EFB applications to come.

The third domain is the global harmonisation of this new approach of AOC services by action toward ICAO to revisit completely the subject and make it more appropriate with the actual situation.

Annex 1

Margins Used in Aeronautical Terrestrial Communications Systems

Protected System or Service	Reference	Signal Type	Aviation Safety Margin	Rationale
ILS	ITU-R SM.1009-1 [3]	Desired	8 dB	None given
MLS	ICAO Annex 10, Vol. 1, Attachment G [4], Table G-2	Desired	6 dB	None given
RNSS (1559–1610 MHz)	ITU-R M.1903 [5]	Undesired	6 dB	To account for risk of loss of life due to RFI that is real but not quantifiable
GNSS (L1)	RTCA DO-235B [6]	Undesired (aeronautical)	None	Undesired aeronautical emissions are relatively predictable
		Undesired (non-aeronautical)	6 dB	Non-aeronautical emissions are less predictable in number, position, and intensity
GNSS (L5)	RTCA DO-292 [7]	Undesired (DME and TACAN)	1 dB	Small margin because DME/TACAN power is closely controlled
		Undesired (non-aeronautical)	6 dB	Non-aeronautical emissions are less predictable
GPS and GNSS	ICAO 9718-AN/957 [2], p. 7-106	Undesired	6–10 dB	To account for aggregate effects of multiple interferers

Table 4: Safety margin usage for aeronautical radio navigation and radio localisation services

Margins Used in Aeronautical Terrestrial Communications Systems: Only two cases have been identified in which ASMs have been stipulated for terrestrial communications systems. Both cases involve link budgets for desired signals and are shown in Table 5. No case has been found of an interference or band sharing analysis in which an ASM was applied explicitly to the calculation of undesired signal levels potentially affecting aeronautical terrestrial communications.

The example is in the signal-in-space minimum aviation system performance standards (MASPS) [8] for the VHF Digital Link (VDL). That document says there “should be a minimum of 5 dB link margin throughout every service volume” to ensure that VDL link availability will be no worse than that of the present analog air/ground voice communications system for air traffic services. That 5-dB margin is not explicitly called an ASM but has the same effect as one. It applies to data communications in VDLM2 as well as to voice and data communications in VDL Mode 3.

Protected System	**Reference**	**Signal Type**	**Aviation Safety Margin**	**Rationale**
VHF Digital Link	RTCA DO-224B [8], p. 275	Desired	5 dB	To ensure link availability is no worse than in current VHF analog voice system

Table 5 : Published Aviation Safety Margins for Terrestrial Communications Systems

Margins Used in Aeronautical SATCOM Systems: Our literature search has not found any mention of aviation safety margins (in decibels) pertaining to AMS(R)S or other SATCOM links in any ICAO, RTCA, or ITU-R document. Instead, a different approach is generally taken in determining safety margins for aeronautical SATCOM systems. The criterion of interest in such systems is generally expressed as a percentage of increase in the noise temperature in the presence of interference to the nominal noise temperature in the absence of interference ($\Delta T / T$), or as a percentage of increase of the interference-plus-noise power level.

An ITU-R Recommendation [10] states that in geostationary AMS(R)S networks in the 1545–1555 and 1646.5–1656.5 MHz bands,

- The total interference power level in a digital channel in the AMS(R)S, caused by the earth station and space station transmitters of all other mobile-satellite service (MSS) and FSS networks should not exceed 20% of the total noise power at the input to the demodulator that would result in the maximum bit-error rate (BER) allowed in [11], and

- The maximum permissible level of interference power in any such digital channel in the AMS(R)S caused by the transmitters of another mobile-satellite network or fixed-satellite network should not exceed 6% of the total noise power.

Section 3.3.1.2.2 of [12], an RTCA document applicable to all AMS(R)S bands, says that an AMS(R)S system is expected to provide adequate performance in the presence of an aggregate interference level from all external sources (non-AMS(R)S as well as AMS(R)S)) equal to 25% of the total noise power in the RF channel.

Similar limits apply to the FSS. An ITU-R Recommendation [13] states in-part that, in FSS digital links operating below 30 GHz:

"error performance degradation due to interference at frequencies below 30 GHz should be allotted portions of the aggregate interference budget of 32% or 27% of the clear-sky satellite system noise in the following way:

– 25% for other FSS systems for victim systems not practicing frequency re-use;

– 20% for other FSS systems for victim systems practicing frequency re-use;

– 6% for other systems having co-primary status;

– 1% for all other sources of interference,

Annex 2

Diverging views between ICAO and ITU

Differences between ICAO and ITU regarding the communication performance key parameters

Concept	ICAO (ICAO Doc 9869)	ITU R (ITU R Recommendations S.1424 and S.1806)	Remarks
Availability	ICAO defines availability as the probability that an operational communication transaction can be initiated when needed. Availability refers to whether the end-to-end link is available when required. The value for the availability parameter is selected based on the results of an operational hazard assessment, which should include a severity of effect analysis of the detected loss of the system prohibiting the initiation of a communication transaction needed to support the Air Traffic Management (ATM) function. ICAO then associates the probability that the electronic equipment is faulty when needed under this concept. In addition, it also includes the availability of the communication means, which might be made unavailable due to other users sharing the same resource. It should be noted that commercial equipment availability typically reaches levels of one failure every millions of transactions giving figures in the range of 99,998 to 99.9998 % Typical availability required for relying ATM messages are 99.99% and the highest one is 99.998%.	Availability in the ITU-R is mostly related to the performance of the radio link which is usually limited by rain fade. The link availability is expressed as a percentage, as defined in Section A 1-3.	This parameter is defined differently in ICAO and ITU-R and it is the main source of possible misunderstanding. The main difference stands from the fact that the ITU-R defines those criteria upon which a transmission can be initiated and successfully received, while ICAO focuses only on the availability of the system when an attempt to initiate a transmission is made. In the ITU-R this concept is related mostly to the availability of the overall FSS radio link (including transmission and reception), for which the main cause of disruption is represented by rain fade effects. In ICAO both terms "availability" and "continuity/transaction time" are used to describe what the ITU-R associates to the concept of link availability.

Concept	ICAO (ICAO Doc 9869)	ITU R (ITU R Recommendations S.1424 and S.1806)	Remarks
Continuity	The probability that an operational communication transaction can be completed within the transaction time Continuity refers to the ability to complete an end-to-end communication transaction within the prescribed transaction time. Typical continuity values are 99.9%.	No explicit definition by the ITU-R.	There is no definition in the ITU-R of "Continuity" . This parameter is directly related to the ITU-R link availability of a given communication link and is dependent on the particular system architecture (e.g. how multiple messages retransmissions are managed by the system). Both ICAO's terms "availability" and "continuity/transaction time" are used to describe the system performance as a statistically measurable quantity.
Integrity	The probability of one or more undetected errors in a completed communication transaction. Typical integrity values are 10^-5.	The parameter in the ITU-R which is most similar to the ICAO's integrity is the Bit Error Rate (BER) for a given communication link	In the ITU-R the BER objective of a link is defined depending on the type of the application. The ICAO's integrity drives not only the BER requirement for a radio link but also other design choices of the system (e.g. how multiple messages retransmissions are managed). The BER depends on the criterion made for the coder/decoder. Digital communication systems are designed to decode messages for a given minimum Bit Error Rate. Depending on this parameter, the corresponding target minimum Eb/N_0 (or, equivalently minimum C/(N+ I)) is defined. Then, the system is usually designed in such a way that messages are received at the demodulator with a margin on top of the target minimum Eb/N_0 (or, equivalently minimum C/(N+ I)).
Transaction time	The maximum time for the completion of the operational communication transaction after which the initiator should revert to an alternative procedure. Typical transaction times are between 10s and 400s.	No definition by ITU-R. However, reference time is given to compute the availability of a link.	From an ITU-R link availability percentage the total time on an average year during which the link is not available can be computed. Furthermore, by using methodologies defined in various ITU-R literature (e.g. Recommendation ITU-R P.1623), it's possible to apportion the total time to fade events of fixed duration. Once this is done, it's then possible to determine the maximum time required to make multiple number of retransmissions till a successful transmission is completed. This parameter is then directly related to the % availability of a given communication link and is dependent on the particular system architecture (e.g. how multiple messages retransmissions are managed by the system)

Table 6 : ICAO and ITU differences regarding the communication performance key parameters

From ITU's perspective, analyses to date have resulted in levels of "ITU-R link Availability" for various FSS link parameters and operating conditions (see Annex 2 of this report). However, note should be taken that the concept of "Availability" is different between ITU-R and ICAO. Additionally, the ITU-R does not explicitly address

ICAO's Transaction Time, Integrity or Continuity concepts in its Reports and Recommendations.

Nevertheless, various ITU-R documents define the ITU-R's concept of link Availability; typical of these is for example ITU-R S.579, which defines Availability for Hypothetical Reference Digital Paths as:

" Availability = (100 – unavailability) %
where:

$$\text{Unavailability} = \frac{\text{unavailable time}}{\text{required time}} \times 100 \quad \%$$

where the required time is defined as the period of time during which the user requires the digital path to be in a condition to perform a required function, and unavailable time is the cumulative time of digital path interruptions within the required time." The above availability ratios are applicable for the whole end-to-end radio link including equipment at transmission and reception sites as well as propagation factors. Nevertheless, the ITU-R usually considers that the equipment availability (usually called equipment reliability) is many orders higher than the radio link availability. Therefore, the availability of the radio link dominates over the whole end-to-end availability.

Statistically these ITU time-based definitions are equivalent to the per-attempt based definition for Availability used by ICAO, and both ITU and ICAO definitions include not only propagation related unavailability but also unavailability due to equipment malfunction. However, these ITU definitions also include criteria for what constitutes an unavailable path. For example ITU-R S.579 defines the path to be unavailable if the digital signal is interrupted (i.e. frame alignment or timing is lost) or if the bit error ratio (BER), averaged over 1 s, exceeds 10−3. ICAO's definition of Availability provides no such criteria.

Therefore, following ICAO's definitions, it is complex to determine upon which criteria a link has to be considered unavailable from an ITU-R perspective.

Additionally, the ITU-R does not explicitly consider ICAO Continuity, Integrity or Transaction time.

Annex 3

Categorisation of some AOC applications

				Involved stakeholders			In interest of		On-board role			Safety - Security		
Name	**Description**	**Down**	**Up**	**Airline Operational Control Centre[iii]**	**Other stakeholders[iv]**	**Exercise of authority on the flight[i]**	**Safety**	**Regularity/ Efficiency**	**ACD**	**AISD**	**Pax[v]**	**Time criticality[vi]**	**Security: Confidentiality, Integrity[vii]**	**Performance[ii]**
Cabin Log Book Transfer	The CABINLOG service allows the cabin crew to complete the aircraft's cabin equipment log electronically and send the updated log to the Airline.	Y			AAC					Y			C	
Engine Performance Reports	The ENGINE service is used to downlink aircraft condition monitoring system (engine and systems) reports in real time, automatically and on request. This is usually done in the En-Route phase.	Y			MAIN					Y		M	C	M
Flight Log Transfer	The FLTLOG service is used to track the aircraft's flight times, departure and destination information, etc. Flight log information may be manually requested by the AOC or automatically downlinked.	Y		Y	AAC			Y?					C	
Flight Plan Data	The FLTPLAN service provides the operators with the ability to request and receive the AOC-developed flight plan for comparison to that assigned by ATC and for loading into avionics.	Y		Y				Y?				M	C	
Flight Status	The FLTSTAT service includes, for example, malfunction reports including fault reporting codes that allow maintenance and spares to be pre-positioned at the parking stand after landing.	Y			MAIN			Y?		Y			C	

				Involved stakeholders		Exercise of authority on the flight[i]	In interest of		On-board role			Safety - Security		Performance[ii]
Name	**Description**	**Down**	**Up**	**Airline Operational Control Centre[iii]**	**Other stakeholders[iv]**		**Safety**	**Regularity/ Efficiency**	**ACD**	**AISD**	**Pax[v]**	**Time criticality[vi]**	**Security: Confidentiality, Integrity[vii]**	
Free Text	The FREETEXT service includes miscellaneous uplinks and downlinks via textual messages between the cockpit and AOC or other ground based units.	Y	Y										C	
Fuel Status	The FUEL service downlinks fuel status En-Route and prior to landing. This service allows ground services to dispatch refuelling capability promptly after landing.	Y			Fuel			Y?					L	
Gate and Connecting Flights Status	The GATES service for passengers and Flight Crew includes manual and automatic uplink of connecting flights, estimated time of departure (ETD), and gate assignments before landing.		Y		Pax						Y		L	
Load Sheet Request/Transfer	Upon downlink request, the Load Sheet Control System uplinks planned load sheet and cargo documentation in the LOADSHT service. The load sheet includes weight and balance information.		Y				Y		Y			M	I	
Maintenance Problem Resolution	Using the MAINTPR service, maintenance personnel and a Flight Crew are able to discuss and correct technical problems while the aircraft is still airborne.	Y	Y		MAIN			Y?		Y		M	C	
Real-Time Maintenance Information	The MAINTRT service allows aircraft parameters to be sent to the airline maintenance base in real-time to monitor the operational status of the aircraft and to troubleshoot problems identified during the flight.	Y			MAIN			Y?		Y			C	

				Involved stakeholders		Exercise of authority on the flight[i]	In interest of		On-board role			Safety - Security		Performance[ii]
Name	**Description**	**Down**	**Up**	**Airline Operational Control Centre[iii]**	**Other stake holders[iv]**		**Safety**	**Regularity/ Efficiency**	**ACD**	**AISD**	**Pax[v]**	**Time criticality[vi]**	**Security: Confidentiality, Integrity[vii]**	
Notice to Airmen	The NOTAM service provides information to alert the Flight Crew		Y	Y		Y ?	Y		Y				I	
Out-Off-On-In	Movement Service messages including Out-Off-On-In (OOOI) report data are automatically routed to the AOC Movement Control System. This service is a one-way downlink from the aircraft to AOC to report significant points in the flight's progress.	Y		Y	AAC			Y					C	
Position Report	The POSRPT service includes automatic downlink of position during the climb, cruise, and descent portions of the flight. The primary purpose of this service is delivery of position reports at required waypoints for use in AOC tracking systems.	Y		Y				Y				M	C	
Software Loading	The SWLOAD service allows new versions of software to be uploaded to non-safety related aircraft systems whilst the aircraft is at the gate.		Y		MAIN								I	
Technical Log Book Update	The TECHLOG service allows the Flight Crew to complete the aircraft's technical log electronically and send the updated log to the maintenance base.	Y			MAIN			Y		Y			C	

				Involved stakeholders			In interest of		On-board role			Safety - Security		
Name	**Description**	**Down**	**Up**	**Airline Operational Control Centre**[iii]	**Other stakeholders**[iv]	**Exercise of authority on the flight**[i]	**Safety**	**Regularity/ Efficiency**	**ACD**	**AISD**	**Pax**[v]	**Time criticality**[vi]	**Security: Confidentiality, Integrity**[vii]	**Performance**[ii]
Update Electronic Library	The UPLIB service enables on-board information to be updated electronically either by request or automatically (e.g., Aircraft Manual, Standard Instrument Departures (SIDs), Standard Terminal Arrival Routes (STARs), and Airspace Charts). The transmitted information will be used to update various avionic systems (e.g., an Electronic Flight Bag [EFB] device). As such, this service carries safety-related information used for navigational purposes by the Flight Crew/Aircraft.		Y	Y			Y		Y			M		
Graphical Weather Information	The WXGRAPH service sends weather information to the aircraft in a form that is suitable for displaying graphically on displays in the cockpit (e.g., vector graphics). This service provides **advisory** information which supplements or replaces the textual weather information available in current AOC services.		Y		MTO	Y	Y		Y				I	
Real-time Weather Reports for Met Offices	With the WXRT service, information derived by the aircraft on the environment in which it is flying (e.g., wind speed and direction, temperature) can be sent automatically in real-time to weather forecasting agencies to help improve predictions.	Y			Weather agencies									
Textual Weather Report	The WXTEXT service is initiated by Flight Crew requests for airport weather information. The WXTEXT service includes Meteorological Aerodrome Reports (METARs) and Terminal Area Forecasts (TAFs). The AOC responds to Flight Crew requests by delivering the requested weather information to the cockpit.		Y	Y		Y	Y?		Y			M	L	

				Involved stakeholders		Exercise of authority on the flight[i]	In interest of		On-board role			Safety - Security		Performance[ii]
Name	**Description**	**Down**	**Up**	**Airline Operational Control Centre[iii]**	**Other stake holders[iv]**		**Safety**	**Regularity/ Efficiency**	**ACD**	**AISD**	**Pax[v]**	**Time criticality[vi]**	**Security: Confidentiality, Integrity[vii]**	
Take-Off and Landing Data Calculation (TODC, LDC)	Using data from the load sheet and ATIS, the pilot can request and receive a Take-off Data Calculation (TODC) from the ground performance system. After few seconds the crew receives an uplink with the speed figures and flap settings for the take-off.		Y	Y			Y		Y				I	
Delay Report, Approach report, Diversion report	If the flight is delayed, a pilot can send a Departure Delay message to the flight operations department.	Y		Y				Y						
Wind data uplink	Allows to receive wind data for each flight phase at waypoints. They can be directly used by the Flight management System.		Y	Y			Y		Y			M	I	

Table 7: Categorisation of some AOC applications

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[i] "Exercise of authority over the initiation, continuation, diversion or termination of a flight"
[ii] Requirements concerning mainly the throughput (L=Low, M=Medium, H=High)
[iii] « Y » means the message is in support of the Operational Control function of the aircraft operator (under the responsibility of the flight operations officer/flight dispatcher)
[iv] MAIN=Maintenance, MTO=Provision of Weather information to aircraft, AAC=Operator organisation in charge of Administrative information, Pax=Operator organisation in charge of passenger information, Fuel=Operator organisation in charge of fuel management
[v] PIESD (Passenger Information and Entertainment Services Domain)
[vi] Requirements relative to time criticality (L=Low, M=Medium, H=High requirements)
[vii] C=Confidentiality constraints, I=Integrity constraints

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