FUTURE CONNECTIVITY FOR AVIATION

EU/US task force

White Paper

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Foreword

The European Union Aviation Safety Agency, the Federal Aviation Administration, Airbus and Boeing have launched a joint cooperation initiative to rethink aviation connectivity, defining a blueprint for the modernisation and harmonisation of the aviation data communication landscape by 2035.

Aviation connectivity supports the various air-ground data exchanges that are becoming increasingly essential to support safe, sustainable and efficient Air Traffic Management (ATM) and the air operations of tomorrow. It is currently supported by a set of technologies that rely to a large extent on VHF datalink and on first generation aviation SATCOM connectivity. While these technologies have served the aviation community well for decades, they are in need for upgrade and for more harmonisation.

The present white paper offers a jointly proposed vision for the future aviation connectivity landscape which is based on the combination of aviation specific solutions (VHF datalink and higher performance L-band SATCOM) – that will offer guaranteed safety and performance – with commercial, non-aviation specific solutions – that are expected to provide for high capacity and economic efficiency.

Key objectives were that the future connectivity landscape must provide the required safety, security and performance levels as well as sufficient capacity. While adopting state of the art and future-proof technologies, there was also an objective of global economic efficiency. A further aim was to make efficient usage of the bandwidth spectrum already assigned to aviation, without needing to request additional spectrum.

The four parties are looking forward to engaging with the wider community of actors – including ICAO, as well as Regulators, Standards Organisations, Manufacturers, Operators, Air Navigation Service Providers and Communication Service Providers – to build together a safe, performant and harmonised connectivity future for aviation.

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I. Executive Summary

Aviation connectivity supports the various air-ground data exchanges that are becoming increasingly essential to support safe, sustainable and efficient Air Traffic Management (ATM) and the air operations of tomorrow. It is currently supported by a set of technologies that rely to a large extent on VHF datalink and on first generation aviation SATCOM connectivity. While these technologies have served the aviation community well for decades, they are in need for upgrade and for more harmonisation.

EASA, FAA, Airbus and Boeing have therefore launched a task force to reflect on the current and future challenges of aviation connectivity and to develop joint proposals to address those challenges. As an overall outcome, a common vision is proposed herein for the future aviation connectivity and communication landscape at the time horizon 2035.

The task force completed the below steps in support of its goals:

- An analysis of the long-term connectivity needs for the ATM, Airline Operations and Autonomy connectivity domains.[1]
- An assessment of available connectivity solutions (both existing and in-development ones) and the elaboration of a joint position about which solutions should be preferred.
- The drafting of an associated transition roadmap, optimized on a regional basis (Europe and US having been so far considered).

For the analysis of long-term connectivity needs, the connectivity domains have been split in 4 domains: Air Traffic Management (ATM), Aeronautical Information Services (AIS), Airlines Operations and Autonomy. The overall connectivity needs are quickly increasing, due to two main drivers:

- The necessary improvements to ATM operations require the deployment of additional Air Traffic Services (ATS) data link services with increased capacity.
- The last generation aircraft make a much more extensive use of air-ground connectivity to improve aircraft operations and maintenance.

With respect to the assessment of connectivity solutions, those have been selected based on existing solutions and ongoing standardisation and research / development initiatives. They have all been allocated into one of three (simplified) following communication layers: the application, the network, and the physical link layer – and analysed through a Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis. The recommended solutions have been selected based on following strategic objectives:

- Adequate safety and security.
- Adequate capacity.
- State of the art and future-proof technologies.
- Economic efficiency, at the global industry scale.
- Efficient usage of the available aviation protected spectrum and not asking for more.
- EU-US harmonisation and global interoperability.

A summary table of the recommended solutions is provided here below:

[1] The analysis done for the Autonomy domain remains notional at this stage. Passenger Connectivity needs and RPAS payload needs have remained out of scope.

<table>
<tr><th></th><th></th><th>Applications</th><th>Network</th><th>Links
Preferred Option</th><th>Links
Fallback
Option</th></tr>
<tr><td rowspan="4">*PRELIMINARY*</td><td>ATM[2]
Autonomy (ATM)</td><td>B2</td><td rowspan="4">IPS</td><td rowspan="3">VDL2
SATCOM Performance Class B
Commercial links as complement
(Hyperconnected ATM)</td><td rowspan="3">SATCOM Performance Class B +
LDACS[3]</td></tr>
<tr><td>AIS urgent</td><td>Standard applications</td></tr>
<tr><td>*Autonomy (assistance)*</td><td rowspan="2">Proprietary applications</td></tr>
<tr><td>*Autonomy (C2)*</td><td>C-band
(SATCOM and/or ground-based)</td><td>Commercial link (FSS)</td></tr>
<tr><td></td><td>*ATM negotiation*</td><td rowspan="3">Standard / Custom applications</td><td rowspan="3">IP</td><td rowspan="3">Non-safety links[4]</td><td rowspan="3">N/A</td></tr>
<tr><td></td><td>*Airline Operations[5]*</td></tr>
<tr><td></td><td>*AIS not urgent*</td></tr>
</table>

Regarding the transition roadmap, the task force aimed at securing a smooth transition, taking into consideration EU and US specificities.

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[2] Use cases highlighted in red in this table are subject to required demonstrated performance.
[3] For Autonomy (ATM), the alternative option could be a ground-ground link.
[4] This does not preclude the use of additional redundant links for backup purposes for airline operations.
[5] Some Airline Operations communications may still be routed over protected spectrum due to aircraft architectural constraints.

The transition steps therefore include steps for the communication service providers to provide services within their systems that support multiple protocols and multiple aircraft configurations during the transition. They also include (FAA) an evaluation of the possibilities to translate between FANS and B2 messages to provide a middle ground of datalink services, which can support mixed fleets.

The recommended solutions, along with the proposed transition roadmap, are defined to limit the overall investment costs (leveraging existing or planned infrastructures to the maximum extent), and to optimize the share of complexity between air and ground, while providing the required performance.

Summary of key takeaways:

- For ATM connectivity:
  - "B2 over IPS" is the target solution for the applications and network layers.
  - **Communications subject to required demonstrated performance will make use of VDL2, SATCOM Performance Class B and non-safety links (as a complement), as per the Hyperconnected ATM technology - assuming this solution is fully validated.**
  - The 'Hyperconnected' ATM technology is to be further developed and validated.
  - No new terrestrial communication infrastructure is deemed necessary provided the "Hyperconnected ATM technology" is validated and deployed.
  - The ground ATM segment will need to be able to accommodate the future mix of aircraft configurations (both at network level and at application level).

  As a conclusion, the preferred future physical link landscape is based on **VDL2 + SATCOM Performance Class B (safety links) + non-safety (commercial) links.**
- Communications not subject to required demonstrated performance (this includes a priori all Airline Operations communications) should be offloaded from the safety links.

  Regulatory clarity about which communications are subject to required demonstrated performance needs to be consolidated.
- For Autonomy (C2 link), use of C-Band (terrestrial or SATCOM) is recommended (preliminary assessment).

The conclusions of this task force and the proposed transition roadmap will further need continuous close coordination and effective steering, both at regional and global level.

II. Introduction

A. Statement of Issue

The technologies, standards and applications currently deployed for data communication in aviation (typically for today's Air Traffic Management (ATM)) are fragmented and not systematically interoperable. Moreover, underlying connectivity capabilities are sometimes deficient regarding the performance achieved in operations (impacting both ATM and Airline Operations (AO) communications).

The current situation is also characterized by the need for multiple aircraft equipment (to secure for example both ATN B1 and FANS data communication capability). There is furthermore a high likelihood for saturation of the spectrum allocated to air-ground communications.

At the same time the aviation data communication needs are expanding– e.g., with the need to support trajectory-based operations (TBO) in the ATM domain, with the increased possibilities to digitise certain services such as weather information and NOTAMS, and with always increasing information exchange needs in the Airline Operations domain. The characteristics of the current aviation connectivity landscape (number of "connected" aircraft, performance of existing links, lack of interoperability, etc.) are such that it is unlikely that future needs can be met without implementation of several significant, internationally coordinated changes.

B. Objective and scope

The task force has aimed to propose a common vision for the future aviation connectivity landscape and to propose an associated transition roadmap, having in mind the time horizon of 2030-2035. These proposals have been developed based on consensus views among the four participating organisations (Airbus, Boeing, EASA, and FAA).

It is fully acknowledged that the participating organisations represent only a fraction of all stakeholders to be involved, and that coordination amongst a larger group of organisations is required to achieve a larger consensus on 1) the target solutions 2) the transition roadmap elements.

Regarding the scope of work, the task force has focused on:

1. piloted large aircraft and "new entrants" (RPAS and more autonomous aircraft), as far as those operate in the same airspace as piloted aircraft
2. the US and European airspace and
3. the following domains of air/ground communication needs: ATM, aeronautical information, airline operations and (for RPAS and more autonomous vehicles) command and control.

However, the use cases related to RPAS and "more autonomous aircraft" have been subject only to a very preliminary assessment.

The following main use cases remained out of scope: 1) smaller RPAS operating at low level altitude or in U-space 2) passenger and RPAS payload connectivity 3) ground/ground data communications.

C. Working methodology

The working methodology followed by the task force is reflected in the structure of this report.

The starting point is an analysis of the needs in the various connectivity domains (Chapter IV). In the specific context of this report, the connectivity domains have been split in 4 groups: ATM, Aeronautical Information Services (AIS), Airline Operations and Autonomy. For each connectivity “use case” (i.e., a communication application /service of a grouping of them) the task force performed a qualitative characterisation of the associated performance requirements.

In a second step, available solutions have been analysed through a Strength, Weakness, Opportunities and Risk (SWOT) analysis. Solutions have been each allocated in one of three (simplified) following communication layers: the application, the network, and the physical link layers. This SWOT analysis has supported the proposals made herein about which solutions are preferred (Chapter V).

Finally, some elements of a possible transition roadmap have been compiled (Chapter VI) as well as a summary list of key recommendations for follow-up work (Chapter VII).

III. Overview of related activities

A. Strategy documents

The work of this task force can be seen as a follow-up of the "*European Union and United States Air/Ground Data Communications Strategy*", issued in November 2017 as the result of an EU/US working group led jointly by FAA Next Gen and SESAR. Compared to this 2017 deliverable which was limited in scope to ATM data communications, the present report is wider in scope. For the ATM communications solutions it remains largely consistent with the "harmonisation target" that was retained in 2017 – which is based on IPS - while promoting a solution that makes maximum possible use of connectivity solutions offered for the air/ground link level through "non-safety" ("commercial" or "public") links.

B. Existing mandates

In the US the implementation of ATM datalink capabilities is driven by voluntary stakeholder actions and appropriate incentives. There is no active nor planned regulatory mandate.

In Europe two European Commission regulations are driving changes in both airborne equipage and ground capabilities:

- Commission Regulation 29/2009 (and its amendments) (the "DLS Regulation") laying down requirements on data link services for the Single European Sky. This text regulates the *current* deployment of datalink communications in Europe based on the ATN B1 standard, over the VDL Mode 2 subnetwork.
- Commission Implementing Regulation 2021/116 (the "Common Project (CP) 1 Regulation") regulates amongst others the deployment of initial trajectory information sharing, driving the need for the aircraft and ground systems to be ADS-C EPP capable, as part of B2 services while keeping compatibility with CPDLC services as required by the DLS Regulation (implementation target date of 31st December 2027 for new aircraft) and the additional need for ground system to remain ATN B1 compatible.

C. Aircraft Certification Requirements

The EASA certification requirements applicable to ATS airborne communication systems are detailed in CS-ACNS, which is currently at issue 4 (dated April 2022), and which includes detailed requirements for the installation of communication datalink systems. This issue 4 of CS-ACNS does not yet address compliance with the CP1 EU Regulation.

The FAA equivalent certification requirements are contained in AC 20-140 – Guidelines for Design Approval of Aircraft Data Link Communication Systems Supporting Air Traffic Services (ATS) currently at issue C.

General aircraft level certification requirements are contained in the Federal Aviation Regulations (FAR – US) and Certification Specifications (CS – EU) 23 and 25.

D. Standardisation activities

The following provides a (non-exhaustive) overview of existing standards and/or standard drafting groups which are related to the scope of the task force.

a. General

ICAO has issued and is maintaining the ICAO Performance-based Communication and Surveillance (PBCS) Manual 9869, and ICAO Annex 10 Volume III, Part I (Digital Data Communication Services SARPS)

b. Standardisation of the link layer

RTCA SC-214 (VDL subgroup), EUROCAE WG-92 and the ARINC DLK subcommittee are developing and maintaining the standards related to VDL2. ICAO CP-DCIWG is maintaining the VDL2 SARPs and Technical Manual.

RTCA SC-222 and EUROCAE WG-82 are developing and maintaining the standards related to new air-ground datalink technologies: AeroMACS, LDACS, AMS(R)S data and voice communications (SATCOM Class B).

c. Standardisation of the network layer (moving to IPS)

The ICAO Aeronautical Communications Panel Data Communications Infrastructure Working Group (ICAO CP- DCIWG) (WG I) is maintaining or developing the Doc 9896 IPS Technical Manual and Guidance Material, related Annex 10 SARPS.

RTCA SC 223 and EUROCAE WG-108 are developing standards to support the deployment of IPS, both for the airborne avionics and the ground systems.

The ARINC IPS committee is developing IPS industrial specifications for airborne systems and interoperability requirements for ground gateways. The ARINC DLK subcommittee develops standards for IPS-over-VDL2.

d. Standardisation of the applications layer

RTCA SC-214 and EUROCAE WG-78 have published and continue to maintain standards to support ATS data communication services (FANS1/A, ATN B1, B2).

RTCA SC-206 and EUROCAE WG-76 are currently developing standards for AIS and MET data communication services.

There are many standardisation activities regarding applications within the Airline Operations domain. Additionally, there are multiple standards published via ARINC that serve as the basis for AOC applications. However, the implementation of these standards is not uniform across operators and manufacturers and options chosen within the standards vary widely. There are also customised, non-standard applications created for specific user purposes that are employed.

e. Standardisation of data communications needs for RPAS

The ICAO RPAS Panel (working group 2) is developing the "ICAO Manual on RPAS C2 links". RTCA SC-228 and EUROCAE WG-105 (subgroup 2) are developing standards for RPAS data communications needs (C2 link): using C-Band satellite spectrum or using a terrestrial cellular network.

f. Standardisation of security requirements for aeronautical data communications

ICAO CP-DCIWG (WG-I) is developing various policy and guidance material for security of aeronautical communications, in coordination with the ICAO Trusted Framework Panel (TFP).

E. Research and development activities

Under the European SESAR research programme related to "integrated communication, navigation and surveillance system", several projects relate to solutions which are relevant for the future aviation connectivity landscape and are regrouped under the concept of "Future Communication Infrastructure". To be specifically mentioned are the "Hyperconnected ATM" project - which explores the integration of non-safety, commercial links into a hybrid communication infrastructure for ATM safety communication needs - and the ongoing research project on the new terrestrial link LDACS.

SESAR has also run for several years an extensive trial programmes to validate the operational benefits of the early implementation of Trajectory based Operations, mostly focused on the exchange and use of ADS-C Extended Projected Profile (EPP) data. In particular, an ambitious Very Large-scale Demonstration (VLD) programme, relying on more than 100 equipped revenue flights, still running today, has captured several thousands of ADS-C EPP reports during normal commercial operations, allowing to progress on the characterization of the operational benefits for the involved European ANSPs, thanks to the processing of these trajectory data sent by the aircraft.

The FAA has a major focus on establishing full information connectivity with all stakeholders as aviation moves into an information centric environment, also sometimes labelled as digitization. This has included major efforts on Connected Aircraft, which supports modern flight and flow messaging. In relationship to this communication strategy the FAA has and is planning continued emphasis on the air-ground connectivity related to applications using the VHF protected spectrum.

The FAA participated in IPS demonstration flights with the Boeing 2021 737-9 MAX ecoDemonstrator. This included trials with an IPS-enabled red-label Communication Management Unit (CMU) as well as a 'soft CMU', with FANS-1/A messaging communicating over both VDL2 and SATCOM via a Collins-provided IPS-ACARS Gateway to the FAA Tech Center. The FAA Tech Center used the standard Data Comm CPDLC workstation and was able to seamlessly communicate with the ecoDemonstrator. The Alaska Airlines airline operations center was also able to communicate via AOC messaging with the ecoDemonstrator through the same IPS-ACARS Gateway using their existing systems. Future trials with more mature versions of all components are planned in order to gain more experience for IPS deployment requirements.

Additionally, considering air-ground negotiations related to ATFM, the FAA is currently conducting validation activities on Multi-Regional TBO flights utilizing non-protected spectrum and portable electronic devices for trajectory negotiation.

The FAA also continues its effort on Connected Aircraft for the Exchange of Reference Trajectory Information, which includes current state, future intent, guidance modes, and performance limits, to further broaden the set of information available through traditional exchanges, especially in support of Flight and Flow – Information for a Collaborative Environment (FF-ICE).

In line with the strategy developed in the present paper, the FAA anticipates expanding its Connected Aircraft effort by initiating Hyperconnected ATM research and validation activities in the near future. Research to determine the nature of the future ground architecture will enable this concept. Additionally, the FAA has initiated the analysis of a FANS –B2, B2-FANS transformation service to provide existing FAA data communications services to early adopters of B2 avionics in US domestic airspace. This will lead to prototyping and architectural alternatives analysis.

These combined capabilities can then potentially be tested and demonstrated in collaboration, between the ground system and aircraft, in support of Trajectory-Based Operations (TBO) and FF-ICE.

IV. Key assumptions and underlying objectives

Several assumptions and key objectives are underlying the proposals laid out in this report.

A. Key assumptions

- Both the US and EU regions will move towards trajectory-based operations, which require strategic and tactical information negotiation/exchange capabilities. This will require connectivity solutions that will bring significant capacity and performance enhancements over the ones currently deployed.
- The Airline Operations connectivity needs will continue to significantly increase, due to the continuous modernization of fleets and to the expected benefits of new data-centric AOC applications, for optimisation of operations and maintenance.
- The connectivity offer supplied over public networks, coming from commercial service providers, with technologies that range from SATCOM to ground networks for mobile communications, will continue to quickly expand, providing most of the time good performance. Additionally, aircraft connectivity equipage will continue to grow, driven by the passenger connectivity market.
- Although the current aviation protected spectrum remains fundamental but reaching saturation, expansion of this spectrum is not likely to happen.

B. Key underlying objectives

- The recommended solution proposals should be compatible with the forecasted aviation connectivity needs, in terms of capacity, safety and security performance requirements.
- They should be both "state of the art" from a technology point of view, and "future-proof", in the sense that they need to be able to accommodate fast evolving link technologies.
- The recommended solution proposals and transition roadmaps should be economically efficient, looking qualitatively at the global business case[6] for all involved aviation stakeholders (including manufacturers, operators, ANSPs and CSPs / DLSPs).
- The recommended solution proposals need to follow the principle of efficient usage of the available aviation protected spectrum. This means that protected aviation spectrum should be primarily used for those use cases with required demonstrated performance.
- With respect to aircraft equipage, the recommended solutions should secure the EU-US harmonisation, allowing, in the long term, to operate in the EU and in the US (with respect to ATM air/ground data communications) with a single aircraft avionics capability. EU-US harmonisation is seen as a first step to reach global harmonisation (i.e., on a worldwide basis), in compliance with the ICAO GANP.

[6] The task force has considered here in particular the business case study completed under SESAR: "Future Communication Infrastructure Business Case", SESAR deliverable ID D5.1.500, issued 21st April 2022.

V. Needs

A. Introduction

This chapter documents the qualitative analysis of aviation connectivity needs as performed by the task force. The analysis represents a forecast for the time horizon 2030-2035 and has been performed on the basis of expert knowledge, available studies, and strategy papers (refer to the list of references).

Those needs have been analysed through identification of "use cases" in 4 functional domains: ATM, Airline Operations, AIS, and Autonomy.

For each identified use case, the task force made a preliminary evaluation of associated performance requirements, acknowledging that for specific use cases (ATM), some performance aspects were already clearly standardised through published RCP/RSP requirements.

To enable this evaluation of performance requirements, the task force first agreed on how to characterize them: both through performance dimensions (e.g., integrity, availability, throughput, etc.) and performance values (e.g., high/medium/low).

An additional requirement dimension is whether the particular use case requires protected aviation spectrum. The driver used to answer this question has been the necessity for required demonstrated performance.

Summary views of the needs analysis are provided here below and in Annexe A– Summary of needs.

B. Connectivity domain: Air Traffic Management (ATM)

Communication of the future to support Air Traffic Management are comprised of and will continue to be a combination of voice and digital data communication means. In domestic airspace where direct access to voice is available, time-critical safety exchanges will remain with voice while routine exchanges including both near-tactical and strategic flow instructions will increasingly shift to digital data exchanges. Digital communications will be the primary means for communications related to ATM functions.

Voice communications are expected to remain the same as today in the foreseeable future with analog air-ground communications based on a frequency assignment to each volume of controlled airspace. Therefore, voice use cases have not been further explored in the context of this paper, although it is acknowledged that a long-term strategy for voice is needed.

The task force identified seven high-level ATM use cases:

1. ATM #1 – Basic DL in ENR-2
2. ATM #2 – Basic DL in ENR-1/TMA
3. ATM #3 – Complex DL in ENR-2

4. ATM #4 – Complex DL in ENR-1/TMA
5. ATM #5 – DL in APT
6. ATM #6 – Trial Plan Coordination Flight Deck
7. ATM #7 – Trial Plan Coordination ATM

Some ATM use cases, addressing autonomous vehicles, are documented in section D of the present chapter.

The first use case highlights Basic DL in ENR-2, which supports the delivery of instructions such as routine clearances in remote airspace, e.g., direct to, altitude change, etc.

The second use case demonstrates Basic DL in ENR-1/TMA and supports the delivery of simple instructions to support Air Traffic Control functions in domestic or terminal areas such as change of frequency and climb.

The third use case supports the delivery of complex instructions such as reroute clearance (e.g., Path Stretch and Tailored Arrival) in remote airspace (ENR-2).

The fourth use case supports the move towards complex services such as Trajectory-Based Operations or Advanced Interval Management in domestic and terminal areas (ENR-1/TMA).

The fifth use case supports the delivery of both complex and basic surface instructions such as DCL and taxi instructions on the airport surface to the cockpit.

For all above use cases, the requirements for continuity and integrity are generally “High”, and demonstrated performance is required.

Use Cases #6 and #7 corresponds to trajectory negotiation prior to clearance (delivered as part of Use Case #4), respectively with the OCC or the ANSP. Continuity requirements are “Low”, and demonstrated performance is not required.

C. Connectivity domain: Airline Operations

Airline Operations require the aircraft to exchange data with the operator’s operations centre or with other operator services, to serve a wide variety of needs: administrative data transfer (e.g., cabin logbook), flight plan optimisation, maintenance support and engine reports, software updates, etc. Currently, most of these use cases are routed on protected spectrum, for historical reasons and airborne architecture constraints.

With new generation aircraft and engines and with the increased needs from airlines to optimize their operations, the data volume needs are increasing, and congestion issues are now a key concern. It is to be recognised that not all Airline Operations communications have the same performance requirements, which also differ from the ATM ones.

The task force tried therefore to group the low-level Airline Operations use cases into generic use cases, almost being performance classes, using performance requirements as grouping criteria. The assessment led to the establishment of three generic use cases:

1. AO #1 – High-capacity, reliable, high latency, pre-departure and post-arrival.
2. AO #2 – High-capacity, reliable, medium latency.
3. AO #3 – Non-priority communications.

The first use case serves pre-departure and post-arrival communication needs, mostly for transferring large files to the aircraft or for offloading data buffered during flight (engine, aircraft components reports, etc.). This would require a high throughput, high integrity, and confidentiality, to ensure that data transferred to or from the aircraft (that can be subject to proprietary rights) is not corrupted.

The second use case addresses all in-flight and on-ground use cases that require high-integrity communications, either because the safety of the flight could be impacted if erroneous data is transmitted or because information transferred could directly impact the regularity of the flights. High integrity and continuity are required, while the data volumes are expected to be High.

The third use case encompasses all other needs, where integrity and continuity of the communication is not the key concern, serving use cases that could be seen as lower priority communications.

The task force concluded that these use cases do not need to operate in the aviation protected spectrum, because they are not subject to required demonstrated performance. Annexe A– Summary of needs. d Airline Operations includes further details on the performance requirements established for each use case.

However, it may be that certain Airline Operations applications (not yet identified) will be subject to required demonstrated performance. It is assumed that the associated performance requirements will be comparable to the ones identified for the ATM use cases.

Note: Distress tracking in the sense of ICAO Annex 6 is not considered as within the scope of this task force. Quick recovery of flight recorder data would be a further connectivity use case, deserving further assessment. However, in the current ICAO and ITU frameworks, use of aviation protected spectrum is not mandated.

D. Connectivity domain: Airline Information Services

Airline Information Services (AIS) support strategic and tactical situational awareness by providing data to the pilot as well as gathering data from the pilot/aircraft to support a richer representation of the airspace environment.

The task force has identified four high-level use cases regarding AIS, which encompass the various capabilities stated above. They are, as follows:

1. AIS #1 – Situational awareness data for pilot decision
2. AIS #2 – Urgent situational awareness data for pilot decision
3. AIS #3 – Enhanced situational awareness
4. AIS #4 – Aircraft as sensor

All of the use cases have a need for in-flight connectivity, for the timely exchange of AIS to support strategic and tactical planning of operations.

The first use case pertains to the exchange of airspace status information including NOTAMs, turbulence awareness messages, as well as airspace constraint data. This use case has “High” integrity and availability requirements.

The second use case focuses on the exchange of hazardous and emergency data sharing with the pilot, to ensure tactical decision-making. It has “High” requirements for continuity, availability, and integrity from an operational/safety perspective, for the exchange of nearby hazardous conditions. This use case is subject to required demonstrated performance.
The third use case covers enhanced situational awareness for improved in-flight planning mainly focusing on weather forecast. This includes textual and graphical MET information as well as wind data, which support flight deck planning to achieve efficient operations. This requires “High” integrity from an operational and link perspective.
In the fourth use case the aircraft is acting as a sensor, enabling sharing of MET and state data from the aircraft to construct a holistic picture of the operational environment. These information exchanges require “High” integrity of the link to ensure the authenticity of the data being received.

E. Connectivity domain: Autonomy

The last years have seen the development of more autonomous vehicle projects that should ultimately be fully integrated within the current IFR traffic. Despite the wide variety of projects, different high-level scenarii can be foreseen:

1. Unmanned aircraft, designated as RPAS (Remotely Piloted Aircraft System), operating international IFR operations controlled from a ground control station.
2. Highly automated unmanned aircraft, designated as UAS (Unmanned Aircraft System), encountering an emergency situation requiring ground control.
3. Highly autonomous manned aircraft requiring some form of ground assistance, for example in the frame of single pilot operations.

Note: high-altitude and supersonic or hypersonic operations are outside the scope of this report. Very low level or U-space RPAS operations are also out of scope, and RPAS payload data is also excluded.

The detailed concepts of operations supporting the above-mentioned options are not yet completely developed. Consequently, the use cases detailed below will remain at a conceptual level. Performance requirements may therefore need to be adapted and additional operational mitigations might be necessary.

The task force has identified four high-level use cases, always keeping in mind that RPAS / UAS / highly autonomous manned aircraft integration should be as transparent as possible, i.e., the vehicle should act as "manned aircraft" from an ATM and ATCO perspective.

1. AUT #1 – RPAS - Remote pilot to permanently control the RPAS (ICAO RPAS IFR operations).
2. AUT #2 – UAS - Remote pilot to control the highly automated UAS (emergency).
3. AUT #3 – Manned aircraft - Ground assistant to assist the highly autonomous piloted aircraft/crew.
4. AUT #4 – RPAS & Manned aircraft - Remote pilot to communicate with ATC / datalink.

The first use case corresponds to the “C2 link” concept, for the part dedicated to the command and control of the vehicle, as envisaged by the ICAO RPAS Panel. An operator/remote pilot located in a ground control station needs to be able to control the RPAS. The performance requirements associated to this use case are quite demanding, since the ground-based control implies a high performance and secure link, for the integration within IFR traffic to be feasible (unless specific operational mitigations are defined and implemented). However, the "command and control" link is not supposed to require high data throughput, hence the "Medium" rating for this aspect.

The second use case addresses the case where a highly automated UAS (i.e., almost fully autonomous) encounters an emergency requiring ground support. In this case, performance requirements are equally stringent to the AUT #1 use case to support emergency situations.

The third use case relates to the assistance provided by a ground operator to a piloted aircraft. Concepts of operation are very preliminary, and assumption is taken that the performance requirements of the link should be similar to the performance requirements identified for the most stringent ATM use case. Indeed, this assistance is not expected to include command and control over the aircraft.

The fourth use case is equivalent to the ATM use cases for conventional aviation. It allows the integration of all non-conventional aircraft within the IFR traffic, from a datalink perspective: in the frame of TBO, datalink messages need to be exchanged between the remote pilot and the ATC. The performance requirements are equivalent to the ones specified for ATM #2 and #4.

All Autonomy use cases, under the current assumptions, would be subject to required demonstrated performance.

VI. Candidate and Recommended Solutions[7]

A. Introduction

This chapter aims at presenting on the one hand the available solutions (already mature or being developed) and on the other hand, the technologies that are recommended by the task force members.

The recommended solutions are being consolidated into different options, for use cases subject to required demonstrated performance:

1. A **Preferred Option**. This option is the ultimate target that should be pursued. This option allows the use of non-safety links.
2. An **Alternative Option**, proposing the deployment of a new terrestrial infrastructure (on aviation protected spectrum), in case the Preferred Option cannot be achieved.

The two proposed options should be understood as mutually exclusive: the point is not to deploy both targets, but rather focus on the Preferred Option, while keeping the Alternative Option as a contingency plan. A timely decision will have to be made, regarding which option is to be selected, to allow implementation by 2032.

The summary presented in this chapter is supported by the following annexes:

- Annexe B – Summary of solutions SWOT analysis
- Annexe C – Summary of recommended solutions

B. Applications

As part of the original EU and U.S. Air/Ground Data Communications Strategy document[8], the transition plan of applications was considered for ATS purposes. With the further maturing of concepts such as the Connected Aircraft as well as the emergence of new types of links that can support higher bandwidth data exchanges, the concept of 'applications' has expanded. Applications can now also include capabilities to enhance situational awareness, assist in route planning and trajectory negotiation/brokering, provide aircraft intent and other information, assist flight crews in airline operations, and enhance maintenance predictions and efficiency (among others). In addition, other airspace users (e.g., various types of RPAS and more autonomous aircraft) will also be introduced and need to be supported.

a. ATS Applications

ATS Applications refer to datalink applications supporting data exchange between the aircraft and Air Traffic Control systems. Onboard, their safety critical nature leads to host them within the avionics architecture. The ATS capabilities are defined by

[7] The task force will consider a wide range of available solutions, assess those, and select the ones that fit best the identified needs. A rationale for discarding a certain solution will be provided.
[8] See Annexe F – References for the list of references.

industry standards. They have a minimum design assurance level (DAL) and normally operate within performance requirements guidelines to ensure minimal behaviour for critical ATS operations. They also currently operate over protected spectrum networks. ATS applications form the main means for ANSPs to initiate data communications, exchange clearance information, and retrieve some types of data via data link with aircraft. ATS applications can support both routine and complex clearances and can perform services in most types of airspace (within required performance parameters).

Current ATS applications include FANS-1/A (AFN, CPDLC, ADS-C), ATN B1 (CM, CPDLC) and B2 (CM, CPDLC, ADS-C). These are envisaged to continue to be used throughout the notional timeframe of this project.

b. Airline Operations Applications

Airline Operations applications refer to capabilities that are initiated and performed with actors other than ANSPs. These applications can be either outside of the aircraft avionics (within devices such as EFBs) or can access functions within the avionics (such as AOC messaging for performance or flight plan messaging). They may be developed to a lower DAL than applications that are integrated in the communication or flight management avionics. Airline Operations applications can access, bi-directionally, avionics via various methods. This means they can retrieve and input data from/to various aircraft systems; however, depending on the type of operation regulatory as well as operational approval may be required. Airline Operations applications can communicate with peer systems on the ground over a wide variety of communication link types, including both protected and unprotected spectrum links.

c. AIS Applications

AIS applications refer to the wide range of airspace information and meteorological-related services that provide additional information for the safety and efficiency of flights. The core components of the D-FIS application types (as well as additional ones) are currently being defined in EUROCAE WG-76/RTCA SC-206.

AIS applications cover a wide range of operational usages, from more informational up to urgent notices that are safety related. The applications are however not meant to be a replacement for voice communications. Additionally, the services, with the possible exception of the Emergency Diversion Services (EDS), do not have updated performance specifications. Therefore, the services will generally fit within the envelope of RCPs established for other ATS data link services. DO-324/ED-175 provides the RCP values specific to AIS type services.

d. Autonomy Applications

As UASs are introduced into various airspaces, there will need to be safe and efficient integration into existing and planned manned operations. This means ensuring that the necessary information is exchanged between UAS vehicles, operators and systems and the systems and vehicles that normally operate in categorized airspace. These data exchanges may require extensions to existing systems and/or entirely new capabilities. The changes to current systems would ideally be minimized where possible.

e. Application Summary

Application capability across all aspects of operations, ATS, AOC, AIS, and Autonomy, will continue to increase with advances in processing power, automation and the availability of updated communication protocols and links as described in the following sections. Depending on the operational usage, some applications require a level of standardization; others may be more user-dependent and could change frequently. This will drive the evolution of the applications that are currently used.

ATS

The B2 standard has been designed to support the majority of ATM operations independently of the operating airspace. Existing services supported by FANS-1/A and ATN B1 can also be supported by B2 (if operationally appropriate), with minimum impact on ground systems and controllers.

AOC and AIS

There is a wider range of AOC and AIS application types and usages than for ATS. There should be a clear distinction made between applications that may be subject to required demonstrated performance and those that are not. There seems to be limitations in current message type classifications that may unnecessarily over-constrain requirements such as spectrum usage. As performance-based requirements become more universally used, message classifications should be revisited. In particular urgent AIS may imply required demonstrated performance.

Autonomy Applications

Autonomy concepts for UAS are still being developed. As mentioned previously, integration into the manned airspace is critical. The more of the manned application space that can be leveraged for commonality in services (as applicable to the RPAS concept of operations), the smoother the transition will be. This may require expanded or new capabilities from the ground system provider within the timeframe of this paper, but these should be considered for a more integrated airspace. The RPAS side should also plan on being able to use common applications where possible for non-interfering, compatible operations.

C. Networks

The Network layer refers to the protocol that supports the conveyance of application information for all types of communications. The network supports routing functions to ensure delivery and depending on the technology also may have additional capabilities such as guaranteed delivery, mobility, multilink and security aspects.

Networking technologies include ACARS, ATN/OSI, IPS and IP.

Communications will need to handle different types of operations, and in a way that ensures safety related applications are not impeded by other lower priority communications.

a. Existing and Near-Term

Legacy ACARS communications are widely used around the world for AOC communications and can serve both safety (ATS and AOC) and non-safety (AOC) functions.

Europe has deployed an OSI network to support the use of ATN B1 applications and plans to leverage on this infrastructure to support B2 applications going forward. OSI can only serve safety ATS applications.

Airline Operations communications can use ACARS, as previously mentioned, and depending on the origin and destination of the data can also use IP as per commercial links.

b. Mid and Long-Term

ACARS and OSI will exist for the mid- and long-term. IPS will start to be introduced in order to provide upgrades, particularly in the areas of security, and also provide a migration path towards future native-IP safety applications (such as air-ground SWIM). IPS Gateways located on the ground are key to the introduction of IPS technologies, as the gateways will provide ways to enable transition from current technologies as well as potentially provide other advantages such as the logical place for security endpoints.

In order to allow mixed link usage (safety and non-safety) under the Hyperconnected ATM technology, in addition to confirmation of the performance feasibility and regulatory changes, there will also need to be a monitoring function created. This monitoring function would likely reside in the upper layers of the protocol stack, as it will be different than traditional multi-link type usage mechanisms (although existing multi-link protocols may be able to be adapted). There are currently no standards for this capability, and the potential impact on aircraft architectures can be substantial. This would have to be well-defined prior to implementation, as consistent operation would be key to being able to meet the performance requirements.

c. Network Summary

The existing network protocols will continue to be used for some time, given the current equipage base on both aircraft and ground systems. As the move to B2 starts to occur in other airspaces, it is a good opportunity to start to move towards a more capable network layer specified by IPS. In order to ease this transition, the use of IPS Gateways on the ground will be key to allow the gradual introduction of IPS technology without requiring an immediate change to legacy aircraft and ground systems. Further leveraging IPS for other types of non-safety communication will also have benefits of unified architectures and reduced complexity.

The use of commercial link protocols could also be leveraged via the Hyperconnected ATM technology. This would require the creation of a new network monitoring function on both the aircraft and ground side, which would likely require a high DAL. The monitoring function would also require aircraft architecture modifications and need to be supported by regulatory changes to allow its intended usage. Finally, the monitoring function itself would need to be standardized in order to ensure consistent implementation in aircraft and ground systems. All of these factors would need further clarity and definition prior to implementing the Hyperconnected ATM technology.

D. Links

a. Introduction

The objective of this section is to list all the link technologies that could be candidates to support short-, medium- and long-term technologies for Aviation connectivity use cases.

Each of these technologies is described with its main characteristics, in particular in terms of coverage, capacity, maturity, scalability, etc. The result of a first analysis is also presented in terms of strengths, weaknesses, threats, and opportunities (described in Annexe B – Summary of solutions SWOT analysis).

The candidate technologies are by definition the ones that are usable by aeronautical vehicles (on ground or in-flight) as per the ITU regulation definition.

Technologies used currently or in a very near future for the cabin connectivity are described as well. But some more mid to long-term technologies such as Q/V bands or laser communications are not described as they are in a very early stage of development for the aeronautical world and there are still some hurdles to overcome. They could be clearly considered though for the future as eligible solutions bringing extremely high throughputs and some very differentiating features.

b. VHF datalink (Mode A and Mode 2)

Aeronautical VHF data links use the band 117.975–137 MHz assigned by the International Telecommunication Union to Aeronautical mobile (R) service.

VHF Data Link is mostly operated over two different modes:

- Mode 0/A (also known as VHF ACARS network) can provide the aircraft with ACARS data link connectivity only. It was originally introduced in 1978 to provide air-ground connectivity for Airline Operational Control (AOC) communications. VHF Data Link Mode 0/A performance is not accepted to support some safety data link transmissions, such as CPDLC (some enroute

FANS 1/A, ATN B1 or B2). As such, this technology will not be detailed any further in this document.

- Mode 2 can provide the aircraft with both ACARS and ATN data link connectivity. It was introduced to complement Mode A for AOC communications, with the potential to offer a data rate that is ten (10) times faster. Its use was later expanded to become the primary link used to support safety data link transmissions in domestic airspaces, such as CPDLC or ADS-C (FANS 1/A, ATN B1 or B2).

c. L-band SATCOM (safety services)

Two Aeronautical Mobile Satellite (Route) Service (AMS(R)S) systems support oceanic data link and voice safety services – Inmarsat and Iridium. Both systems are being enhanced to support continental Required Communication Performance (RCP) and Required Surveillance Performance (RSP) requirements (i.e., RCP-130 / RSP-160).

Inmarsat SB-Safety

SwiftBroadband Safety (SB-Safety) is a natural evolution of Inmarsat Classic Aero services, which have served airlines for over 25 years. It is implemented as a set of overlay services on top of the Inmarsat SwiftBroadband (SBB) services, which are offered through a constellation of geostationary L-band satellites.

SB-Safety uses digital high-speed and secure IP broadband and supports simultaneous voice and broadband data (IP data at up to 432 kbps, and IP data streaming on demand at 32, 64, and 128 kbps).

Iridium Certus

Iridium Certus broadband service will support voice and data link communications through its polar orbiting Iridium NEXT constellation of low earth orbit satellites (66 operational satellites, 6 in-orbit spares, and 9 ground spares) with global coverage (ensuring at least one satellite is able to provide coverage to the entire planet surface at all times).

Iridium Certus Broadband Service uses digital high-speed and secure IP broadband and supports simultaneous voice and broadband data (88 kbps to 1.4 Mbps).

d. Hyperconnected ATM" – Use of "Non-safety" Commercial Bands

Non-safety commercial communication systems relying for instance on public cellular networks like 4G/5G or commercial Ku/Ka band satellite communication services, are increasingly used on aircraft for passenger internet browsing or pilot-airline interactions. These systems benefit from technological advances in the public wireless telecommunication markets, evolving toward enhanced and cheaper services, unlike legacy aviation communications.

The Hyperconnected ATM technology assumes that it will become acceptable and beneficial to use public non-safety commercial communication systems as a component of aircraft safety communications. A key assumption of the concept is that the use of these public non-safety commercial links is done **without enforcing any new requirement to these solutions**, as a complement to safety links.

The demonstration that safety, security, and performance requirements are met is supported by the timely fallback on a safety network if the data has not been delivered through the non-safety links. To this purpose, an overlay monitoring mechanism (developed at a high level of development assurance, with the appropriate DAL/SAL, and independent from the commercial links) will assess the probability of success to use commercial link (based on consolidated link status/performance indication and data delivery reporting) and finally ensure a timely fallback on the safety network if necessary. The monitoring function (both air and ground) need to be defined and consistently specified prior to full implementation.

Such mechanism will integrate appropriate security mechanisms to protect the traffic when using the commercial links (in particular a VPN tunnel between the airborne endpoint at the edge of the aircraft control domain and a ground peer endpoint at the edge of the network of a trusted organisation involved in aeronautical safety communications (e.g., in a CSP domain), but also firewalling functions, deep packets inspection functions, additional end-to-end security functions, etc.).

e. LDACS

The L-band Digital Aeronautical Communications System (LDACS) is a terrestrial communications system identified in the FAA and EUROCONTROL Future Communications Study and endorsed by ICAO in 2008.

LDACS has been considered, particularly in Europe, as one of the options to complement VHF and SATCOM data link communication means in the future when additional capacity would be required.

The LDACS protocols utilise commercial technologies based on Frequency Division Duplex (FDD) with Orthogonal Frequency Division Multiplexing (OFDM) modulation. To date, Europe is taking the lead with LDACS definition and development efforts. Under the SESAR1 activities, the LDACS system specifications were refined.

As a terrestrial technology, LDACS can cover continental areas. Typical data rate supported by LDACS is 500 kbps to 2 Mbit/s.

f. AeroMACS

AeroMACS is a radio access network that supports ATC and AOC applications for safety and regularity of flight on the airport surface. It operates on globally reserved ITU spectrum in the C-band (5091-5150 MHz) with locally optional extensions in the 5000-5030 MHz spectrum.

AeroMACS ICAO, RTCA, EUROCAE and ARINC standards have been developed.

AeroMACS is based on WiMAX (cellular technology using a communications profile of the IEEE 802.16-2009 standard).

AeroMACS can cover Airport areas (and vicinity) for ground usage only. Typical data rate supported by AeroMACS is 2 to 10 Mbps.

g. HF

Aeronautical HF (High Frequency) radio links use the portion of the radio spectrum extending from 3 to 30 megahertz (MHz) although only some of this RF spectrum is available for aeronautical use. is the backbone of long-range aircraft communications, as HF transmissions are reflected off the Earth's ionosphere, allowing aircraft to communicate. The main advantage of HF is propagation, where a single link can reach distances as great as 3,000 km.

Aircrafts utilise HF communications when VHF (Line of Sight) communications is not sufficient or is not available. The primary usage of HF is for Trans-oceanic flights. Trans-oceanic flights communicate with ground stations via HF for position reports and other purposes.

h. L-Band SATCOM (non-safety services)

SATCOM L Band (1-2GHz) solutions are long-term well established communication solutions for the cockpit and cabin inflight connectivity. They generally operationally use the portion of the radio spectrum extending from 1.3 to 1.7 GHz. They have started to develop decades ago to deliver highly reliable connectivity solutions while providing global (Iridium) or almost global (Inmarsat) coverage.

Some regional players operating in L Band also exist.

These solutions are very reliable and highly available because the L Band spectrum is much more resilient to weather conditions and rain fade attenuations than other RF bands. The main limitation comes from the relatively low throughput that these solutions actually deliver. These solutions are proprietary and non-interoperable.

i. Ku/Ka GEO

SATCOM Ku/Ka GEO solutions are well established communication solutions for the cabin inflight connectivity. They have started to develop 2 decades ago to deliver higher throughput than L Band while providing almost global coverage.

For satellite communications, Ku band radio links generally use the portion of the radio spectrum extending from 10.7 to 14.5 GHz. Similarly, Ka band radio links use the portion of the radio spectrum ranging between 27,5 and 31 GHz for the transmission and between 17,3 and 21,2 GHz for reception. Terminals are smaller than in Ku for similar performances, but Ka is more sensitive to rain fade conditions than Ku.

The main Satellite Operators providing almost global solutions are Inmarsat and Viasat operating in Ka, Intelsat, SES, Eutelsat and Telesat operating in Ku and Ka bands.

Solutions for mobility are generally proprietary and technically complex and non interoperable

j. Ku/Ka LEO/MEO

SATCOM Ku/Ka LEO/MEO/HEO constellations are currently quickly developing and deploying to provide truly global hight throughput communication solutions targeting all types of applications and market segments including mobility.

They use the same portion of the radio spectrum as the GEO satellites. As they come later, they need to coordinate with all legacy GEO satellite operators to make sure they will not interfere with existing operational services.

The main Satellite Operators operating, deploying, or developing these types of disruptive solutions are SES (O3B then mPOWER), OneWeb, Starlink, Amazon Kuiper, Telesat LightSpeed, etc. operating in Ku or Ka bands. Most of the solutions are still in the deployment phase and will become fully operational with global coverage in the very near future. Some other initiatives may come.

Ground System infrastructures are closed, proprietary, non interoperable, and complex.

k. (5G) Air-To-Ground

Air-To-Ground (A2G) communication solutions have developed as a cost-efficient alternative to satellite communication for inflight connectivity. This type of solution is operated via cell towers deployed on the ground. They enable it to perform a direct broadband internet data communication between the aircraft and the ground.

Among the main benefits, the speed of such networks is high latency is very low thanks to the short distance between the aircraft and the antenna on the ground (only a few milliseconds). The cost and integration of this type of solution makes it an attractive alternative to the SATCOM but is constrained by the fact that it is only available in continental areas

A2G has started with proprietary and non-standard solutions but 5G has initiated the standardisation of 5G Non-Terrestrial Network (5G NTN) which will enable future convergence and interoperability of the different solutions across the world.

l. Wi-Fi Gatelink & 3G/4G/5G Cellular Gatelink

Wi-Fi is a family of wireless network protocols, based on the IEEE 802.11 family of standards, which are commonly used for local area networking of devices and Internet access, allowing nearby digital devices to exchange data by radio waves.

3G, 4G and 5G are the 3rd, 4th, and 5$_{th}$ generations of cellular technology, respectively. The difference between each generation primarily comes down to their capabilities.

For example, each generation has made improvements to: Speed (lower latency) Network volume (higher bandwidth).

These technologies are widely deployed and adopted worldwide. Even though these are commercial off the shelf solutions, Wi-Fi availability is limited to major airports while 3G and 4G can be found in most airports for the aircrafts to connect at the gate. 5G is still in the maturation stage as it continues to be standardised through the different 3GPP releases.

m. Links Summary

Two categories of communication links can be used for aviation:

- Communications operating on Safety-of-Life spectrum (protected from harmful interferences by ITU regulation) and standardised at ICAO level to ensure Required Demonstrated Performance.
- Communications operating in non-safety spectrum for commercial services.

Existing and future communications safety links offer a range of capacity, generally from low to medium bandwidth, with significant costs but guaranteed quality of service. Performance is demonstrated.

Communications in non-safety spectrum offer medium to high bandwidth, low costs, but no guarantee of performance.

The Hyperconnected ATM technology aims at combining the benefits of both types of links, providing enhanced performance for a lesser cost than introducing a fully new safety link technology.

E. Recommended solutions

This chapter summarises the recommended connectivity solutions for applications, networks, and links. General recommendations are also provided for security aspects. Transition considerations are detailed in sections VII and VIII of this document.

In a nutshell, the recommendations for each category of identified use cases are the following:

		Applications	Network	Links **Preferred** Option	Links *Fallback* Option
PRELIMINARY	ATM[9] Autonomy (ATM)	B2	IPS	VDL2 SATCOM Performance Class B Commercial links as complement (Hyperconnected ATM)	SATCOM Performance Class B + LDACS[10]
	AIS urgent	Standard applications			
	Autonomy (assistance)	Proprietary applications			
	Autonomy (C2)			C-band (SATCOM and/or ground-based)	Commercial link (FSS)
	ATM negotiation	Standard / Custom applications	IP	Non-safety links[11]	N/A
	Airline Operations[12]				
	AIS not urgent				

[9] Use cases highlighted in red in this table are subject to required demonstrated performance.

[10] For Autonomy (ATM), the alternative option could be a ground-ground link.

[11] This does not preclude the use of additional redundant links for backup purposes for airline operations.

[12] Some Airline Operations communications may still be routed over protected spectrum due to aircraft architectural constraints.

a. General Recommendations on cybersecurity

Future aviation connectivity will have to rely on a strong end-to-end cybersecurity architecture.
A global risk-based approach for each Use Case (i.e., each dataflow) will be necessary to identify the relevant assets, the applicable threats, their associated risks, and the security objectives as outcomes of the risk assessment process.
To achieve these security objectives, the end-to-end security architecture of both the air and ground environment shall provide the following security properties: Confidentiality[13], Integrity (Authentication[14]) and Availability, known as the “CIA” triad.
The integrity protection and authentication mechanisms of the communication means shall be based on strong or basic cryptographic/authentication algorithms when used in networks, within a cryptographic protocol.

In addition, the end-to-end security architecture will also stick to the defence-in-depth principles[15], i.e., involving several layered security measures, in order to achieve the security objectives. In some cases, exceptions can be made when there is an equivalent mitigation[16] that is shown to satisfactorily address the risk.
Moreover, aviation connectivity and communications infrastructures should progressively evolve to support compatibility with the “Zero Trust Security Model”[17]. The Zero Trust Model is based on the principle that users have to be systematically checked before being granted any access to the resources (e.g.: assets, applications, services, workflows, etc.). This approach, therefore, implies securing the resources strongly rather than having a security perimeter based on protecting network segments only.
Finally, the future aviation connectivity and communication means have to be considered as a particular Information Security Management System, and as such, cybersecurity related processes have to be put in place (e.g., PKI for digital certificate management, incident management, vulnerability management, monitoring of security relevant data, etc.).

b. Recommendations on Applications

For ATS applications, the proposed vision is that the **Baseline 2 Applications** shall be the global convergence point for all ATM operations.

As explained in the section VI.B Baseline 2 ATS Data Link Applications have been designed to support all known Air Traffic Services use cases, and in all types of airspaces. Their deployment should allow to provide equivalent level of service to currently operated technologies (e.g., FANS 1/A and ATN B1) in the concerned

[13] Could be optional, depending on the sensitivity of the data to be processed
[14] Mutual authentication should be preferred
[15] https://csrc.nist.gov/glossary/term/defense_in_depth
[16] An organisational security measure may be used instead of a technical security measure.
[17] https://www.nist.gov/publications/zero-trust-architecture

airspaces, and to introduce new ATM capabilities where relevant (e.g., full Trajectory-Based Operations, Advanced Interval Management or Dynamic Required Navigation Performance).

The convergence towards a unique B2 definition is expected to be achieved via the deployment of the Revision B of the B2 standards. This version will allow an aircraft implementation to operate seamlessly worldwide, while the set of supported services may differ from one region to the other, depending on the local operational need. Ongoing efforts to finalise the revision B of the standards shall be pursued in order to obtain as soon as practicable a solid basis for future convergence.

The definition of Baseline 2 ATS Data Link Applications, also allowing some early implementations on existing network and communications links (e.g., ATN/OSI over VDL2 in Europe), is fully compatible with the recommendations agreed for network and communication links set in this document (see next two paragraphs).

AOC applications remain largely under airlines' control and will continue to evolve according to the needs for optimization of aircraft operations. There may be sets of more standardized applications that are used to supplement ATM operations by exchanging information and negotiating routes between aircraft and ground automation systems.

Standards (including safety, performance, and interoperability requirements) should be developed to support the urgent AIS use case (AIS #2).

Applications supporting autonomy use cases (C2 link and assistance) are expected to be proprietary solutions.

c. Recommendations on Network

The proposed vision is that the **IPS** shall be the network solution for communications subject to required demonstrated performance.

IPS is recognised as a state-of-the-art protocol, with performance, safety and security features supporting current and future applications with required demonstrated performance.

IPS standardisation shall be pursued to finalise as soon as practicable the basis for future implementations, taking into consideration the recommendations made in this document for cybersecurity and for the links (i.e., developing necessary solutions to adapt IPS over legacy links and to ensure compatibility with the Hyperconnected ATM technology).

For communications not subject to required demonstrated performance, use of commercial off-the-shelf standard IP protocols is expected.

d. Recommendations on Links

For communications subject to required demonstrated performance, the **Hyperconnected ATM technology as a complement to VDL2 and SATCOM Class B** looks like the most promising option:

1. **Capacity**: the Hyperconnected ATM technology has the potential to provide the additional capacity needed for future ATM needs, in complement to VDL2 and SATCOM Performance Class B.

2. **Timely implementation**: the Hyperconnected ATM technology has the potential to be timely deployed, as aircraft and ground modifications are assumed relatively simple (e.g., possibly software upgrades only).

3. **Fleet penetration**: this solution should allow a large penetration on the aircraft fleet given the increasing adoption rate of broadband connectivity for the cabin domain.

4. **Cost effectiveness**: this solution is likely to be the most cost effective (compared with the deployment cost of a new safety link). It relies on commercial links infrastructure that is already widely deployed and will continue to grow significantly (5G, LEO/MEO constellation, etc.).

5. **Performance and future-proofness**: this solution is considered future proof as the cabin connectivity will continuously evolve towards more efficient and cost-effective solutions delivering higher throughput and better performances.

It is acknowledged that the technical maturity of the Hyperconnected ATM technology is still low, and its feasibility and acceptability remain to be confirmed. The concept is based on the use of safety links as backup to ensure the required performance. The first studies performed in the frame of SESAR did not identify any showstoppers. There needs to be clear agreement on the regulatory impacts resulting from Hyperconnected ATM.

It is then recommended that this maturation is pursued and accelerated in the frame of both NextGen and SESAR programs, including large scale demonstration of the associated benefits.

On the other hand, the task force recommends that the **communications not subject to required demonstrated performance should make maximum use of "commercial links", i.e., non-safety links, in the future**. The primary objective is to support decongestion of the links operating over protected spectrum.

When it comes to autonomy, it is important to mention again that discussions have remained notional. Anyway, the TF has come to the following recommendations:

- For the autonomy assistance and ATM use cases, the same set of link solutions as for ATM is recommended.
- For the RPAS C2link, the C-Band spectrum (5.030-5.091 GHz) which is currently allocated to this purpose is the recommended solution.

VII. EU-US transition roadmap

A. Introduction to the transition roadmap

In order to achieve the long-term harmonised connectivity landscape described in the previous chapter, some transition steps need to be taken by European and US stakeholders.

The key stakeholders include the aircraft manufacturers (and their avionics equipment suppliers), the operators, the aviation datalink service providers, the ANSPs (and their ground system suppliers) and the policy setting organisations: ICAO, the European and US Regulators (EC, EASA, FAA), and the involved Standardisation Organisations (RTCA, EUROCAE, ARINC).

The transition roadmap has been defined to answer the strategic objectives shared by all actors about the future of the aviation system, such as the modernisation of the ATM system or aviation sustainability. Each transition step will need adequate drivers or incentives, which can be related to business benefits, or to the need for regulatory compliance.

The transition roadmap has been defined for the Preferred option only.

This transition roadmap is visually summarized in section B and provided as a detailed table in Annexe D – Transition roadmap. It has been established with following methodology:

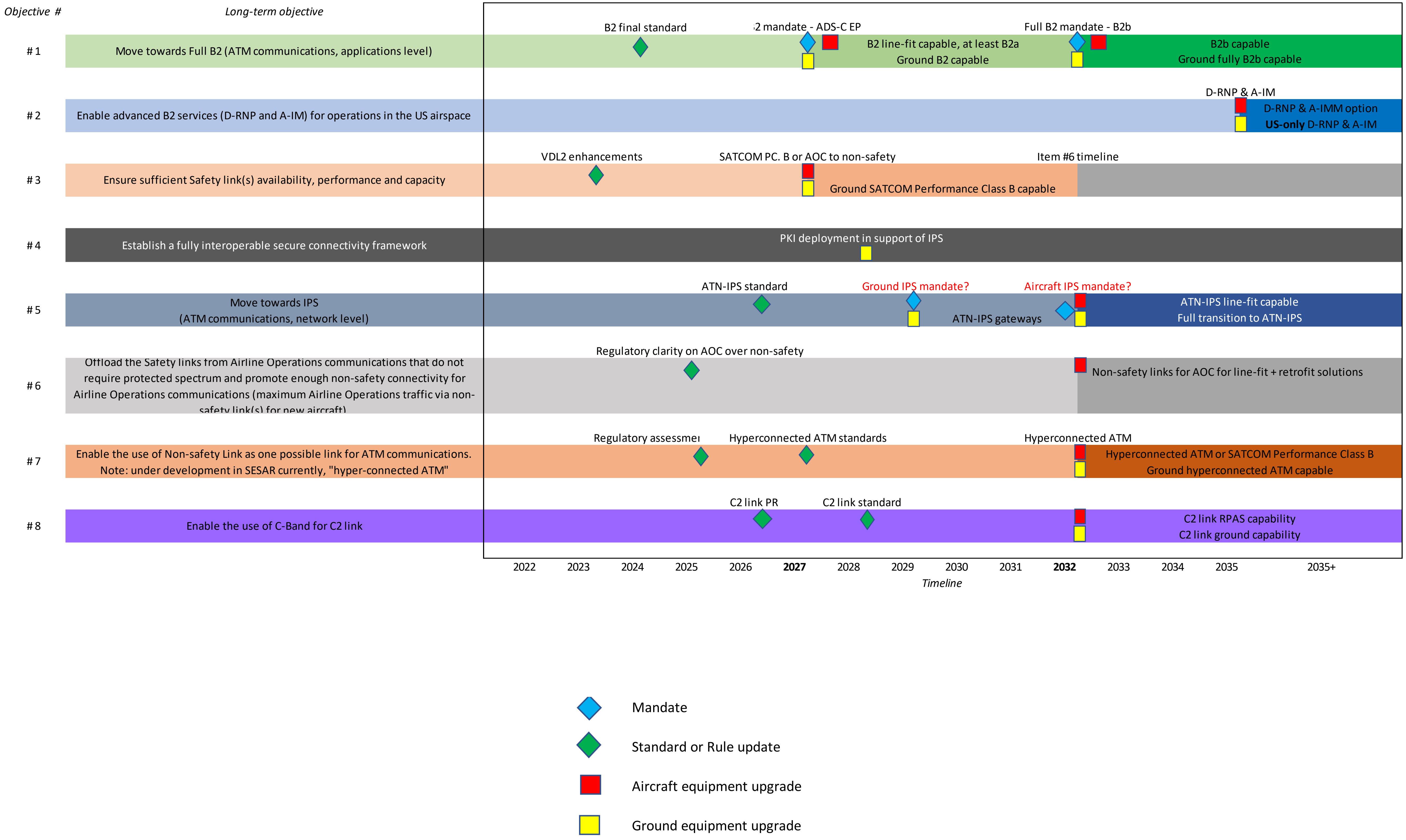
The long-term future connectivity landscape is first described through 8 "**long-term objectives**" which are intended to be descriptors of the important change areas that need to happen for the connectivity landscape to become a reality.

1. Move towards Full B2 (ATM communications, applications level)
2. Enable advanced B2 services (D-RNP and A-IM) for operations in the US airspace
3. Ensure sufficient Safety link(s) availability, performance, and capacity
4. Establish a fully interoperable secure connectivity framework
5. Move towards IPS (ATM communications, network level)
6. Offload the Safety links from Airline Operations communications that do not require protected spectrum and promote enough non-safety connectivity for Airline Operations communications (maximum Airline Operations traffic via non-safety link(s) for new aircraft).
7. Enable the use of Non-safety Link as one possible link for ATM communications.
   Note: under development in SESAR currently, "Hyperconnected ATM"
8. Enable the use of C-Band for C2 link

For each long-term objective, the actions that need to be taken by the various stakeholders are described, together with what are believed to be the main drivers.

B. Timeline summary

In order to achieve the end goal at the horizon 2035, the task force identified key milestones for each objective, which are depicted in the below table. The critical transitions items are then detailed in chapter VIII. It should be noted that most of the milestones identified are further described in the transition roadmap itself, as included in Annexe D – Transition roadmap of the present document. For the below table, please refer to the key on the following page.


Objective #
Long-term objective
1
Move towards Full B2 (ATM communications, applications level)
B2 final standard
2 mandate - ADS-C EP
B2 line-fit capable, at least B2a
Ground B2 capable
Full B2 mandate - B2b
B2b capable
Ground fully B2b capable
2
Enable advanced B2 services (D-RNP and A-IM) for operations in the US airspace
D-RNP & A-IM
D-RNP & A-IMM option
US-only D-RNP & A-IM
3
Ensure sufficient Safety link(s) availability, performance and capacity
VDL2 enhancements
SATCOM PC. B or AOC to non-safety
Ground SATCOM Performance Class B capable
Item #6 timeline
4
Establish a fully interoperable secure connectivity framework
PKI deployment in support of IPS
5
Move towards IPS
(ATM communications, network level)
ATN-IPS standard
Ground IPS mandate?
ATN-IPS gateways
Aircraft IPS mandate?
ATN-IPS line-fit capable
Full transition to ATN-IPS
6
Offload the Safety links from Airline Operations communications that do not require protected spectrum and promote enough non-safety connectivity for Airline Operations communications (maximum Airline Operations traffic via non-safety link(s) for new aircraft)
Regulatory clarity on AOC over non-safety
Non-safety links for AOC for line-fit + retrofit solutions
7
Enable the use of Non-safety Link as one possible link for ATM communications.
Note: under development in SESAR currently, "hyper-connected ATM"
Regulatory assessme
Hyperconnected ATM standards
Hyperconnected ATM
Hyperconnected ATM or SATCOM Performance Class B
Ground hyperconnected ATM capable
8
Enable the use of C-Band for C2 link
C2 link PR
C2 link standard
C2 link RPAS capability
C2 link ground capability
2022
2023
2024
2025
2026
2027
2028
2029
2030
2031
2032
2033
2034
2035
2035+
Timeline
Mandate
Standard or Rule update
Aircraft equipment upgrade
Ground equipment upgrade

VIII. Critical transition items

A. Cross-stakeholders

There are a number of areas that need definition by multiple stakeholders in order to ensure that the roadmap as defined in this document can be realized. While there is no set timeline for these items to be completed, some of them are pre-requisites to successful transition. Some of these aspects that need consideration are listed below, although this list is not meant to be exhaustive.

- To define and develop a strategy for supporting the security aspects of data communications, including how the PKI will be created, operated, and funded. Developing security policies that are compatible between different stakeholders will also need to be performed.
- To assess any potential sovereignty issues for stakeholders for the envisaged technologies in the roadmap.
- To identify opportunities for trials and large-scale demonstrations between the US-EU to mitigate implementation risk (especially for low TRL items) and confirm key system performance aspects.
- To refine capacity estimates and forecasts for safety links, including what is required for ATM traffic as well as the expected impacts of the Hyperconnected ATM technology.
- To propose backwards compatibility solutions for transition, including supporting B2-capable aircraft by ATN B1 ground systems and B2 equivalent messages for FANS-1/A systems.
- To create a concept of operations and propose a strategy for digital addressable voice in preparation for future transition past current voice systems.

B. Manufacturers and operators

a. General

In order to support the proposed transition roadmap, the manufacturers need to develop and provide additional aircraft capabilities (indicated dates are providing the latest time when such solutions should be available). These solutions shall be available for line-fit and retrofit (unless otherwise indicated).

The offering of these capabilities in line-fit (either offered as part of the standard aircraft definition or selectable as an optional capability by the airline) will depend on the aircraft type and its target area of operations. For instance, B2 capability is likely to be offered as an option, at least initially as long as it is deployed in Europe only. Similarly, SATCOM Performance class B solution and non-safety connectivity will remain options to allow operators to select one or the other.

From an operator's perspective, changes introduced to the operators' fleet or ground systems environment need to have a clear benefit to be voluntarily equipped, and in general the return-on-investment period for a change has a short time span. These need to be fully considered when deciding on broad airspace changes from an ANSP perspective.

Complying with mandates will of course need to be considered depending on where particular aircraft types operate. Planned fleet refreshes will also play a role, as aircraft that are exempt from mandates would be costly to upgrade, and aircraft that operate in areas not subject to mandates will need to consider the cost-benefit of upgrading as previously mentioned.

Additionally, an operator's communication strategy (how it leverages AOC communications in its operations, uses different types of auxiliary devices like EFBs, subscribes to different services which require off-board communication, etc.) will also influence the equipage and availability of additional links that could potentially be leveraged. The less an airline uses connectivity in their operations, the higher the entry cost is to equipage to the preferred equipage end state.

b. Short-term milestone (by 2027)

Applications: Full B2 solution (CPDLC and ADS-C, including ADS-C EPP downlink as required by the CP1 mandate, excluding Dynamic RNP and Advanced IM). This solution should comply with B2 Revision A at the minimum.
Operators should select this optional capability for all line-fit aircraft flying in Europe, as a minimum.

Links:
SATCOM Performance class B solution supporting the B2 ATS communications.
OR
Capability to offload AOC from safety links (e.g., "ACARS over IP" or similar solutions) and at least one operative non-safety links (e.g., Cabin SATCOM or A2G).
For B2 equipped line-fit aircraft, operators should select at least one of these two options.

c. Mid-term milestone (by 2032)

Network: IPS network capability. Retrofit may not be feasible on some legacy aircraft. This capability will be offered as part of the B2 package.

Links:
SATCOM Performance class B solution supporting the B2 ATS communications.
OR
Hyperconnected ATM technology available with non-safety links (e.g., Cabin SATCOM or A2G).
For B2 equipped line-fit aircraft, operators should select at least one of these two options.

d. Long-term milestone (by 2035)

Applications: Advanced B2 services (including A-IM D-RNP). This solution should comply with B2 Revision B at the minimum. This capability will be offered a part of the B2 package.
Retrofit of these capabilities will be on a voluntary basis only, operators will need to revisit the costs of adopting these upgrades versus the return on investment.

Network and Links: unchanged compared to the mid-term target.

C. ANSPs and CSPs

a. General

The common thread for data communications is the datalink service and its providers. FANS aircraft, ATN OSI, IPS aircraft (either FANS or ATN over OSI) all use these datalink services. The datalink providers will have to support all the protocols in their role as the middle of the data-communications and provide a triplet of services as they do today with ACARS and OSI geographically. By offering protocol and triple stack gateway support, datalink providers deliver a globally available service and remove this parameter of a compatibility requirement from the end systems (i.e., ANSP and aircraft).

ANSPs will provide services using B2 applications, while continuing to support legacy applications (FANS 1/A and ATN B1) and transitioning using B2 equivalent messaging.

The C2 link is critical for the introduction of unmanned operations. There have been standards definitions of the C2 link technical details, and these will need to be brought into operational usage. There may be some cases where UAS systems are fully autonomous, but there will be a need for C2 links for IFR-type operations. Considerations for transition include:

- Certifying C2 link technology for operation;
- Assessing C2 link performance based on operational concept for UAS operators; and
- Establishing service level agreements for suppliers of C2 links, including in-service monitoring and performance evaluation.

b. Short-term milestone (by 2027)

Applications: EU ANSPs will have to ensure B2 ADS-C capability of ground systems and maintain B1 CPDLC backward capability (EU ANSP). The US ANSP will have to ensure FANS 1/A services backward compatibility for B2 aircraft.

Networks: the EU ANSPs/CSP(s) will have to maintain compatibility of ground network backbone with ATN-OSI and ensure compatibility of ground network backbone with

ATN-IPS. The US CSP will have to maintain compatibility of ground network backbone with FANS/ACARS, ATN/IPS and potentially ATN/OSI.
Links: Both EU and US ANSPs/CSPs will have to deploy VDL2 improvements and work towards transparent integration of SATCOM Class B in the datalink infrastructure.

c. Mid-term milestone (by 2032)

Applications: EU and US ANSPs will have to ensure Full B2 (CPDLC + ADS-C) capability.

Networks: EU and US ANSPs and CSPs will have to ensure support of ATN-IPS and SATCOM Class B.

Links: EU and US ANSPs and CSPs will have to ensure seamless and transparent integration of multiple datalinks (i.e., Hyperconnected ATM).

d. Long-term milestone (by 2035)

Applications: the US ANSP will ensure advanced B2 capabilities.

D. Standardization organisations & Policy making bodies

Key actions for **policy making bodies** will be to:

- Drive the transition to B2/IPS for ATS applications, through a combination of mandates or other types of actions.
- Define clearly in the international regulatory framework which types of AOC applications (if any) require the use of aviation protected spectrum, due to specific performance requirements.
- Enable the use of non-safety link as one possible link for ATS applications
- In addition, for the EU region, the set-up of a centralised EU datalink infrastructure and service provide should be pursued, in order to enable the harmonisation of datalink services and infrastructures across all states.

Key actions for **standardisation organisations** will be the following:

- RTCA – EUROCAE:
    - Finalize the B2 standard.
    - Complete the IPS standard.
    - Standardise the ACARS over IP protocol, if appropriate.
    - Develop performance-based standard(s) for Hyperconnected ATM.
- AEEC:
    - Develop the necessary ARINC standards.
- ICAO:
    - Update of the GANP.
    - Complete IPS technical manual and guidance.
    - Security standards, including PKI security policy.

- RTCA – EUROCAE & AEEC:
    - Transpose the VDL2 improvements into the relevant standards.
    - Define standard(s) to support harmonization / compatibility / interfacing of C2 link systems and equipment.
    - Propose Hyperconnected ATM Monitoring Function.

IX. Next steps

The conclusions of this task force and the proposed transition roadmap will further need continuous close coordination and effective steering, and this at two levels:

- at the regional level, between all stakeholders relevant for the changes to be driven in a region
  and
- at bilateral (or multilateral) level between the regions.
  A starting point for a bilateral level steering could be the setting up of a permanent EU-US future aviation connectivity landscape steering board. This board will have to ensure the transition actions defined are effectively implemented in a coordinated manner.

It is also recommended that the retained solutions are promoted at ICAO level (within the Air Navigation Bureau in ICAO headquarters, but also in each of the regional offices) to seek a global adoption and future global interoperability.

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X. Annexes

The below pages present the different Appendices supporting the present document.

Annexe A– Summary of needs

a. Description of dimensions

Type	Name	Value Type	Measurement Unit	Possible Values	Performance Threshold (PT)	Desired performance
Safety	Latency	Integer	s (seconds) Equivalent to one-way Transaction Time in the RCP.	Low	1	Inferior to PT
				Medium	15	Inferior to PT
				High	60	Inferior to PT
	Continuity	Float	% (probability)	High	0.999	Superior to PT
				Medium	0.99	Superior to PT
				Low	0.95	Superior to PT
	Availability	Float	% (probability)	High	0.989	Superior to PT
				Medium	0.95	Superior to PT
				Low	N/A	N/A
	Integrity	Float	% (probability per FH)	High[1]	1.00E-05	Inferior to PT
				Medium	1.00E-03	Inferior to PT
				Low	No Safety Effect	Inferior to PT

Type	Name	Value Type	Measurement Unit	Possible Values	Performance Threshold (PT)	Desired performance
Security	Availability	Effectiveness	Likelihood (probability)[2]	High	Very unlikely	At least matching
				Medium	Unlikely	At least matching
				Low	N/A	N/A
	Integrity (incl. authenticity & non-repudiation)	Effectiveness	Degree of difficulty	High	Strong cryptographic algorithms	At least matching
				Medium	Basic cryptographic algorithms	At least matching
				Low	Error detection on transmission medium only	At least matching
		Binary	N/A	Yes	Strong authentication required	At least matching
				No	No authentication required	At least matching
		Binary	N/A	Yes	Strong non-repudiation mechanisms required	At least matching
				No	No specific requirement	At least matching
	Confidentiality	Effectiveness	Degree of security	High	Strong encryption	At least matching
				Medium	Standard encryption	At least matching
				Low	No encryption required	At least matching
Data Rate	Throughput	Integer	Kbps	High	1000	Superior to PT
				Medium	100	Superior to PT
				Low	10	Superior to PT
Connectivity type	In-flight connectivity required?	Binary	N/A	Yes	APT, TMA, ENR-1 and ENR-2	N/A
				No	APT connectivity only	N/A
	Protected spectrum?	Integer	N/A	0 = Yes	ITU protected spectrum	N/A
				1 = Backup	Non-protected, but ITU protected spectrum available in case of failure of primary mean of communication[3]	N/A
				2 = No	Non-protected	N/A

[1] Corresponds to a Major failure condition

[2] Level of Threat/Likelihood Classification as defined in the ED-201A (cf. Appendix B.3.3)/ED-203A/DO-356A.
For example: High -> Very Unlikely: Level of Threat (Low) /likelihood should be Very Unlikely to occur

[3] Backup solution should also meet the Performance Requirements.

b. ATM

	Dimension	Safety					
	Criteria	RCP	RSP	*Latency*	*Continuity*	*Availability*	*Integrity*
UC #	**Use Case**						
ATM #1	Basic DL in ENR-2	RCP 240	RSP 180	High	Medium	Medium	High
ATM #2	Basic DL in ENR-1/TMA	RCP 130		Medium	High	High	High
ATM #3	Complex DL in ENR-2[1]	RCP 240	RSP 180	Medium	High	Medium	High
ATM #4	Complex DL in ENR-1/TMA	RCP 130	RSP 160	Medium	High	High	High
ATM #5	DL in APT[2]	RCP 130	RSP 160	Medium	High	Medium	High
ATM #6	Trial Plan Coordination - OCC			Medium	Low	Medium	High
ATM #7	Trial Plan Coordination - ANSP			Medium	Low	Medium	High

[1] Might require Low latency and High integrity if deconfliction is planned.

[2] Departure Clearance will have different RCP.

	Dimension	Security			Data rate	Connectivity type	
	Criteria	*Availability*	*Integrity (incl. authentication)*	*Confidentiality*	*Throughput*	*In-flight connectivity required?*	*Protected spectrum?*
UC #	**Use Case**						
ATM #1	Basic DL in ENR-2	Medium	High	Low	Low	Yes	Backup
ATM #2	Basic DL in ENR-1/TMA	High	High	Low	Low	Yes	Backup
ATM #3	Complex DL in ENR-2[1]	Medium	High	Low	Low	Yes	Backup
ATM #4	Complex DL in ENR-1/TMA	High	High	Low	Low	Yes	Backup
ATM #5	DL in APT[2]	Medium	High	Low	Low	Yes	Backup
ATM #6	Trial Plan Coordination - OCC	Medium	High	Medium	Medium	Yes	No
ATM #7	Trial Plan Coordination - ANSP	Medium	High	Medium	Medium	Yes	No

c. Autonomy

	Dimension	Safety				Security			Data rate	Connectivity type	
	Criteria	*Latency*	*Continuity*	*Availability*	*Integrity*	*Availability*	*Integrity (incl. authenticity & non-repudiation)*	*Confidentiality*	*Throughput*	*In-flight connectivity required?*	*Protected spectrum?*
UC #	**Use Case**										
AUT #1	RPAS[1] - Remote pilot to permanently control the RPAS (ICAO RPAS IFR operations)[2]	Low	High	High	High	High	High	High	Medium	Yes	Backup
AUT #2	UAS - Remote pilot to control the highly automated UAS (emergency)	Low	High	High	High	High	High	High	Medium	Yes	Backup
AUT #3	Manned aircraft - Ground assistant to assist the highly autonomous piloted aircraft/crew	Medium	High	High	High	High	High	High	Medium	Yes	Backup
AUT #4	RPAS & Manned aircraft - Remote pilot to communicate with ATC / datalink[3]	Medium	High	High	High	High	High	Low	Low	No	Backup or N/A if ground-ground link

[1] C2 link as defined by the ICAO RPAS Panel. RPAS integration should be as transparent as possible, i.e. RPAS acting as "manned aircraft".

[2] Performance Requirements may need to be adapted; operational mitigations might be necessary.

[3] Ground-ground connection could be proposed. Else, RPAS acting as relay.

d. Airline Operations

	Dimension	Safety				Security			Data rate	Connectivity type		
	Criteria	*Latency*	*Continuity*	*Availability*	*Integrity*	*Availability*	*Integrity*	*Confidentiality*	*Throughput*	*In-flight connectivity required?*	*Down/Up-link*	*Protected spectrum?*
UC #	**Use Case**[1]											
AO #1	High-capacity, reliable, high latency, pre-departure and post-arrival	High	Low	Medium	High	Medium	High	High	High	No	Both	No
AO #2	High-capacity, reliable, medium latency	Medium	Low	Medium	High	Medium	High	High	High	Yes	Both	No
AO #3	Non-priority	Medium	Low	Medium	Medium	Medium	Medium	High	Low	Yes	Both	No

[1] Use of ITU aviation protected spectrum is still permissible but not necessary. Performance requirements need to be operationally appropriate.
Use of unprotected spectrum for certain applications might require operational usage approval and/or regulatory/certification agency approval.

e. AIS

	Dimension	Safety				Security			Data rate	Connectivity type	
	Criteria	*Latency*	*Continuity*	*Availability*	*Integrity*	*Availability*	*Integrity (incl. authenticity)*	*Confidentiality*	*Throughput*	*In-flight connectivity required?*	*Protected spectrum?*
UC #	**Use Case**										
AIS #1	Situational awareness data for pilot decision	Medium	Medium	High	High	High	High	Low	Low	Yes	No
AIS #2	Urgent situational awareness data for pilot decision	Medium	High	High	High	High	High	Low	Low	Yes	Backup
AIS #3	Enhanced situational awareness	High	Medium	Medium	High	Medium	High	Medium	Medium	Yes	No
AIS #4	Aircraft as sensor	High	Medium	Medium	Medium	Medium	Medium	Low	Medium	Yes	No

Annexe B – Summary of solutions SWOT analysis

a. Applications

• ATS applications

Strengths / Opportunities

- Develop and support consistent, technology-agnostic services (e.g., route clearances); de-risk future services using all technologies.
- Upgrade European ground systems to use B2RevA or B2RevB CPDLC, even if only ATN B1 services are used.
- Explore other methods to get EPP-like data that satisfy the US operational need for the transition period, increase equipage base, and ease airline costs.
- Provision of full en-route services (less D-RNP and A-IM) to B2RevA aircraft in U.S. could be transparent (B2RevB ground systems should be compatible with B2RevA aircraft).
- Explore message set compatibility between FANS 1/A and B2.

Weaknesses / Threats

- Consistent operational use between regions – services offered and service details.
- Achieving required equipage for benefits.
- Version compatibility, global harmonization, interoperability.
- Implementing B2 on non-OSI network (prior to IPS).
- Expense/ensuring business cases.
- Fleet commonality.

• AOC applications

Strengths / Opportunities

- Supplementing existing data communications services plans by providing additional connectivity and collaboration capability.
- Leverage non-integrated systems to get EPP-like data to augment current trajectory predictors.
- Use of unprotected spectrum links to provide enhanced capability for data exchange in support of ATM operations.
- Moving of capabilities to auxiliary systems (e.g., EFB) to provide more agile development and near-term benefits for flight deck support services.

Weaknesses / Threats

- Clear definition of “AOC” messages and categories.

- Potential ICAO/WTU aviation spectrum and message category requirements changes.
- Need for additional standardization vs more less stringent requirements/interoperability.
- Determining regulatory impact of pushing more safety critical functions to lower-DAL components.
- Use of unprotected spectrum for specific services may levy additional requirements on service providers and/or avionics to monitor and react to outages.
- Coordination with ATC for eventual clearance input into system, from a technical aspect (interfaces, processing requirements, etc.) and operational aspect (workload, ensuring conflict free changes, coordination, etc.).
- Formatting and input of messaging into aircraft systems (loadability, etc.).
- Impacts on avionics architectures for potentially mixing AISD with ACD.

- **AIS applications**

Strengths / Opportunities

- Provide additional service paths for AIS by leveraging EFBs/SWIM/Connected Aircraft.
- Flexibility in implementation.
- Faster deployment of capabilities.

Weaknesses / Threats

- Clear definition of messages and categories and how they apply to current ICAO/ITU definitions.
- Hazard analysis to be performed for potential safety services.
- Identification of new SPRs may be necessary.
- Combining AIS RCPs with ATS RCPs.
- Ensuring performance levels and availability of AIS data (e.g., ATS Winds) as a general service to provide.
- Level of standardization beyond WG-76/SC-206 to be determined.

- **Autonomy Applications**

Strengths / Opportunities

- Leveraging ATS and AOC applications for autonomous usage, minimizing changes to existing systems.
- Identifying additional capabilities (e.g., TBO) that fit within both manned/unmanned roadmaps that can be developed to serve both communities.
- Identifying new RPAS applications to serve RPAS needs while offloading/avoiding changes to current systems.

Weaknesses / Threats

- Level of standardization is to be defined, particularly given different technologies and use cases.
- Level of integration and compatibility of UAS services into existing airspace automation systems, classifications, and control.
- Ensuring non-interference between UAS and ATM applications.

b. Networks

Strengths / Opportunities

- Leverage IPS architecture and features for both safety and non-safety communications, including AOC and AIS.
- Addition of security through IPS.
- Unified aircraft architectures for connectivity from a network perspective; removal of legacy protocols to simplify implementation and reduce life cycle costs.
- Leveraging IP communications to off-load protected spectrum messaging.
- Use of IPS for additional, native IP safety services.
- Gateway deployment to enable transition to IPS.
- Optimization of OSI and ACARS to ease congestion (non-use of IDRP, MIAM, ACARS over IP, etc.).
- Addition of monitoring function capability to enable Hyperconnected ATM technology.

Weaknesses / Threats

- Transitioning to IPS, including security infrastructure, and supporting aircraft and ground equipage Gateway interoperability and architectural considerations.
- Service provider interoperability and performance guarantees, depending on which services are supported.
- Performance monitoring layer definition for Hyperconnected ATM technology, and where it would be specified (which standards organization is responsible, impacts on other standards bodies/standards, etc.).
- Avionics changes necessary to support potential new routing paths for existing avionics (e.g., allowing CMU messages to go over IP links).
- DAL requirements allocated to the performance monitoring layer will result in expensive implementations.
- Regulatory changes and approvals necessary to prove a monitoring capability can meet the RCP of various services, including performance numbers and message tracing requirements.
- Accommodating broadcast technologies.
- Mobility management.

c. Links

- **VHF datalink (Mode A and Mode 2)**

Strengths / Opportunities

- Fully standardised, through a number of ICAO, EUROCAE/RTCA and ARINC standards. Lately, efforts have been made to update and clarify these standards to improve the robustness of VHF Data Link Mode 2 implementations.
- Deployed in most domestic airspaces across the globe (including Europe and US), with the ability for local ANSPs to control the operations of the service (sovereignty).
- Today, a large part of newly delivered aircraft is delivered with VHF Data Link Mode 2 capability activated (even though a significant number of aircraft are flying -and will continue to fly for many years- without such capability).
- Solutions available to limit the use of VHF Data Link Mode 2 to support the increasing volume of non-safety data link transmissions (favouring use of commercial links as soon as they are available on the aircraft).
- In parallel, new areas of improvement are explored to improve VHF Data Link Mode 2 performance and extend its lifetime, like:
    - "Broadcast/Super VGS" VDL2 is under definition: Several alternatives are currently discussed (EUROCAE WG-92/RTCA SC-214/ARINC DLK SC) to reduce the protocol overhead on VDL2, while improving the performance.
    - Space based VHF may extend the coverage (pending feasibility is confirmed)

Weaknesses / Threats

- Limited bandwidth shared between safety ATM services (such as CPDLC or ADS-C) and ACARS based non-safety applications (such as AOC supporting flight operations, maintenance…).
- Operated for many years over a single frequency, becoming saturated. This strongly affects the overall network performance (for both safety and non-safety transmissions).
- Addition of new frequencies (a few available only anyway) may have its limits. As a consequence, VHF Data Link Mode 2 performance may not be sufficient to ensure RCP-130 and RSP-160 compliance (most stringent performance specifications for safety ATM services in domestic airspaces).
- In recent years, with the arrival on the market of new generation aircraft (e.g., A320NEO and B737MAX), the volume of non-safety AOC data link transmissions has significantly increased (as an average, three or four times higher than legacy models).

- **L-band SATCOM (safety services)**

Strengths / Opportunities

- Fully standardised, through a number of ICAO, EUROCAE/RTCA and ARINC standards.

- Highly available, high priority link for the reliable and safe transfer of safety ATM transactions.
    - Inmarsat SB-Safety has already been deployed to support oceanic operations and has been demonstrated to meet RCP-240 and RSP-180 for remote oceanic operations and is intended to meet RCP-130 and RSP-160 (most stringent performance specifications for safety ATM services in domestic airspaces).
    - Iridium Certus broadband service is designed to meet both RCP-240 and RSP-180 for remote and oceanic operations, and RCP-130 and RSP-160 (most stringent performance specifications for safety ATM services in domestic airspaces).
- Some Inmarsat SB-S aircraft terminals have already been certified.
- European Space Agency (ESA) and SESAR are collaborating under the Iris Programme to prepare the integration of the SwiftBroadband Safety (SB-Safety) into the European ATM air-ground data link infrastructure as a complement to VHF Data Link Mode 2.
- In the long-term, both constellations should be leveraged to provide an overall increase of the proposed capacity.
- Support of IPS protocol already under study (in the frame of the ESA IRIS project), in particular over Inmarsat SB-Safety.
- In particular, the opportunity to propose dual L-Band SATCOM installation on long-range aircraft is studied to allow HF voice decommissioning while maintaining compliance with regulatory requirements for long-haul communication (BLoS). This would be an opportunity to increase availability of safety links on the concerned aircraft.
- Both systems offer non-safety bandwidth in parallel with the safety services (could ease the effort to move non-safety traffic out of safety links).

Weaknesses / Threats

- On short range aircraft, cockpit SATCOM remains an optional feature for the operators. As of today, equipage rate on these aircraft models remains limited (~20% of newly produced short-range aircraft).
- Provided the impact on the aircraft in terms of installation, retrofit costs are significant and limit the penetration of these capabilities on the existing fleet.
- Both satellite service operators, i.e., Iridium and Inmarsat are now US-based companies. This may cause some sovereignty issues for ANSPs in other regions.
- Communication costs over satellite safety services are commonly considered high. This could impair the acceptability of such services by some ANSPs (and potentially operators as a ripple effect).
- Iridium Certus broadband service performance not yet demonstrated as compliance with any RCP/RSP performance specification (action in progress in FAA PARC WG).

- **Hyperconnected ATM” – Use of “Non-safety” Commercial Bands**

Strengths / Opportunities

- The solution leverages existing commercial connectivity services, already operational or planned to be deployed, independently from the safety links (to address the increasing need of passenger’s connectivity) and would benefit from investments already made or protected.
- The main assumption of the concept is to make sure no additional requirements are allocated to the commercial links (no performance requirements, no priority or quality of service requirements). That being said, the expected availability and continuity performance of the known and upcoming public commercial links is considered sufficient to allow their use for a large part of the safety related communications.
- The cost associated with the deployment of this solution is expected to be lower than for a new solution over Protected spectrum, both in terms of development and deployment of the air-ground infrastructure and in terms of operational costs.
- The additional bandwidth capacity made available for safety related communications is huge and should cover all the identified use cases.
- SESAR is exploring the concept to develop a hybrid open/protected ‘Hyperconnected’ communications infrastructure for air/ground data to support future ATM and U-space operations.
- We can observe a growing use of Passenger Connectivity systems (line-fit and retrofit), including short-haul aircraft (cabin connectivity becomes a must for airlines). This should allow to maximise the penetration of the function onto the overall aircraft fleet.
- The concept may be the first step towards a long-term Performance-Based use of commercial links for safety communications (i.e., as primary means, without consideration of safety links as a backup).

Weaknesses / Threats

- The potential benefits of the concept are huge, but the maturity of the concept is still low, and its feasibility is still to be demonstrated (in particular certification/eligibility of the use of commercial links for safety services). It is also unclear how other potential requirements (e.g., message tracing) will be achieved using this concept. In order to ensure global interoperability, the function will likely need to be standardised. They are no standards / regulations available yet.
- As of today, the deployment of commercial connectivity is still limited on short-range AIRCRAFT. Nonetheless, the proportion of equipped short-range aircraft is steadily increasing, both for newly delivered aircraft and in service fleet.
- The concept obviously raises new exposure to data security risks, in particular because the solution shares commercial links with non-safety traffic including passenger traffic and relies on the use of commercial (Internet) networks.

- Clear acceptance and guidance will also be needed from regulatory bodies to ensure there are no ambiguities in certifying or providing operational acceptability for this concept.
- The feasibility and efficiency of using spectrum with shared access are still to be demonstrated.
- The concept, because it relies on commercial connectivity services, will not provide any additional sovereignty to ANSPs for ATM services, unless new constellation or new services are deployed through the EU Govsatcom / Secure Connectivity initiative.
- Lastly, given the low maturity of the concept, the cost of implementations and deployment (air and ground) is not yet consolidated, even though they are assumed to be much competitive compared with the cost of a new safety infrastructure.

- **LDACS**

<u>Strengths / Opportunities</u>

- Based on protected spectrum already allocated: AM(R) allocation in frequency band 960 - 1164 MHz, 46 MHz for UL and DL
- Standardisation launched. As of December 2016, ICAO initiated a group to develop the SARPs and Technical Manual for LDACS.
- A ground infrastructure could be deployed and controlled by ANSPs (sovereignty)
- Increased bandwidth compared to VHF Mode 2
- Built in cyber security means and authentication
- It may share a common technology with AeroMACS (5G) while remaining on protected spectrum (pending feasibility is confirmed)
- Offers potentially digital voice, surveillance, and navigation functions (more “integrated CNS”)

<u>Weaknesses / Threats</u>

- The maturity is not demonstrated at large scale (R&T programs only), there is no ground infrastructure, no serial equipment; it is still research program
- Significant costs are anticipated (airborne, ground, operations…)
- Currently, it is “only” an EU centric initiative.
- No deployment plans may discourage further investments on the technology

- **AeroMACS**

<u>Strengths / Opportunities</u>

- Based on Protected spectrum already allocated
- Some standards are already available
- A ground infrastructure could be deployed and controlled by ANSPs (sovereignty)
- Increased bandwidth for equipped Aircraft for future services
- Built in cyber security means and authentication

- A possible update to 4G/5G technology, more spectrum efficient than other aviation legacy systems could be investigated.
- It could share a common technology with LDACS while remaining on protected spectrum (pending feasibility is confirmed)

Weaknesses / Threats
- Maturity is not demonstrated at large scale (R&T programs only), there is no ground infrastructure, no serial equipment; it is still research program
- Significant costs are anticipated (airborne, ground, operations, etc.
- Currently, there are “only” regional initiatives (no global deployment plan).
- No or uncertain business case (compared to 4G/5G for non-safety use cases)
- It could be considered as an obsolete technology today compared to Cellular
- No deployment plans may discourage further investments on the technology

- **HF**

Strengths / Opportunities
- ICAO & EUROCAE/RTCA & ARINC standard (legacy HF).
- HF provides worldwide coverage including the poles.
- Almost 100% of aircrafts equipped at least for Voice.
- Almost 100% of Long-Range aircrafts equipped with datalink HF capacity.
- Existing proposals (being addressed at ICAO & ITU) to refresh and modernise HF with increased data rate, improved voice quality.

Weaknesses / Threats
- Generally speaking, the performance is rather low, and poor compared to the current generation of telecom technology:
    - Very low data rate
    - Very poor voice quality
    - Limited performances (not RCP/RSP compliant) (only backup to SATCOM L-band for FANS)
- The footprint of the equipment is not optimal (size, weight, consumption, installation…).
- Last, HF is only usable by ACARS.
- Dual SATCOM L-band recognised as dual LRCS, may fully replace HF on some aircraft.

- **L-Band SATCOM (non-safety services)**

Strengths / Opportunities
- Very reliable as L-Band as not impacted by rain fade as other bands operating in higher parts of the RF spectrum.
- Service operated for decades with strong and successful track record.
- Only service currently providing truly global coverage. Iridium has been operating truly globally since the very beginning and Inmarsat will provide almost global coverage excluding the south pole in a couple of years.
- Even if throughput is significantly lower than in other bands such as Ku or Ka, they are increasing with every new satellite generation (Inmarsat 6 / Iridium Certus)
- For low throughput, satellite operators have developed very small form factor

terminals enabling easy integration, reduced cost, and low drag. These terminals provide both L-Band safety and non-safety services, with appropriate segregation.
- L-Band may be the first solution embedding 5G NTN including Direct to Handheld devices (meaning very small form factor and unique terminal on an Aircraft being capable of performing dual satellite and terrestrial communication).

Weaknesses / Threats
- Remain low throughput compared to all new Broadband solutions including constellations.
- The equipment cost (and price) will remain high per design and spectrum limitations.
- Sovereignty question as both Iridium and Inmarsat (via Viasat) are now US-based companies meaning that L Band solutions providing global coverage are exclusively US solutions.
- Communication costs remain high and could be prohibitive for airlines.

- **Ku/Ka GEO**

Strengths / Opportunities
- Commercial Off The Shelf (COTS) cost effective solution vs. safety coms means. It does not have to meet any of the safety requirements that are required for the safety links.
- Extensively deployed with almost global coverage excluding poles leveraging the large development and deployments performed for other demanding market segments (Gov and Defence, Enterprise) though not safety related.
- Quick adoption of such solutions with almost 100% of new Long-Range aircraft now equipped for cabin connectivity, most of them going for broadband solutions.
- GEO satellites technologies have proven extremely reliable and have a very strong track record in this respect as they are designed for at least 15 years lifetime.
- Performance is planned to significantly improve in a very short timeframe.

Weaknesses / Threats
- Do not provide truly global solutions as they do not cover the poles and performances are degrading when elevations are low.
- Not certified for safety (not RCP/RSP compliant)
- The performances vs. expectations are still quite poor for cabin experience because of use of wide beam solutions but HTS and VHTS solutions have proven to significantly improve and satisfy user experience.
- More weather sensitive than legacy safety bands (HF, VHF and L Band) especially Ka.
- The equipment size, weight, consumption, installation, and costs remain high as users expect more and more bandwidth.
- Retrofit of aircraft remains a complex and expensive process as it requires aircrafts to be grounded which means that operations are suspended for the whole retrofit duration.
- Every single solution is unique and not standard which is leading to a complex

ecosystem for the airlines.
- Generally, no guaranteed SLA.
- Future use of such a solution remains subject to the adoption rate.

- **Ku/Ka LEO/MEO**

Strengths / Opportunities
- Commercial Off The Shelf (COTS) cost effective solution vs. safety coms means. It does not have to meet any of the safety requirements that are required for the safety links.
- Not 100% in service with truly global coverage, but quick deployment is on-going backed by massive funding capabilities.
- Natively provide truly global coverage including poles.
- Can complement GEO solutions (Inmarsat HEO, OW and GEO SNOs).
- These solutions provide very low latency (typically below 40ms for LEO, below 150ms for MEO).
- Performance is planned to very significantly improve in a very short timeframe.
- New generation of equipment should reduce weight, drag and consumption.
- Opportunity to reduce retrofit complexity, cost, and time.

Weaknesses / Threats
- Generally, require Electronically Steered Array (ESA) technology because of switching constraints.
- Not certified for safety (not RCP/RSP compliant)
- Not standard solutions, leading to a complex and non-interoperable ecosystem.
- More weather sensitive than traditional safety bands (HF, VHF and L Band) especially Ka.
- No guaranteed SLA unless specific agreement.
- They will become available soon but have not been tested yet apart from early-stage tests. Maturity is to be confirmed.
- Retrofit will remain complex as it is for all other solutions.

- **(5G) Air-To-Ground**

Strengths / Opportunities
- Commercial Off The Shelf (COTS) cost effective solution vs. safety coms means. It does not have to meet any of the safety requirements that are required for the safety links.
- Very good alternative to SATCOM solutions or complement it especially in the vicinity of airports.
- Very low latency compared to any other SATCOM solution (typically below 10ms).
- 5G A2G initiatives now on all continents.
- Performances are planned to very significantly improve in a very short timeframe.
- Slicing technology may become in the long term an alternative solution for safety coms.
- Terminals may be very low cost, low weight, low drag, and low consumption if passive antenna technology is confirmed as a viable solution.

Weaknesses / Threats

- Continental coverage only. – Regional solutions only.
- Purely commercial and not certified for safety (not RCP/RSP compliant).
- Poorly deployed for the time being.
- Deployment requires upfront large ground infrastructure deployment.
- Not standardised yet and this will come later in future 3GPP releases, which means that there are only proprietary and non-interoperable solutions for now.
- May require expensive active antenna technology not to interfere with terrestrial mobile network operators' infrastructures.
  No guaranteed SLA unless specific agreement.

- **Wi-Fi Gatelink & 3G/4G/5G Cellular Gatelink**

Strengths / Opportunities

- Commercial Off The Shelf (COTS) cost effective solution vs. safety coms means. It does not have to meet any of the safety requirements that are required for the safety links.
- 3G/4G/5G and 6G beyond 5G is moving towards higher throughput. The trend defined by the 3GPP is definitely to go to extremely high throughputs and aero will take benefit of it.
- In the future, we can expect full and harmonised coverage in all airports, making this type of solution available everywhere.
- The number of equipped aircraft may quickly increase (via AIDS).

Weaknesses / Threats

- Wi-Fi deployment has barely developed and is limited to major Airports (Major Airlines hubs).
- Wi-Fi technology may become obsolete compared to 5G and 6G in the future which is leveraging every single part of the spectrum which is still available.
- Purely commercial and is not certified for safety (not RCP/RSP compliant).
- Even if it is cheaper than safety links, this can generate significant costs for the Airlines (service, maintenance…) and pricing regulations are driven by local governments. This can lead to very high-cost discrepancies depending on every individual country's pricing regulations.
- Not all aircraft have been equipped with this technology by far and this may slow down large-scale adoption.
- Obsolescence and "quick technology phase out" following the pace of 3GPP evolutions for terrestrial mobile environments which is much faster than the aero industry. One of the consequences is that legacy technologies (such as 3G) may be phased out to be replaced by the latest standards to enhance use of the spectrum leading to obsolescence and service discontinuity.

Annexe C – Summary of recommended solutions

UC #	Use Case (UC) short description	Long Term target (2035)			
		Applications / Services	**Network / Protocols**	**Links Preferred Option**	**Links Alternative Option**
ATM #1	Basic DL in ENR-2	B2	IPS	AIRBORNE: SATCOM Performance Class B + Hyperconnected ATM using non-safety links as an **option** GROUND: capable of Hyperconnected ATM and SATCOM Performance Class B	AIRBORNE: SATCOM Performance Class B GROUND: capable of SATCOM Performance Class B
ATM #2	Basic DL in ENR-1/TMA	B2	IPS	AIRBORNE: VDL2 + at least one of: 1. Hyperconnected ATM using non-safety links 2. SATCOM Performance Class B GROUND: capable of Hyperconnected ATM, SATCOM Performance Class B and VDL2	AIRBORNE: SATCOM Performance Class B + LDACS GROUND: capable of LDACS, SATCOM Performance Class B and VDL2
ATM #3	Complex DL in ENR-2	B2	IPS	AIRBORNE: SATCOM Performance Class B + Hyperconnected ATM using non-safety links as an option GROUND: capable of Hyperconnected ATM and SATCOM Performance Class B	AIRBORNE: SATCOM Performance Class B GROUND: capable of SATCOM Performance Class B
ATM #4	Complex DL in ENR-1/TMA	B2	IPS	AIRBORNE: VDL2 + at least one of: 1. Hyperconnected ATM using non-safety links 2. SATCOM Performance Class B GROUND: capable of Hyperconnected ATM, SATCOM Performance Class B and VDL2	AIRBORNE: SATCOM Performance Class B + LDACS GROUND: capable of LDACS, SATCOM Performance Class B and VDL2
ATM #5	DL in APT	B2	IPS	AIRBORNE: VDL2 + at least one of: 1. Hyperconnected ATM using non-safety links 2. SATCOM Performance Class B GROUND: capable of Hyperconnected ATM, SATCOM Performance Class B and VDL2	AIRBORNE: SATCOM Performance Class B + LDACS GROUND: capable of LDACS, SATCOM Performance Class B and VDL2
ATM #6	Trial Plan Coordination - OCC	Custom // Standardized if standard available	IP	Non-safety link	N/A
ATM #7	Trial Plan Coordination - ANSP	Custom // Standardized if standard available	IP	Non-safety link	N/A
AUT #1	RPAS1 - Remote pilot to permanently control the RPAS (ICAO RPAS IFR operations)	Proprietary	IP IPS	Safety link = C-band (SATCOM and/or ground-based)	Commercial link (FSS)
AUT #2	UAS - Remote pilot to control the highly automated UAS (emergency)	Proprietary	IP IPS	Safety link = C-band (SATCOM and/or ground-based)	Commercial link (FSS)

UC #	Use Case (UC) short description	Long Term target (2035)			
		Applications / Services	Network / Protocols	Links Preferred Option	Links Alternative Option
AUT #3	Manned aircraft - Ground assistant to assist the highly autonomous piloted aircraft/crew	Proprietary	IPS	AIRBORNE: * Continental: VDL2 + at least one of: 1. Hyperconnected ATM using non-safety links 2. SATCOM Performance Class B * Oceanic: SATCOM Performance Class B + Hyperconnected ATM using non-safety links as an **option** GROUND: * Continental: capable of Hyperconnected ATM, SATCOM Performance Class B and VDL2 * Oceanic: capable of Hyperconnected ATM and SATCOM Performance Class B	AIRBORNE: * Continental: SATCOM Performance Class B + LDACS * Oceanic: SATCOM Performance Class B GROUND: * Continental: capable of LDACS, SATCOM Performance Class B and VDL2 * Oceanic: capable of SATCOM Performance Class B
AUT #4	RPAS & Manned aircraft - Remote pilot to communicate with ATC / datalink	B2	IPS	AIRBORNE: * Continental: VDL2 + at least one of: 1. Hyperconnected ATM using non-safety links 2. SATCOM Performance Class B * Oceanic: SATCOM Performance Class B + Hyperconnected ATM using non-safety links as an option GROUND: * Continental: capable of Hyperconnected ATM, SATCOM Performance Class B and VDL2 * Oceanic: capable of Hyperconnected ATM and SATCOM Performance Class B	Ground-ground link
AO #1	High-capacity, reliable, high latency, pre-departure and post-arrival	Custom // Standardized if standard available	IP	Non-safety link	N/A
AO #2	Medium-capacity, ultra reliable, medium latency	Custom // Standardized if standard available	IP	Non-safety link	N/A
AO #3	Non-priority	Custom // Standardized if standard available	IP	Non-safety link	N/A
AIS #1	Situational awareness data for pilot decision	Custom // Standardized if standard available	IP	Non-safety link	N/A

UC #	Use Case (UC) short description	Long Term target (2035)			
		Applications / Services	Network / Protocols	Links Preferred Option	Links Alternative Option
AIS #2	Urgent situational awareness data for pilot decision	Standard apps (to be defined)	IPS	AIRBORNE: * Continental: VDL2 + at least one of: 1. Hyperconnected ATM using non-safety links 2. SATCOM Performance Class B * Oceanic: SATCOM Performance Class B + Hyperconnected ATM using non-safety links as an option GROUND: * Continental: capable of Hyperconnected ATM, SATCOM Performance Class B and VDL2 * Oceanic: capable of Hyperconnected ATM and SATCOM Performance Class B	AIRBORNE: * Continental: SATCOM Performance Class B + LDACS * Oceanic: SATCOM Performance Class B GROUND: * Continental: capable of LDACS, SATCOM Performance Class B and VDL2 * Oceanic: capable of SATCOM Performance Class B
AIS #3	Enhanced situational awareness	Custom // Standardized if standard available	IP	Non-safety link	N/A
AIS #4	Aircraft as sensor	Custom // Standardized if standard available	IP	Non-safety link	N/A

Annexe D – Transition roadmap

Objective #	Long-term objective *Note : dates have to be understood as the last day of the year mentioned.*	Actors Aircraft manufacturers and suppliers		Operators		Datalink service provider(s) EU		Datalink service provider(s) US		Actors ANSPs EU		ANSP US		ICAO & Standardisation organisations	Actors EU Regulator	US Regulator
		Actions	**Drivers**	**Actions**	**Drivers**	**Actions**	**Drivers**	**Actions**	**Drivers**	**Actions**	**Drivers**	**Actions**	**Drivers**	**Actions**	**Actions**	**Actions**
# 1	Move towards Full B2 (ATM communications, applications level)	1. All line-fit aircraft to be B2-capable in **2027**. *Note: at least B2a.* 2. B2b retrofit option available for B2a-capable aircraft in 2032.	1. European Mandate. 2. Aligned with strategic sustainability objectives (TBO operations enabled).	Voluntary retrofit of existing aircraft to Full B2 capability.	1. Fleet homogeneity. 2. B2 allows more efficient and sustainable operations with TBO.	None.	None.	None.	None.	1. Ensure B2 (ADS-C EPP) capability of ground systems in **2027**. 2. Ensure B1 backward compatibility. 3. Ensure Full B2b capability (except D-RNP and A-IM, refer to item #2) of ground systems in **2032**.	1. CP1 Mandate 2. New mandate for full B2 3. More efficient and sustainable ATC operations.	1. Provide B2 equivalent messages for existing FANS-based automation application messages and timed to match IPS gateway support by the communication service providers. 2. Add additional B2 application and associated messages to automation in 2033, providing the initial FANS as well as the beyond FANS B2 applications and messages are supported.	1. Support B2 IPS only avionics decisions for purchasers by providing access to the current FANS-based applications and messages; allow choice with opportunity for the future growth of B2 beyond FANS-based applications. 2. Solution that is a software automation enhancement, does not change the controller interface, and will require no additional controller training.	Freeze the B2 standard.	Develop the "Full B2 mandate" complementing the CP1 package.	None.
# 2	Enable advanced B2 services (D-RNP and A-IM) for operations in the US airspace	All line-fit aircraft to be B2b (with D-RNP and A-IM)-capable option by **2035**.	1. European support of B2b package compatible with both EU and US operations. 2. Aligned with strategic sustainability objectives (TBO operations enabled). 3. FAA commitment to D-RNP and A-IM services.	Equip and train for advanced capabilities.	1. Increases flight efficiency. 2. Improves capacity utilization.	N/A for EU ATM roadmap	N/A for EU ATM roadmap	None.	None.	N/A for EU ATM roadmap	N/A for EU ATM roadmap	1. Ensure advanced B2 capabilities of ground systems from ***2035***. 2. Demonstrate benefits for D-RNP and A-IM.	More efficient and sustainable ATC operations.	None.	N/A for EU roadmap	Develop and issue policy for tailored procedures for advanced B2 services (with D-RNP and A-IM).
# 3	Ensure sufficient Safety link(s) availability, performance and capacity	1. From **2027**: * All B2-capable aircraft to be equipped line-fit with VDL2 and 1.a. Performance Class B SATCOM OR 1.b. AOC traffic is moved over non-safety link (cabin SATCOM / A2G). 2. From **2032**: refer to #7, superseding point 1 above. 3. When Performance Class B SATCOM is installed, prioritize the use of Performance Class B SATCOM over VDL 2, at least for ATM traffic.	1. Aligned with strategic sustainability objectives (TBO operations enabled). 2. Enabler for hyperconnected ATM. 3. Efficiency of spectrum usage.	1. Voluntary retrofit of existing aircraft with SATCOM Performance Class B. 2. Voluntary move of AOC traffic over non-safety links. 3. When Performance Class B SATCOM is installed, prioritize the use of Performance Class B SATCOM over VDL 2, at least for ATM traffic.	1. Enables AOC/EFB in-flight connectivity: more enabled services. 2. Lower communication cost	1. Ensure transparent integration of SATCOM Performance Class B within the Datalink infrastructure. 2. Deploy VDL2 improvements. 3. Optimize capacity of the safety links.	1. Improved business case. 2. Spectrum efficiency.	1. Ensure transparent integration of SATCOM Performance Class B within the Datalink infrastructure. 2. Deploy VDL2 improvements. 3. Optimize capacity of the safety links.	1. Improved business case. 2. Spectrum efficiency.	1. Ensure transparent integration of SATCOM Performance Class B within the Datalink infrastructure. 2. Support new capability within information routing. 2. Support the VDL2 improvements deployment.	1. More efficient and sustainable ATC operations (enabler of EPP mandate). 2. Spectrum efficiency usage.	1. Ensure transparent integration of SATCOM Performance Class B within the Datalink infrastructure. 2. Support new capability within information routing. 2. Support the VDL2 improvements deployment.	1. More efficient and sustainable ATC operations (enabler of EPP mandate). 2. Spectrum efficiency usage.	1. Finalize the VDL2 improvements in the relevant standards. 2. AEEC architecture standards development.	Create a centralised EU datalink infrastructure and service provider.	None.
# 4	Establish a fully interoperable secure connectivity framework	Support zero-trust architectures	Cyber security	Support zero-trust architectures	Cyber security	Support zero-trust architectures	Cyber security	Support zero-trust architectures	Cyber security	Implement GRAIN - network gateways.	Availability of IPS	Implement GRAIN - network gateways.	Availability of IPS	1. ICAO - Complete IPS standard. 2. ICAO - Complete IATF framework.	States agree to IATF framework, strategy and implementation.	States agree to IATF framework, strategy and implementation.

Objective #	Long-term objective *Note: dates have to be understood as the last day of the year mentioned.*	*Actors*						*Actors*						*Actors*		
		Aircraft manufacturers and suppliers		Operators		Datalink service provider(s) EU		Datalink service provider(s) US		ANSPs EU		ANSP US		ICAO & Standardisation organisations	EU Regulator	US Regulator
		Actions	Drivers	Actions	Drivers	Actions	Drivers	Actions	Drivers	Actions	Drivers	Actions	Drivers	Actions	Actions	Actions
# 5	Move towards IPS (ATM communications, network level)	1. All line-fit aircraft to be IPS-capable in 2032. 2. Develop IPS retrofit options (as feasible).	1. Potential policy level drivers from EU regulator. 2. State of the art technology : - IP network - enables end to end security - enables optimised multilink	Voluntary retrofit of existing aircraft for IPS capability.	1. Retrofit opportunities, combination with other new functionalities (e.g. full B2 or hyperconnected ATM). 2. Security (including operational recommendations) requirements aspect valuable to operators	Provide dual stack support: 1. Maintain compatibility of ground network backbone with ATN-OSI. 2. Ensure compatibility of ground network backbone with IPS by the date of 1^{st} EIS of IPS aircraft (gateway solutions).	1. State of the art technology. 2. Cooperative strategy. 3. Ensure end-to-end security of communications.	Provide triple stack support: 1. Maintain compatibility of ground network backbone with FANS/ACARS 2. Ensure compatibility of ground network backbone with IPS and with ATN-OSI by 2028. 3. Provide as a value-added service.	1. State of the art technology. 2. Cooperative strategy. 3. Ensure end-to-end security of communications.	Ensure full transition of ground systems to IPS by 2032.	1. State of the art technology. 2. Mandate or equivalent driving measures.	Purchase IPS services from DataComm network and Air-ground communication providers by date of 1^{st} EIS of IPS aircraft.	1. US purchase data communication as a service and the network is already IP. 2. Collins and SITA are expected to include IPS links as part of the service offering.	Complete the IPS standard (ongoing).	Develop adequate measures required for deployment of IPS.	Develop the IPS policy.
# 6	Offload the Safety links from Airline Operations communications that do not require protected spectrum and promote enough non-safety connectivity for Airline Operations communications (maximum Airline Operations traffic via non-safety link(s) for new aircraft).	1. Equip all line-fit aircraft with non-safety link for AOC air and ground connectivity in **2032**. (e.g. "ACARS over IP" type of solutions). 2. Develop retrofit solutions for existing fleets enabling non-safety link for AOC air and ground connectivity.	1. Manufacturer proactive decision. 2. Customer requests. 3. Natively connected aircraft can generate additional revenues from manufacturer services. 4. Standardisation of aircraft configuration. 5. Aligned with manufacturer strategy to promote Trajectory Based Operations and ATM	1. Operator to adapt their OCC infrastructure and associated services. 2. When equipping existing fleets with non-safety connectivity, ensure compatibility with AOC connectivity needs.	1. Communication costs much lower with non-safety link solutions. 2. Higher bandwidth enables additional added-value applications.	Providers of ACARS networks to enable transition of AOC traffic to non-safety link	1. Already started. 2. Economic incentive to be confirmed. Business case to be consolidated.	Providers of ACARS networks to enable transition of AOC traffic to non-safety link	1. Already started. 2. Economic incentive to be confirmed. Business case to be consolidated.	None.	None.	None.	None.	1. Need to standardise ACARS over IP protocol (ARINC/SITA). 2. Ensure compatibility with existing ACARS services, as needed. 3. Update the definition of the services that can/should use aviation protected spectrum.	None.	None.
# 7	Enable the use of Non-safety Link as one possible link for ATM communications. *Note: under development in SESAR currently, "hyper-connected ATM"*	1. Validate and mature the concept, architectural impacts, certification impacts, RCP impacts, spectrum assumptions, etc. 2. From **2032**: all line-fit aircraft to be: 2.a. Hyper-connected ATM-capable using non-safety connectivity. **OR** 2. b. Equipped with SATCOM Performance Class B. 3. Develop retrofit solutions for existing fleets enabling hyperconnected ATM connectivity	1. Strategic Opportunity to significantly increase link capacity for ATM use cases, with limited air and ground investment, and with reduced communication costs. 2. Aligned with aviation strategy to promote Trajectory Based Operations and ATM optimisation.	When equipping existing fleets with non-safety connectivity, ensure hyper-connected ATM capability	1. Aligned with aviation strategy to promote Trajectory Based Operations and ATM optimisation. 2. Likely marginal or no additional communication costs. 3. Spectrum efficiency, bandwidth and availability.	Ensure non-safety communication networks can be connected to the ANSPs and meet the defined Performance Requirements, when complemented with a Safety link.	1. Best efforts: increase the resilience and efficiency of the overall system. 2. Economic incentive to be confirmed. Business case to be consolidated.	Ensure non-safety communication networks can be connected to the ANSPs and meet the defined Performance Requirements, when complemented with a Safety link.	1. Best efforts: increase the resilience and efficiency of the overall system. 2. Economic incentive to be confirmed. Business case to be consolidated.	1. Ensure seamless and transparent integration of multiple datalinks. 2. Support development of a single, globally accepted standard.	1. Redundancy. 2. Higher performance.	1. FAA to verify its cyber architecture supports this connectivity. 2. Ensure seamless and transparent integration of multiple datalinks. 3. Support development of a single, globally accepted standard.	1. Redundancy. 2. Higher performance.	Performance-based standards for hyper-connected ATM is needed for the performance and interoperability of the end to end network function.	1. Allow the use of non-safety links for ATM communications. 2. Auditing and monitoring functions and capabilities will need to be established.	1. Allow the use of non-safety links for ATM communications. 2. Auditing and monitoring functions and capabilities will need to be established.
# 8	Enable the use of C-Band for C2 link	Develop the C2 link aircraft system(s).	Best efforts: C2 link will be needed for IFR-operation of RPAS; C2 link always necessary for UAS operation (unless limited cases of full autonomous system with no capability of remote pilot interaction with the UA).	1. Assess which C2 link performance is required for the specific operation and know how to source that performance. 2. Establish service level agreement with suppliers of external C2 link service where necessary	Perform safe operations based on adequate C2 link resources/performances.	To offer C2 link communication services for RPAS operators.	1. Sell the C2 link service to operators abiding to contractual obligations regarding C2 link service performance. 2. Required for vehicle operation.	To offer C2 link communication services for RPAS operators.	1. Sell the C2 link service to operators abiding to contractual obligations regarding C2 link service performance. 2. Required for vehicle operation.	ANSP to contribute as needed and relevant (policy inputs, service offering,…) to the establishment of C2 links adequate to support RPAS integration in non-segregated airspace.	Ensure safe UAS integration in the airspace.	ANSP to contribute as needed and relevant (policy inputs, service offering,…) to the establishment of C2 links adequate to support RPAS integration in non-segregated airspace.	Ensure safe UAS integration in the airspace.	1. Determine minimum required C2 link performances for baseline operations. 2. Define standards to support harmonization / compatibility / interfacing of C2 link systems and equipment.	1. Endorse minimum required C2 link performances. 2. Endorse standards. 3. Establish certification elements for C2 link, harmonize frequency allocation in order to reduce global UAS footprint on spectrum resources, reduce the risk of interference and enable standardization.	1. Endorse minimum required C2 link performances. 2. Endorse standards. 3. Establish certification elements for C2 link, harmonize frequency allocation in order to reduce global UAS footprint on spectrum resources, reduce the risk of interference and enable standardization.

Annexe E – List of acronyms

- 3GPP: 3rd Generation Partnership Project
- A2G: Air to Ground
- AC: Advisory Circular
- ACARS: Aircraft Communications Addressing and Reporting System
- ACD: Aircraft Control Domain
- ADS-C: Automatic Dependent Surveillance - Contract
- AEEC: Airlines Electronic Engineering Committee
- AeroMACS: Aeronautical Mobile Airport Communication System
- AIDS: Aircraft Integrated Data System
- A-IM: Advanced Interval Management
- AIS: Aeronautical Information Service
- AISD: Airline Information Services Domain
- AMS(R)S: Aeronautical Mobile-Satellite (R) Service
- ANSP: Air Navigation Service Providers
- AO: Airline Operations
- AOC: Airline Operation Communications
- APT: Airport
- ARINC: Aeronautical Radio, Incorporate
- ATCO: Air Traffic Controller
- ATFM: Air Traffic Flow Management
- ATM: Air Traffic Management
- ATN: Aeronautical Telecommunication Network
- ATS: Air Traffic Service
- ATSC: Air Traffic Services Communication
- AU: Airspace User
- C2 link: 'Command & Control' link
- CA: Connected Aircraft
- CDM: Collaborative Decision Making
- CIA: Confidentiality, Integrity and Availability
- CM: Context Management
- CMU: Communication Management Unit
- COTS: Commercial Off The Shelf
- CPDLC: Controller Pilot Data Link Communication
- CS: Certification Specification
- CSP: Communication Service Provider
- DAL: Design Assurance Level
- DCIWG: Data Communications Infrastructure Working Group
- DCL: Departure Clearance
- D-FIS: datalink Flight Information Services
- DL: DataLink
- DLS: DataLink Service
- DLSP: DataLink Service Provider
- D-RNP: Dynamic Required Navigation Performance
- EASA: European Union Aviation Safety Agency
- EDS: Emergency Diversion Services

- EFB: Electronic Flight Bag
- ENR: En-Route
- EPP: Extended Projected Profile
- ESA: Electronically Steered Array
- EU: European Union
- EUROCAE: European Organisation for Civil Aviation Equipment
- FAA: Federal Aviation Administration
- FANS: Future Air Navigation System
- FDD: Frequency Division Duplex
- FF-ICE: Flight & Flow Information for a Collaborative Environment
- FSS: Fixed Satellite Service
- FTP: Trusted Framework Panel
- GANP: Global Air Navigation Plan
- GEO: Geostationary Earth Orbit
- HEO: Highly Elliptical Orbit
- HF: High Frequency
- IATF: International Aviation Trust Framework
- ICAO: International Civil Aviation Organization
- IFR: Instrument Flight Rules
- IP: Internet Protocol
- IPS: Internet Protocol Suite
- ITU: International Telecommunication Union
- LDACS: L-band Digital Aeronautical Communication System
- LEO: Low Earth Orbit
- MASPS: Minimum Aviation System Performance Standards
- MEO: Medium Earth Orbit
- MET: Meteorological
- MIAM: Media Independent Aircraft Messaging
- MOPS: Minimum Operational Performance Standards
- NOTAM: Notice to Air Mission
- OCC: Operations Control Centre
- OFDM: Orthogonal Frequency Division Multiplexing
- OSI: Open System Interconnection
- OW: One Web
- PKI: Public Key Infrastructure
- RCP: Required Communication Performance
- RDP: Required Demonstrated Performance
- RPAS: Remotely Piloted Aircraft Systems
- RSP: Required Surveillance Performance
- RTCA: Radio Technical Commission for Aeronautics
- SAL: Security Assurance Level
- SARPs: Standards and Recommended Practices
- SATCOM: Satellite Communication
- SESAR: Single European Sky ATM Research
- SNO: Satellite Network Operators
- SWIM: System-Wide Information Management
- SWOT: Strengths Weaknesses Opportunities Threats
- TBO: Trajectory-Based Operations

- TMA: Terminal Manoeuvring Area
- UAS: Unmanned Aerial System
- US: United States (of America)
- VDL / VDL2: VHF Data Link / VHF Data Link Mode 2
- VHF: Very High Frequency
- WG: Working Group

Annexe F – References

Item	Type	Title
1	ICAO Manual	Doc 10039, Manual on System Wide Information Management (SWIM) Concept
2	ICAO Manual	Doc 9869 - Performance-based Communication and Surveillance (PBCS) Manual
3	Standard	ED-228A – SAFETY AND PERFORMANCE REQUIREMENTS STANDARD FOR BASELINE 2 ATS DATA COMMUNICATIONS (BASELINE 2 SPR STANDARD)
4	Standard	ED-229A – INTEROPERABILITY REQUIREMENTS STANDARD FOR BASELINE 2 ATS DATA COMMUNICATIONS (BASELINE 2 INTEROP STANDARD)
5	Standard	ARINC 811 – COMMERCIAL AIRCRAFT INFORMATION SECURITY CONCEPTS OF OPERATION AND PROCESS FRAMEWORK
6	Strategy	EU and US AG DataComm Strategy
7	Strategy	SESAR Operational Concept Document 2020