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4.1: Connected aircraft concept and associated challenges

CONNECTED AIRCRAFT CONCEPT AND NEXT STEPS

(Presented by the Secretariat)

Connected Aircraft Concept

Draft Version 0.84b

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Revision History

Date	Revision
November 2018	Version 0.1 – Initial Draft for ATMRPP WG/35.
March 2019	Version 0.2 – Additions and adjudication of comments from the Initial Drafting Session Meeting. Incorporates changes based on outcomes of discussions, comments, and Working Papers to date.
April 2019	Additions, edits, and deletions per review of ATMRPP WG/35 and concept drafting members. Continued development. Incorporates changes based on outcomes of discussions, comments, and Working Papers to date.
July 2019	Version 0.3 – Initial Draft Version of the Connected Aircraft Concept Document. Incorporates changes based on outcomes of discussions, comments, and Working Papers to date.
November 2019	Version 0.4 – Updated Draft Version of the Connected Aircraft Concept Document. Incorporates changes based on outcomes of discussions, comments, and outcomes from the drafting session.
January 2020	Version 0.5 – Continued updates of the Draft Version of the Connected Aircraft Concept Document. Incorporates changes based on outcomes of discussions, comments, and outcomes from the drafting session.
March 2021	Version 0.6 – Updates based on initial adjudication of comments from CP-OPDLWG and updates from the drafting team. Alsosaf includes editorial cleanup formatting, grammar, and readability.
November 2021	Version 0.7 – Updated use cases and edits based on drafting session feedback.
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June 2023	Version 0.84a – Updated during ATMRPP/5
March 2024	Version 0.84b – Minor refinement by the Secretariat

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1 Introduction

1.1 Purpose

The Connected Aircraft (CA) concept outlines a framework for the use of performance-based links to accommodate the expected growth in demand for information exchange between the aircraft and relevant aviation stakeholders.

Concepts for future Air Traffic Management (ATM) solutions are emerging to improve operational efficiency of airlines and operators and accommodate the needs of the new entrant community. These traffic management concepts are heavily dependent on the collection, processing, and use of information, and require extensive information exchange between the flight deck and aviation system participants—more than is done today. Data communications systems and information management on the flight deck are key CA concept focus areas.

Using new and existing connectivity solutions, the CA concept enables digital interaction between stakeholders, on the basis of data exchanged with the aircraft. Capturing the value of information available from these digital exchanges enables the operational benefits envisioned through Collaborative Decision Making (CDM) and emerging ATM concepts.

This document describes the CA concept through a series of operational use cases, performance considerations, interoperability requirements, and current regulatory and standardization expectations. It is intended to illustrate the benefits to the ATM community by introducing CA functions supported by performance-based links and frameworks of development, implementation, and usage. It should not be considered implementation guidance.

It is assumed that readers of this document come from a variety of backgrounds related to airworthiness and equipment certification, service delivery, or operational authorizations. Additionally, some readers will be from outside the aviation industry.

1.2 Background

From the earliest global vision of the future operating environment, the Airspace User (AU), including the aircraft and its intent, has been viewed as an integral part of the ATM system. As described in the *Global ATM Operational Concept* (GATMOC; Doc 9854):

> "The future ATM system … will rely on explicit and unambiguous information and on wide information exchange within the system. Key information relates to the future position of aircraft, and to the meaning and status of that information.
>
> Information on planned future aircraft behavior can be obtained from the aircraft systems (avionics). It is associated with the commanded trajectory and will enhance airborne functions. The aircraft intent data correspond either to aircraft trajectory data that directly relate to the future aircraft trajectory as programmed inside the avionics, or the aircraft control parameters as managed by the automatic flight control system. These aircraft control parameters could either be entered by the flight crew or automatically derived by the flight management system."

This incorporation of the aircraft and use of the Four-Dimensional (4D) Trajectory (4DT) was further developed and included as requirements in the *Manual on Air Traffic Management System Requirements* (Doc 9882). Relevant requirements and explanatory text include the following.

> "Use 4-D trajectory control and/or flight deck delegation for aircraft spacing [R182];
>
> Utilize the 4-D trajectory for traffic synchronization applications to meet the ATM system performance targets, unless under certain conditions other means are determined to be more effective [R87];
>
> *Explanatory Text*: It is expected that the separation mode, including wake vortex separation minima will determine the minimum possible aircraft spacing. It is expected that flight parameters, as part of the 4-D trajectories management, will be available to the ATM system to dynamically allow for spacing and sequencing of arriving as well as departing aircraft. It is expected that as flight parameters are available on airborne systems, they will be used continuously and dynamically, both between aircraft and between aircraft and ground, to maximize utilization of the best information available. This will constitute/facilitate a safer and more efficient use of available airspace and will increase aerodrome throughput."

Building on these foundational concepts and requirements, additional International Civil Aviation Organization (ICAO) documents have articulated the use of the 4DT, continuous exchange of data, and reliance on global standards. The *Manual on System Wide Information Management (SWIM) Concept* (Doc 10039) and *Global Air Navigation Plan* (GANP; Doc 9750) describe a robust Air/Ground (A/G) exchange with the aircraft.

CA can support the Trajectory Based Operations (TBO) environment, where higher-fidelity data enables more complex requests, clearances, and negotiation composed of a sequence of requests and clearances. Data exchange technologies currently deployed represent an evolutionary change from past practices. While these technologies allow the digital exchange of content that was previously delivered via voice, the CA concept envisions more extensible data exchanges to include trajectory data via machine-to-machine communications.

CA provides an evolutionary solution to alleviate many of the current limitations of voice and data communications, supporting asynchronous communication and more complex information exchanges. The required performance and security of the CA components can be tailored to support the operations and applications of the operator and ATM expectations.

The operator may utilize the CA concept to introduce or enhance their existing data exchanges, which bring additional operational value, efficiency, and flexibility. Examples include:

- Enhanced weather information sent to the flight crew for improved situational awareness.
- Timely availability of arrival information provided to those who manage aerodrome gates and stands.

- More efficient communications between the flight crew, Operational Control Centre (OCC), and Airline Administrative Control (AAC), including manifests, release documentation, electronic logbooks, and other data exchange related to operations.
- Utilization of new tools on the flight deck supporting data and communication validation activities.
- Enables innovative re-routing capabilities, such as those made possible by FF-ICE.

As the global air transportation data exchange vision has matured, along with the performance-based framework (e.g., *Performance-Based Communications and Surveillance (PBCS) Manual* (Doc 9869), technological advances in commercially available communication have significantly increased the number of service offerings and future possibilities. These provide options for A/G exchanges, available bandwidth, and levels of performance from which to select. The CA concept describes a future in which this range of options will be available to meet the A/G information exchange needs of AUs and Air Traffic Services (ATS) providers. Figure 1 offers a high-level depiction of how the maturing, commercial services may be leveraged. This illustration builds on the "Air-Ground Information Exchange" described and depicted in Doc 10039. A more detailed illustration of the potential paths and networks is included in Appendix A (Figure 14).

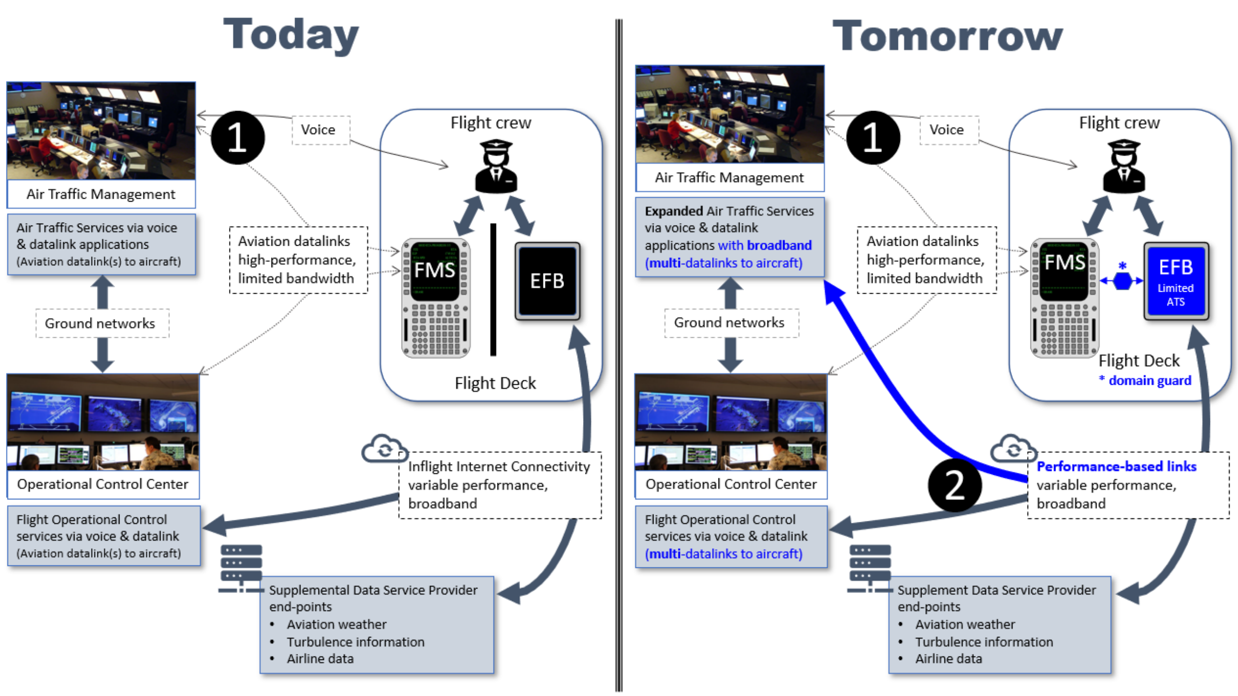


Figure 1. A/G Information Exchange Paths

To realize the future A/G information exchange paths depicted in Figure 1, a variety of opportunities and issues exist today, including the following.

1. Many commercial transport and business aircraft are equipped with inflight internet connectivity, which offers high-bandwidth and low-cost communications, however, ATM use cases still need to be realized.

2. Electronic Flight Bags (EFBs) have been largely isolated from aircraft systems, however, as their role in CA continues to increase, there is a need for some level of integration with aircraft systems such as flight management functions.

3. While today's aviation data links offer high performance, they traditionally have limited bandwidth and are not seen as sufficient to unlock the operational benefits of future applications for CDM.

The future offers the opportunity for communication and information exchanges to evolve in a variety of ways, such as the following.

1. Existing and new ATS and flight deck applications can be supported through the use of both existing aviation data links and higher bandwidth communications services (e.g. commercial) based on performance-based requirements (to be determined).

2. The addition of domain guard functionality, described in Section 4.2, represents a means to further advance applications while reducing flight crew workloads by providing a safe and secure connection between EFBs and aircraft systems, while ensuring the operationally approved/authorized functions of aircraft systems are protected.

3. Connecting all key stakeholders with performance-based links is a key enabler for TBO, which is required for higher efficiency airspace utilization.

4. At lower altitudes, to support the envisioned operational needs, new entrants will benefit from the introduction of rapidly maturing mobile wireless technologies.

5. Leveraging the new range of performance, bandwidth, and connectivity options on the flight deck, new ATS and non-ATS applications will take fuller advantage of existing technologies, providing the basis for introduction of innovative future technologies.

The new entrant community brings a new set of Communication, Navigation, and Surveillance (CNS) capabilities that result in unique performance characteristics. For example, the common framework developed by ICAO for Unmanned Aircraft Systems (UAS) provide an overview of the exchanges of information between operators, ATM services, and other stakeholders. These data communication flows are, in some cases, fundamentally different from traditional operators, using alternative, non-aviation dedicated communication networks to conduct operations. This concept enables an important principle in new entrant air traffic systems: access to airspace is granted based on performance, rather than the traditional equipage-based airspace management.

In support of the operational benefits of the connectivity infrastructure being deployed to meet broader demands, the focus of this document is on the potential availability and use of these performance-based links in concert with the traditional aviation-specific links.

2 Concept for Connected Aircraft (CA)

CA aims to connect AUs (e.g., flight crew and OCC), ATM Service Providers (ASPs), aerodromes, and other third-party information suppliers (e.g., weather services). In its simplest form, CA enables digital interactions between these stakeholders to support a wide range of applications meant to improve ATM system and AU performance. The focus is on information exchanges with the flight deck. These exchanges may be human-to-human, human-to-machine, or machine-to-machine. Full participation between stakeholders is key to unlocking the benefits of CA.

CA enables aviation to take advantage of new and existing connectivity solutions available regionally and globally. As permitted and standardized by international regulations, new data communications pathways may be used in concert with existing capabilities to provide the aviation community flexibility in meeting the full breadth of data communications needs to/from the aircraft. These pathways may be traditional in the sense that they rely on current network infrastructure, equipment, systems, and spectrum specifically to support aviation services or may be built to utilizing commercial rather than existing/dedicated aviation services, thus providing further resiliency of the full network. The data communication system, on-board systems such as the EFB, and Flight Management System (FMS) can form a smart network, dynamically routing data traffic via the most appropriate pathway available.

For example, the TBO concept is enabled through the exchange of data and trajectories via a data communications system connecting the flight crew, ATM, and OCC. This data communications capability allows for the exchange of information and provides a means of negotiation between the ATM and the flight deck. Through the EFB, the flight crew receives weather or constraint information and initiates trajectory negotiations with ATM. Similarly, the flight deck communicates with the OCC, receiving optimized flight plans and environmental information, resulting in an operational benefit.

There are aviation segments without dedicated OCCs during flight, such as general and business aviation, and new entrants. These operations can benefit as well. In these cases, the flight crew bears the full burden of operating the flight and addressing constraints as they are encountered. The connectivity to information sources and an efficient means to interact with ATM enable operational benefits as well.

CA uses a performance-based approach for defining requirements for data communications. The requirements suggested here describe a level of end-to-end performance needed to support the end-application, but not necessarily the means of compliance.

Establishing performance requirements is done in alignment with operational needs and existing regulatory constraints/expectations. Consideration is given to required performance during normal operation, as well as implications to the aircraft and airspace, should the communications system fail. Failures must consider single aircraft as well as widespread outages impacting multiple aircraft. Required performance and failure conditions need to be identified and requirements allocated to the communication systems.

Technical considerations span the full end-to-end system including A/G and Ground/Ground (G/G) network components. Performance requirements will vary based on solution topology, but most will include:

- Data exchange transaction time (one-way or round-trip)
- System availability and continuity
- Data integrity and identity authentication
- Spectrum usage
- System monitoring and alerting

Interoperability with existing airborne and ground systems will drive additional requirements. Mixed aircraft equipage, individual airline choices selected from available performance-based links, and variable deployment across airspace/state boundaries drive the need to include the necessary requirements to achieve interoperability.

Because it brings more information to the flight deck, the CA concept assumes novel solutions to ensure the flight crew will not be overloaded with information and can effectively manage and make best use of the additional information. For this reason, existing equipment like EFBs will need to evolve to support further flight deck integration.

2.1 Overarching Principles

The CA concept enables stakeholders to use both aviation-specific and commercial mechanisms in concert to meet their A/G information exchange needs.

The key performance attributes relevant for CA can be tailored to the individual application needs (e.g., confidentiality, integrity, availability, continuity, and transaction time). This considers and recognizes the performance requirements for information exchanges will vary across applications. *Note:* Solutions implemented to meet the required levels of performance may include architectural or other constructs to ensure applications with varying needs do not impact one another.

Figure 2 illustrates the notion that required performance is determined by the use of the information (i.e., the application), not the content itself. This concept also recognizes CA as a component of the ATM system and the role it plays supporting SWIM. Performance is paramount and dictates whether a specific pathway is compatible with the needs of the operation.

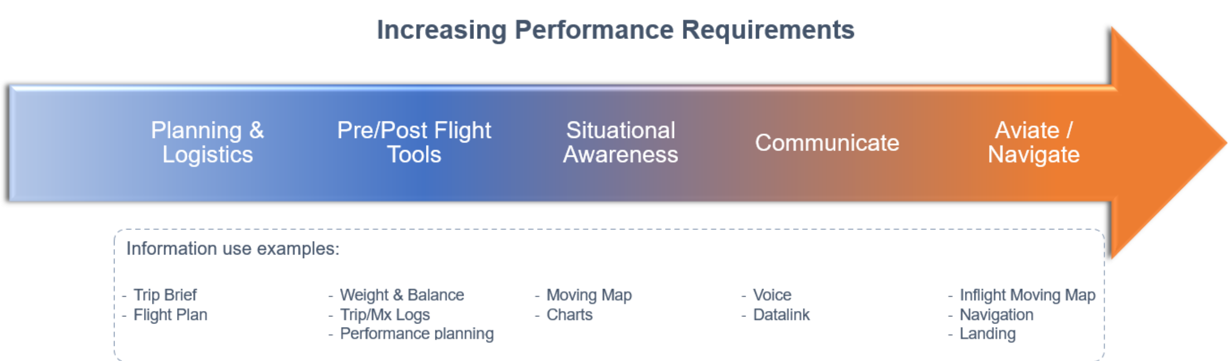


Figure 2. Information System Performance Requirements

2.2 Major Changes

Prior to CA, the collaborative environment mainly focused on the ground-based ASPs and OCCs. This concept enhances collaboration with the flight crew and improves the service efficiency of ASPs to AUs.

The ATC system of today is heavily reliant on voice communications. In some areas, radio voice frequencies have become extremely congested. Across the landscape, the more pronounced effect is that information is captured into small tactical stovepipes. Today, Controller-Pilot Data Link Communications (CPDLC) enables ATCOs and pilots to communicate via data link. With CA, an expanded machine-to-machine exchange environment incorporating commercial pathways that meet required performance will support increased communication capabilities for trajectory revisions in a more cost-effective manner and in more areas. The CA concept envisions that messages can be loaded into the FMS, similar to what CPDLC does today, while respecting necessary requirements for data integrity and segregation, thereby reducing crew workload and eliminating transcription errors.

The addition of commercial pathways provides a supplemental solution to support real-time capabilities and updates to the ATCO. Information regarding the current state—such as aircraft position, future intent, guidance modes and settings, and performance limits—will be able to be sent to both ATM and the OCC.

An aircraft with communications capabilities (both aviation and non-aviation specific subnetworks) will have implications on both airborne and ground-based systems, namely, the establishment and maintenance of multiple active links. This will require new management techniques to ensure safe and effective operations.

3 CA Use Case Scenarios

Technology advances specifically related to Internet Protocol (IP)-based communications and mobile computing are enabling significant advances within society. These same technologies have been adapted for aviation and are now commonly found in many commercial, business, and general aviation cockpits. As communication systems continue to evolve, these new technologies offer the next continuum for aviation communications. Historically, data communication with an aircraft commonly relied on a single link (physical) active at any one time. The introduction and proliferation of aircraft IP-based links means multiple communication links (physical) are now available. In the future, new communications technologies are expected to emerge, including multiple interfaces managed by the end-users. These additional communication links represent an extension to the data link continuum and offer new capabilities for aviation while migrating from a single to multiple links.

With new technology introductions, interoperability within aviation is often a major consideration as ATCO, pilot, and aircraft operator workloads and compatibility often represent significant challenges. The CA is no different, as managing multiple links or threads with the aircraft requires a blended solution, seamless to ATM and AUs. The scenarios presented in this section are intended to illustrate new capabilities enabled by the CA, while maintaining interoperability with existing communication mechanisms.

Scenarios presented in this section are divided into two groups:

1. **Manned Aircraft** – Existing AUs, including commercial, business, and general aircraft.

2. **New Entrants** – New AUs, such as Advanced Air Mobility (AAM) aircraft, UAS, supersonic aircraft, or other manned/unmanned High-Altitude Platform Systems (HAPS).

3.1 Manned Aircraft Scenarios

3.1.1 Background

Use cases presented within this section leverage multiple communication links between ATM and AUs. These communication links are categorized as:

1. **Aviation Specific Link –** Utilizes spectrum specifically designated for aviation and may support safety related functions often based upon Very High Frequency (VHF), High Frequency (HF), or satellite spectrum. These links may support data link applications such as CPDLC.

2. **Performance-Based Link** – May use spectrum designed for aviation, but this is not a requirement. In certain situations, they may support safety related functions. These links are frequently satellite-based, commercial use case driven, and commonly used for operationally authorized/approved uses such as EFBs. They may also be shared with other stakeholders including the passenger information and entertainment systems domain.

The scenarios presented herein are intended to illustrate how both links can be leveraged during flight by manned aircraft (such as an airliner). In addition, new entrants such as UAS can take advantage of performance-based IP links, particularly for unique applications such as machine-to-machine communications.

3.1.2 CA Use Cases – Ideas/Possibilities

Table 1 outlines the CA use cases for manned aircraft scenarios, categories, and high-level rationale.

Table 1. CA Use Cases, Categories, and Rationale

CA Use Case	Category	High-Level Rationale
Trajectory renegotiation/mixed mode operations, intent sharing	Negotiation	Re-routes with ATM, supports mixed mode operations, improves ATC situational awareness and system trajectory predictions
CA data sharing and crowdsourcing *Note:* “Crowdsourcing” in this context involves obtaining data from multiple aircraft to synthesize a better picture of the environment.	Data sharing	Improves forecasting, more accurate data to and from a variety of aviation systems

CA Use Case	Category	High-Level Rationale
CA strategic weather display on EFB	Situational awareness	Increases situational awareness, strategic decision support, including early re-routing negotiation
CA digital NOTAMs	Situational awareness	Increases situational awareness, intuitive graphical user interface
Turbulence awareness and avoidance	Situational awareness, flight safety enhancement	Relevant and current turbulence forecasting and reporting to reduce inflight injuries and unscheduled aircraft maintenance
Communication collaboration platform with operational stakeholders, including flight attendants	Collaboration	Additional communication mechanism offering improve airline communications and collaboration

3.1.3 Trajectory Renegotiation with Single ASP

Trajectory changes are commonplace within most airspace today, particularly around flight hazards such as convective weather and turbulence. This is commonly accomplished through a flight crew request followed by issuance of a revised ATC clearance to the flight crew using voice communications. However, due to the inherent challenges with communications, they are often inefficient and cumbersome. As shown in Figure 3, CA offers opportunity to streamline such primary communications while using performance-based links for multi-party information sharing, including flight intent information sharing, and exchanges beyond a binary request/clearance decision (e.g., go/no-go decisions without feedback).

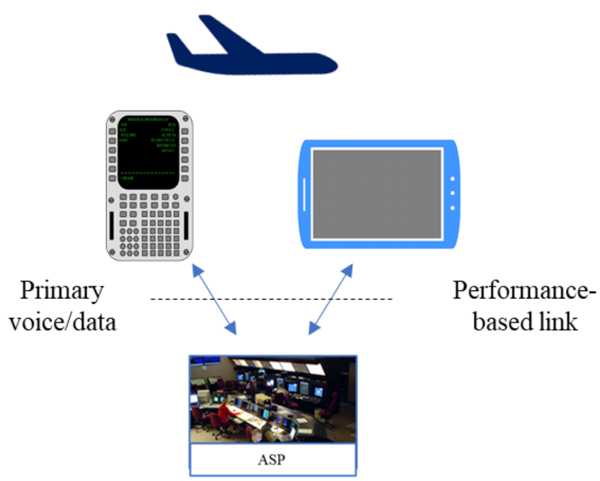


Figure 3. Trajectory Negotiation with Single ASP

Within this use case, AUs utilize connected EFBs to engage in negotiation exchanges with ASP. Details about the trajectory change can be determined using the performance-based link, with the transaction of record taking place over primary voice/data links. Furthermore, CA applications are expected to allow the aircraft to share trajectory information, which may at times be used in coordination with trajectory renegotiations. Subsequent flight intent data distribution on the ground-based users, including ATC and ASP systems, for conformance monitoring and enhanced trajectory information is made possible.

3.1.4 Trajectory Renegotiation with Multiple ASP Facilities (Long-Term with OCC Participation)

When either the AU or ASP needs to change the Agreed Trajectory, the negotiation process involves assessing options based on all constraints shared by all participants. If the aircraft is transitioning through multiple ASPs, coordination and collaboration can be accomplished among the ASPs in developing the new trajectory.

In the example case, ASP-2 informs the AU that a constraint has affected the Agreed Trajectory. The AU may propose a new trajectory via a Trial Plan to all the ATMs, which can all respond with information on constraints. Through such a process, the AU comes to a new trajectory, which can be optimal end-to-end, in lieu of piecewise. Such a trajectory is proposed as a Revision Request. ASP-1 responds with acceptance to revise the Agreed Trajectory. ATC issues the clearance prior to the point of divergence from the original Agreed Trajectory.

As illustrated in Figure 4, through the CA, both dispatch and flight crew maintain situational awareness of applicable constraints on the entire flight and proposed trial trajectories. These can be presented through graphical interfaces on an EFB with greater affordance. For flights without OCC support, the CA allows the flight crew to participate in such negotiations, with supporting software on the EFB to help replan the flight and communicate with the ASPs.

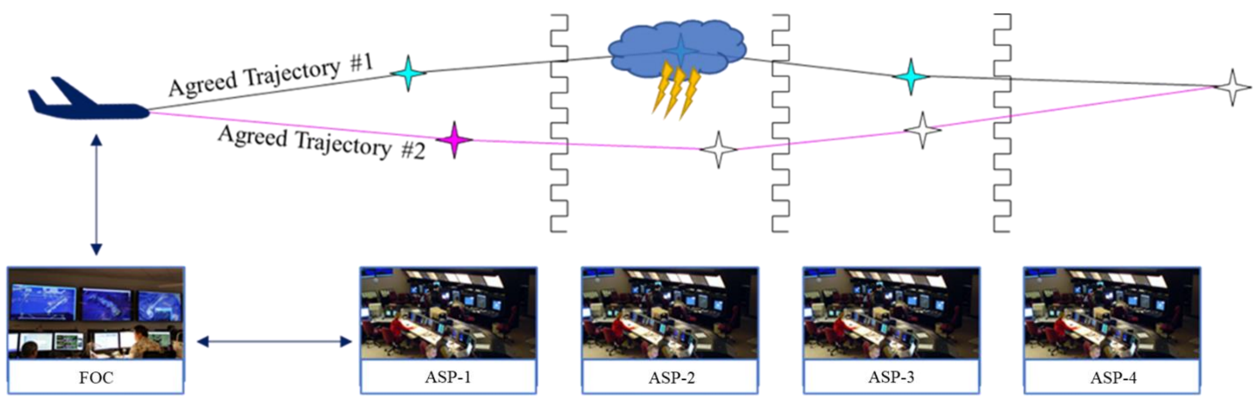


Figure 4. Trajectory Negotiation with Multiple ASPs

3.1.5 CA Data Sharing and Crowdsourcing

The CA offers unprecedented levels of aircraft sensor data sharing opportunities. IP links offer dramatic data cost reductions enabling a variety of use cases, including the ability to send frequent reports or snapshots from the aircraft which contain aircraft sensor data (e.g., actual wind/temperature data measured at current altitude). Today, similar reports are called Aircraft Meteorological Data and Relay (AMDAR)[1] and sent using aviation specific links data links, however, CA economics[2] may enable far more frequent and comprehensive reports at a fraction of the cost.

[1] AMDAR is a component system of the World Meteorological Organization (WMO) Integrated Global Observing System, contributing aircraft-based observations to the World Weather Watch Programme.
[2] Cost per unit data for performance-based links, particularly those based upon commercial systems, can be on the order of 1,000 times less expensive compared to aviation specific links.

Once aircraft data reports are available on the ground, the airline's OCCs can choose to use this data for internal purposes or, in some cases, share some or all of this data with third-party crowdsourcing solutions, as shown in Figure 5. Crowdsourcing of this data type, in particular aircraft sensor derived turbulence reports, is very useful for industry.

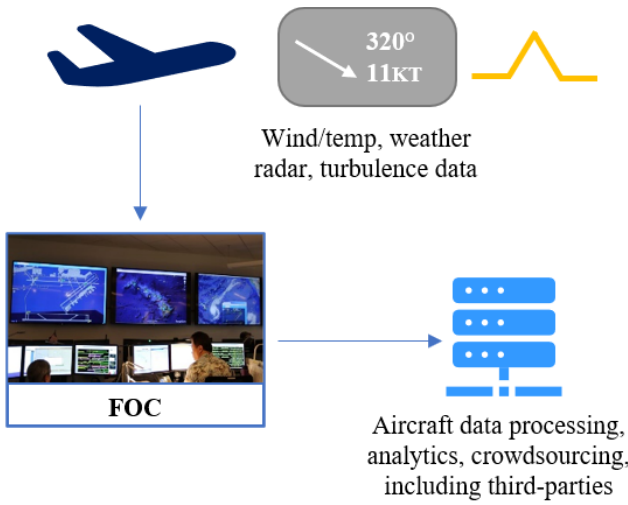


Figure 5. CA Data Sharing and Crowdsourcing

A compelling use case for CA data sharing relates to weather radar data and imagery. In many regions of the world, radar reflectivity data is not available due to remote and oceanic geographies where ground-based radars/sensors do not exist. This presents challenges for AUs particularly when operating within convective weather, such as in the Intertropical Convergence Zone (ITCZ). This can be challenging for flight crews due to ongoing thunderstorm development and dissipation. Via onboard weather radar data collection and communication to ground sources, a mesh network view of radar reflectivity can be stitched together into a complete composite weather view and subsequently shared back to AUs and displayed on connected EFBs. Such developing technology is referred to by industry as the "Connected Radar" and shown in Figure 6.

Figure 6. Composite Weather View Enabled by Connected Radar

3.1.6 CA Strategic Weather Display, Digital NOTAMs, and ATIS on EFB

CA enables the use of tools such as connected EFBs with advanced applications to offer graphical representations of weather data and applicable flight information, such as NOTAMs or Automatic Terminal Information Service (ATIS) messages, which can be used in an intuitive format for strategic purposes. The ability to access strategic weather data, NOTAMs, and ATIS on EFBs during flight enables numerous benefits for flight crews, including greater situational awareness, significantly improved human-machine interface, and ease of access to larger amounts of data, as illustrated in Figure 7. Connected EFBs provide crews a much broader weather perspective versus current onboard weather sources, including those over data link. Transmission of NOTAMs and ATIS information mitigates misinterpretations and transcription errors over voice and facilitates cockpit decision making during operations.

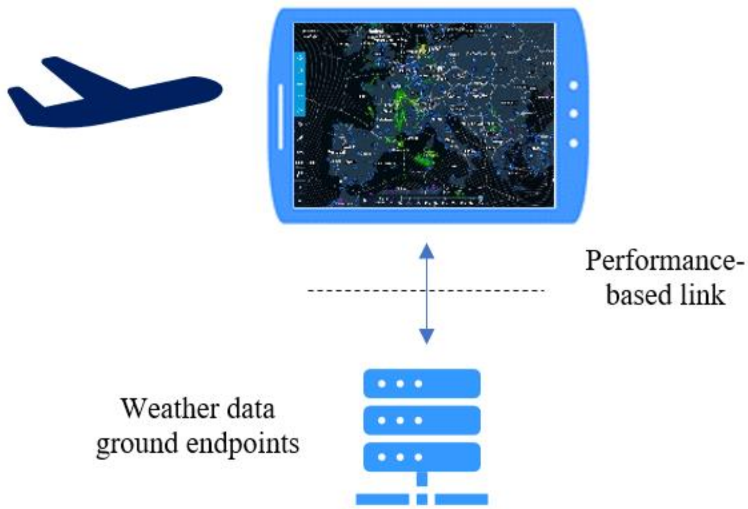


Figure 7. Strategic Weather Display on EFB

3.1.7 Flight Crew and OCC and AAC Communications

Communications related to the business of operating an airline are described as AAC communications. Modern links can be used to more effectively connect flight crews and FOCs during operations. Performance-based links may leverage EFBs with improved user interfaces and capabilities benefiting flight crews, provide lower cost alternatives relative to aviation links, and offer significantly larger data exchange capabilities.

CA enables airlines and operators to improve existing processes through effective information exchanges, which may include flight plans, manifests, release documentation, electronic logbooks, cabin discrepancy logs, and a variety of other data exchange related to activities. The use of modern data formats including the ability to attach media (e.g., photos and videos), shown in Figure 8, offers richer data exchanges between aircraft and ground users.

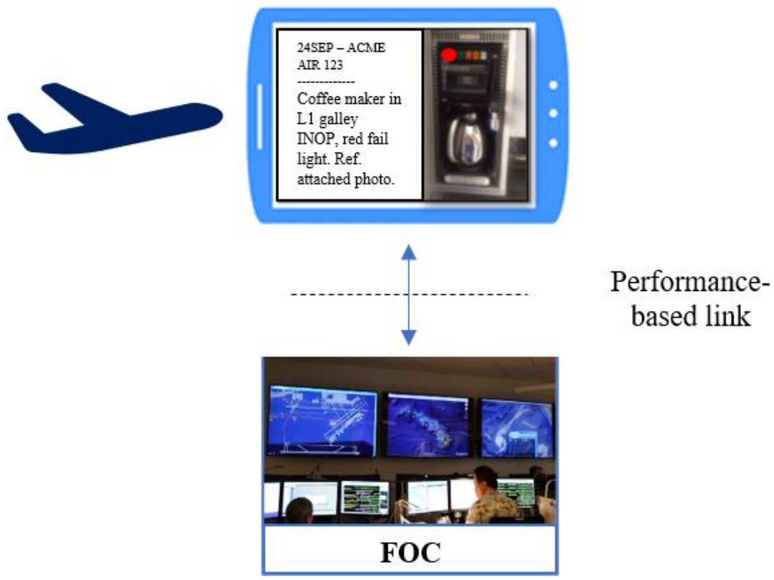


Figure 8. Communication Platform for Aircraft and Ground Users

3.2 New Entrant Scenarios

The Concepts of Operations across the different new entrant ATM systems provide an overview of the exchanges of information between operators, ATM services, and stakeholders. These data communication flows are, in some cases, fundamentally different from traditional operators, using alternative, non-aviation links to support operations. The CA concept enables an important principle in new entrant air traffic systems in that access to airspace is granted based on meeting certain performance requirements unlike the traditional equipage-based airspace management. As the ATM landscape evolves towards a performance-based environment, some of the data communications principles of the new entrant community may be leveraged.

3.2.1 UAS Vehicle Location Streaming

UAS operations may rely on a Remote Pilot in Command (RPIC) who is responsible for the safe conduct of the flight and monitors the location of the vehicle. UAS operators share their flight intent and location among each other and coordinate and deconflict trajectories. The primary communication and coordination channels between UAS operators and stakeholders are not via voice, but through a distributed digital information network that enables shared situational awareness. These exchanges of information occur primarily over commercial networks.

Unmanned vehicles are envisioned to maintain separation using a combination of airborne technology (position sharing, vehicle-to-vehicle equipment, airborne surveillance data, etc.) and assistance from UAS third-party service suppliers that can provide additional tracking and monitoring services and disseminate information on the position of other aircraft. Operators flying Beyond Visual Line of Sight (BVLOS) are required to share the spatial and temporal elements of the operation with service suppliers and other AUs. These operational intents consist of 4D volumes of airspace specifying the flight intent, as well as entry and exit times for these volumes. UAS operators are responsible for maintaining the flight within the boundaries of the operational intent, as well as meeting the requirements for each operation and the associated airspace volume. This requires transmission of location and vehicle state information on a more or less real-time basis. The communications data link may be based on any communication system meeting the appropriate requirements including terrestrial and satellite-based systems.

These transmissions are envisioned to be sent to all relevant stakeholders either directly or made available by a third-party service supplier. Performance and interoperability requirements of the communication system to carry this information are based on the characteristics of the operation and potential failure conditions for individual vehicles, as well as widespread outages impacting multiple vehicles.

3.2.2 UAS Local Weather Crowdsourced Data

The exchanges of information between UAS, operators, service providers, and other third-party suppliers also include weather, terrain, and obstacle data information. UAS operators track weather events throughout the flight and adjust operations accordingly in the event aircraft performance is inadequate for flight in current weather conditions.

Given the sensitivity of operations on weather and the difficulty in predicting micro-weather in an urban environment, crowdsourced weather data for UAS applications is seen as a valuable application. Atmospheric events that are not an issue for large commercial aircraft become a hazard for these smaller vehicles. Events such as turbulence or wind bursts can highly affect these operations and are hardly predicted through forecast models.

In this application, weather data sensed by each participating vehicle is sent to a third party who uses the data to create a consolidated view of weather information, which is then made available to all AUs. This information can be used to enhance operations and operational safety.

Performance requirements for crowdsourced data applications may need to consider the higher throughputs required for data intensive applications and disparity in communications performance of the different data links and communications systems. BVLOS data links using satellite or HAPS are expected to offer modest data rates and different latency and range conditions compared to terrestrial A/G links. Cellular networks are emerging as a potential alternative to provide wireless connectivity. Advanced mobile wireless systems bring large bandwidths, possibly meeting the performance requirements for mapping applications. The use of these alternative communication systems will be based on the ability to meet performance requirements, illustrating the principles of the CA concept.

4 Additional Considerations

4.1 The Role of EFBs

EFBs play a notable role in the CA concept, providing a potential interface for the AU to take advantage of additional efficiency, flexibility, and cost effectiveness in the delivery and display of certain kinds of information, supplementing and enhancing the information provided by the FMS. The EFB represents a control and validation point for numerous functions, such as trajectory negotiations, surface operations, or aeronautical charting. EFB applications work in concert to the FMS to negotiate and execute new trajectories. Therefore, the interaction between EFB and FMS becomes a critical element in the CA concept. This interaction requires an interface protection device to ensure a secure data connection, referred to in this document as a domain guard. Domain guard functionality is typically incorporated into Aircraft Interface Device (AID) hardware. In contrast with FMS communications, which occur through aviation dedicated data links, portable EFB devices can be connected via other means (e.g., commercial satellite technologies). The management of multiple links with the aircraft requires a blended solution that is seamless to ATM automation and the flight crews. The concept of multiple link communications is also a critical element to the CA concept.

Today, hosted EFB software applications are limited to those functions whose failure effect are considered a minor hazard or have no safety effect and described in further detail below and within the *Manual on Electronic Flight Bags (EFBs)* (Doc 10020). *Note:* This use of the term “minor” is not to be confused with the “minor” associated with installed aircraft components and for which risk mitigation is satisfied by meeting DO-178/254 Level D objectives. Because “minor” in the EFB context is a minimal effect of workload alone, this risk mitigated operationally and is the responsibility of each operator (versus the responsibility of the manufacturer).

EFB hardware has two different classifications of EFB hardware, summarized as follows.

1. **Portable** – Portable components supporting EFB applications are considered Portable Electronic Devices (PEDs). For a PED to be considered an EFB, the PED must actively display Type A and/or B software application(s). For example, when a PED is displaying personal email, the PED is not considered an EFB; when the same PED is approved for use as an element of an operationally approved EFB program, and actively displaying a Type B aeronautical chart application, it is then considered an EFB. Portable EFBs must be capable of being easily removed from or attached to their mounts by flight crew member personnel without tools or maintenance action; can be temporarily connected to an existing aircraft power port for battery recharging; and may connect to aircraft power, data ports (wired or wireless), or installed antenna, however, those installed provisions must be considered under a type design approval (e.g., Type Certificate (TC), Supplemental Type Certificate (STC)) (see below). Due to the portable and Commercial off-the-Shelf (COTS) nature of portable EFBs, implications to information security should be considered.

2. **Installed** – Installed equipment or EFB components that are approved under aircraft type design (e.g., TC, STC). Installed EFB hardware may host EFB applications categorized as Type A or B and may also be capable of hosting applications which are subject to type design approval. *Note:* EFB applications/functions/data are not subject to installation approval and therefore have no requirement for Continued Airworthiness Instructions (CAIs) and are not required to be reflected or managed per Minimum Equipment List (MEL) requirements.

Along with the two classifications of portable and installed EFB hardware, there are two EFB hosted application categories.

1. **No Effect** – These applications have a failure condition classification considered to be no safety effect. They also do not require specific authorization for use.

2. **Minor Effect** – These applications have a failure condition classification considered minor. They may substitute or replace paper products of information required for dispatch or to be carried in the aircraft; they require specific operational authorization or approval for use.

In the CA context, it is important to note that both types of applications are considered operationally authorized/approved. These applications have no certification requirements for installation under aircraft type design. Additional analysis regarding Connected Aircraft application's impact on crew workload and data saturation, is recommended as the concept matures towards implementation.

4.2 Aircraft Domain Guards

EFBs and associated applications play a key enablement role in CA as these items represent the primary user interface for AUs and, more specifically, flight crews. However, to realize portions of the CA concept set forth within this document, an additional aircraft domain guard function is required to complement and enable EFB functions as proposed in this document. Relevant to CA, aircraft domain guards include at least the following two functions.

1. Protection mechanism(s) between the Aircraft Control Domain (ACD) and Airline Information Services Domain (AISD). EFBs are considered to be part of the AISD as operational authorized/approved devices. A domain guard firewall or partition function protects installed systems and functions from EFB hardware/software failures, ensuring safe aircraft operations.

2. Aircraft data gateway enables the exchange of aircraft avionics data in other protocols and services consistent with COTS technologies.

These functions are further described within ARINC Specification 834-8, *Aircraft Data Interface Function (ADIF),* and ARINC Characteristic 759, *AID.*

ADIF can be implemented in a number of ways, including as a hosted function on generic onboard domain guard hardware (e.g., onboard servers) or on dedicated hardware (e.g., AIDs).

In the context of CA, domain guard functionality can be used to safely bridge between certified avionics equipment and portable, operationally approved EFBs. This functionality becomes increasingly important as EFBs are expected to not only receive data from the aircraft, but also safely transmit data into the aircraft, such as the FMS. In these roles, domain guard functions hosting ADIF not only fulfill the functional requirements but fulfill critical regulatory requirements as well. Since associated hardware and software are considered to be installed equipment, aircraft domain components and associated design assurance levels commensurate with intended function are addressed through aircraft type design processes (e.g., TC, STC). The ability for portable EFBs to transmit data into the aircraft, including for ATS, can be addressed through certification processes related to domain guard commensurate with the intended function, enabling this needed communication link from portable EFBs into systems such as FMS. Figure 9 illustrates the aircraft domain guard function.

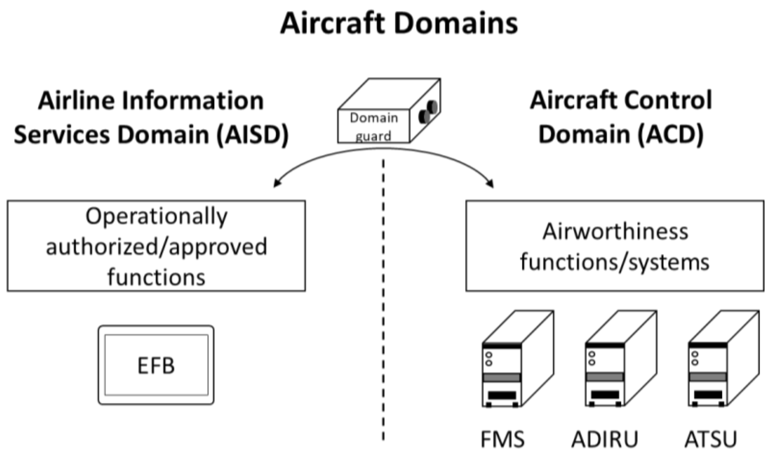


Figure 9. Aircraft Domain Guard

Domain guard capabilities can unlock additional CA functions beyond enabling new digital data links. Access to aircraft data can be provided from flight-critical systems such as FMS, Air Data Inertial Reference Unit (ADIRU), and others. Aircraft data can then be introduced into new applications on the aircraft or ground. An example of the functionality achieved by accessing aircraft data and its role in CA is provided in Section 3.1.5.

It is important to note that using commercial links for data exchange creates the need for a comprehensive data integrity and cybersecurity solution, as proposed for Internet Protocol Suite (IPS), a high priority. A message directly uploaded in the FMS via a commercial IP-based link is a significant challenge today for these cybersecurity reasons, in addition to the performance aspects.

5 Technical Considerations

5.1 Overview

It is assumed that readers of this document come from a variety of backgrounds related to airworthiness and equipment certification, service delivery, or operational authorizations. Additionally, some readers will be from outside the aviation industry. This section serves to accommodate these varied perspectives.

A "performance-based communications system" contains the elements described as necessary to move data between stakeholders that meets a set of performance requirements consistent with the needs of the supported applications. Broadly, the requirements can be measures of end-to-end system performance, such as transaction time, or more foundational, such as a requirement for cybersecurity or use of specific spectrum.

Figure 10 depicts the boundaries for the scope of this document. This is a notional diagram used to illustrate various system domains under consideration. It is meant to show example subnetworks to depict the breadth of future systems; it is not meant to limit future choices.

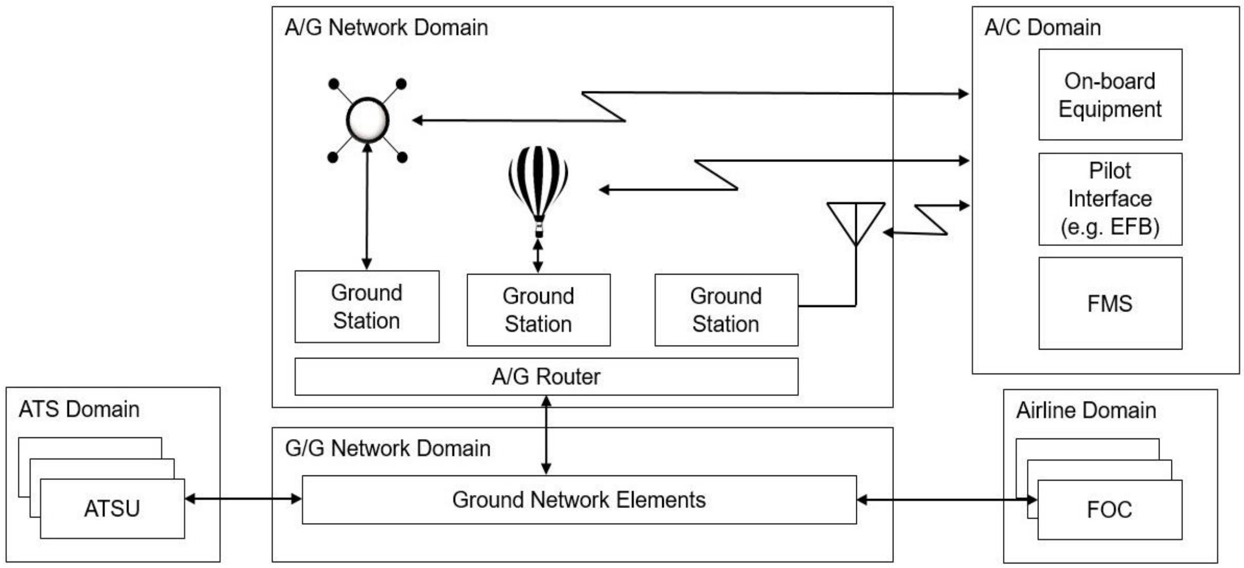


Figure 10. Key Systems Domains

Note: The aircraft domain includes equipment and applications approved in both an "airworthiness" and "operational" context.

Airworthy functions/systems are those accounted for directly in aircraft TC documentation, or indirectly under a separate authorization reference (e.g., Technical Standard Order (TSO), TSO Authorization (TSOA), European TSO (ETSO)) reference within that TC documentation.

Operational functions/systems are those systems not having an airworthy nature (i.e., are not "aircraft functions") and are credentialed by virtue of operational authorization activities.

Figure 11 shows a highly simplified diagram of a data communications system. The three primary users of this system are the ATS Unit (ATSU), airline operations, and aircraft flight crew (or flight deck automation).

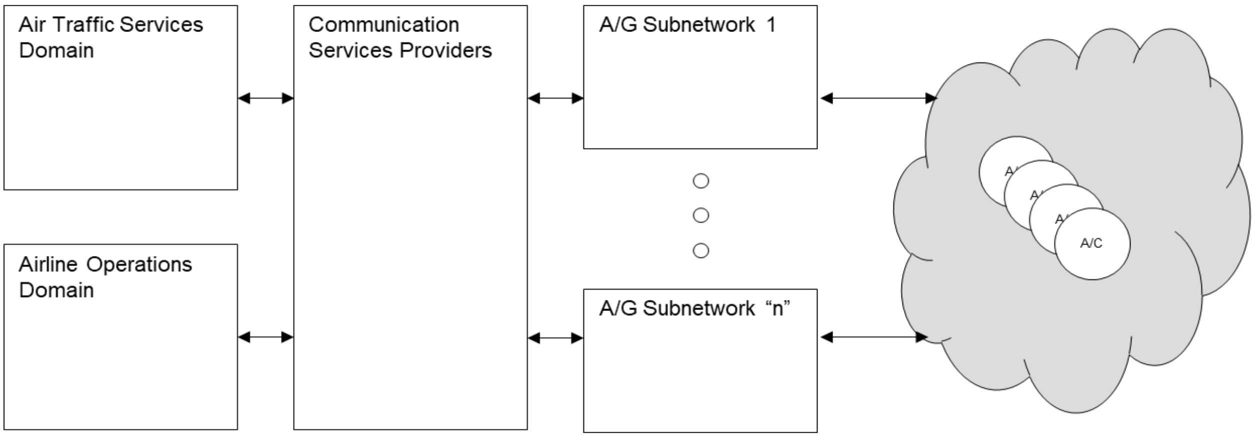


Figure 11. Simplified Diagram of a Data Communications System

Communications occur via a set of available subnetworks. The use of any given subnetwork for any specific function can vary between Flight Information Regions (FIRs). For example, a space-based subnetwork can have global coverage, but not all functions (e.g., CPDLC, Automatic Dependent Surveillance – Contract (ADS-C)) are available in all FIRs.

Routing between users occurs via Communication Service Providers (CSPs). These organizations keep track of the aircraft, what networks they are connected to, and the routing paths between aircraft and organizations on the ground.

The performance of any communications systems will have to meet all relevant performance requirements for the intended function.

The performance requirements of any communications path are defined in the context of intended use (function) and the operational environment. A common example is the performance required for CPDLC. A communications path is allocated performance requirements aligned with the performance objective for this service. Methods to represent failures or degraded performance are required to indicate the performance is no longer suitable for use and switching to alternate subnetworks is required. Key performance characteristics applied to CPDLC are described in Table 2.

Table 2. Key Performance Characteristics for Air-ground Communications

Performance Characteristic	Description
Availability	Probability that an operational communication transaction can be initiated or that the surveillance data can be provided
Continuity	Probability, once communications have started, that a transmission will complete successfully
Transaction Time (Latency)	Total time budgeted for round-trip communications including human response or for one-way report delivery
Integrity	Probability of an undetected failure in the end-to-end system, including data transmission

Additional characteristics to be considered in the context of the intended function include cybersecurity, resiliency, spectrum usage, and human factors (operational considerations). Monitoring and alerting is required to ensure all stakeholders know the communication system is operating at the required performance levels.

5.2 System-Level Performance

A key element of any system performance discussion is the concept of an end-to-end performance requirement. The Required Communications Performance (RCP) is used here as an example construct due to its relevance to datalink applications. Required Surveillance Performance (RSP) is a similar construct covering the delivery of surveillance information.

These concepts can be applied more broadly to include new applications, operational concepts, and network topologies, as well as incorporating an expanded list of required performance parameters. Some future use cases may not fit these constructs. One-way exchange of information or streaming services are two examples where the performance requirements definition construct would vary and need to be developed to match the unique aspects of the service.

The *PBCS Manual* (Doc 9869) defines RCP as:

> "A set of requirements for air traffic services provision and associated ground equipment, aircraft capability, and operations needed to support performance-based communication."

The RCP specification covers the performance parameters for each particular RCP value (e.g., RCP-240, RCP-400, etc.). The RCP contains parameters that represent the maximum communication transaction time after which the initiator should be alerted by the system that a reply is overdue. The total time is allocated among all participants in the end-to-end communications path, as illustrated in Figure 12.

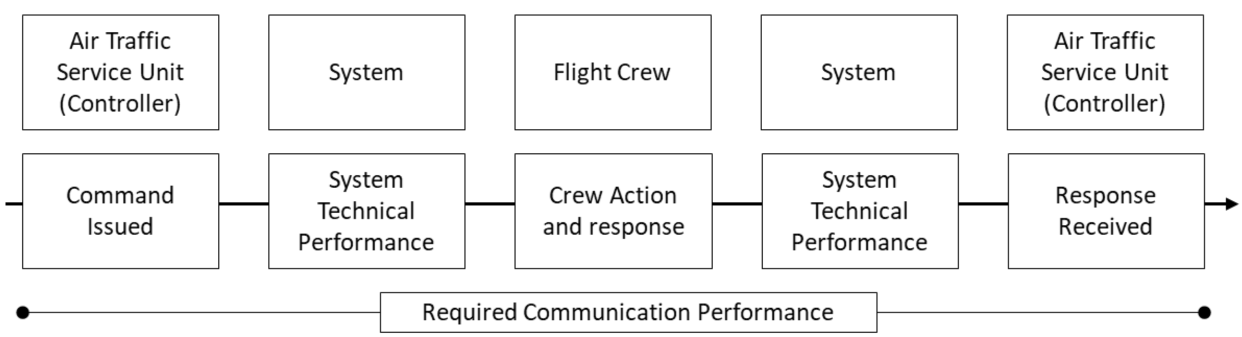


Figure 12. Required Communication Performance

As shown in Figure 13, a breakdown of the System Technical Performance block illustrates the non-human elements that make up the time allocation.

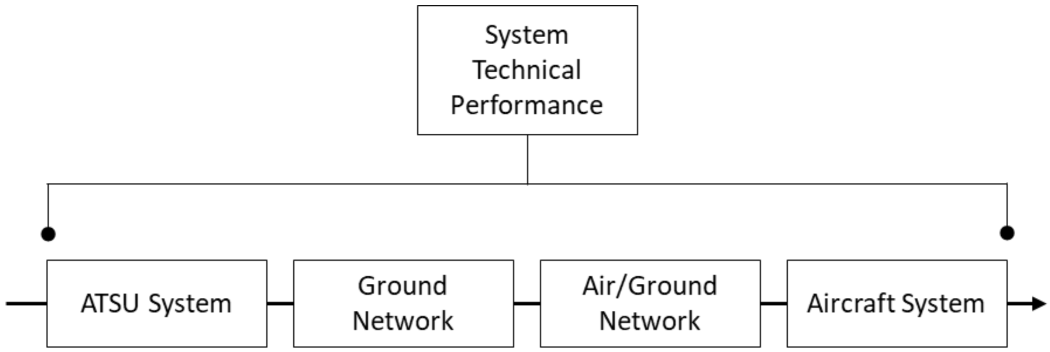


Figure 13. System Technical Performance

According to the *PBCS Manual* (Doc 9869), the Required Communication Technical Performance (RCTP) is defined as:

> "An RCP allocation that specifies the maximum technical time for relevant parts of the unit's system, aeronautical station's system, the network systems, and the aircraft system, for which there is no human contribution to the communication transaction performance."

Appendix B of the *PBCS Manual* (Doc 9869) contains the detailed specifications for approved RCP values, namely availability, continuity, integrity, and transaction time allocations. Table 3 summarizes the required performance categories for RCP 240 and 400.

Table 3. CPDLC Communication Performance Specifications

RCP Specification	Transaction Time (seconds)	Continuity	Availability	Integrity
RCP 240	240	0.999	0.999	Malfunction = 10^{-5} per flight hour
RCP 400	400	0.999	0.999	Malfunction = 10^{-5} per flight hour

Any new subnetwork that supports ATM operations predicated on an RCP specification would need to be analyzed and have RCTP allocations assigned within the overall desired RCP specification. Additionally, new functions using data communications require an assessment of the required communications performance and have allocations set based on both technical and human response aspects.

While communication networks are generally sensitive to all of these performance parameters, networks designed for non-aviation purposes may have a primary focus on other parameters. Reliability, maintainability, availability, integrity, confidentiality, transit time, capacity, continuity, and cost are important measures of communications system performance. In general, the balance of these factors may vary in accordance with the needs of the application.

By definition, a system defined by performance-based requirements does not have a comprehensive set of prescriptive design and approval criteria. A high degree of dependence is placed on monitoring system performance and providing an alerting function to stakeholders. The time to detect and alert for a system failure or degraded performance must be accounted for in overall performance requirements. *Note:* Some prescriptive requirements may be required such as those necessary to ensure interoperability.

Current International Telecommunications Union (ITU) regulations require the use of protected spectrum for ATS and other messages, and well defined technical requirements exist. Services covered by these regulations are delineated in *Procedures for Air Navigation Services* (PANS-ATM; Doc 4444). These messages are generally related to movement and control, metrology, and regularity of flight applications. New applications using data communications capabilities in both the existing aviation and new entrant communities will require an assessment of spectrum usage consistent with these regulations when setting overall system performance requirements.

5.2.1 Fine-Tuning Performance Requirements

The CA concept allows for flexibility in implementation so that assets which are required to be high performing are not overused (i.e., communications subnetwork capability). The basic premise is that higher performance comes with higher cost, and possibly limited capacity (bandwidth, data rates, etc.). Business rules specific to an airline may also be applied to balance cost and performance needs. Technology in onboard equipment is envisioned in the future that would support this concept, thereby making it possible to fine-tune the usage of available subnetworks from a cost and performance standpoint.

5.3 System Safety

Functions proposed for implementation must have a functional hazard assessment performed to identify potential failure cases and the associated risks. This is important to ensure the resulting system design supports the full range of functions in the most efficient manner.

Additionally, revalidation of function-level safety case(s) will allow higher fidelity of new system-level evaluations ("new" being the inclusion of SWIM), where it may be desired to blend safety and non-safety-critical systems in order to realize full system vision/value.

Approached this way, modern technologies and engineering methods should allow solutions that ensure all end-use functional and non-functional requirements are satisfied, regardless of the safety criticality level of a function. This allows individual elements to carry their own safety identities across the blended system.

The results of the functional hazard assessment will inform minimum performance requirements and architectural designs necessary to ensure function level requirements are satisfied.

Table 4 shows an operational safety assessment matrix for illustrative purposes to help the reader understand the relationship between hazard classifications and the impacts on various stakeholders.

Table 4. Operational Safety Assessment Classification Matrix

Hazard Class	1 (Most Severe)	2	3	4	5 (Least Severe)
Effect on Operations	Normally with hull loss; total loss of flight control, mid-air collision, flight into terrain or high-speed surface movement collision	Large reduction in safety margins or aircraft functional capabilities	Significant reduction in safety margins or aircraft functional capabilities	Slight reduction in safety margins or aircraft functional capabilities	No effect on operational capabilities or safety
Effect on Occupants	Multiple fatalities	Serious or fatal injury to a small number of passengers or cabin crew	Physical distress possibly including injuries	Physical discomfort	Inconvenience
Effect on Air Crew	Fatalities or incapacitation	Physical distress or excessive workload impairs ability to perform tasks	Physical discomfort, possibly including injuries or significant increase in workload	Slight increase in workload	No effect on flight crew
Effect on Air Traffic Service	Total loss of separation	Large reduction in separation or a total loss of ATC for a significant period of time	Significant reduction in separation or significant reduction in ATC capability	Slight reduction in separation or slight reduction in ATC capability; significant increase in ATCO workload	Slight increase in ATCO workload

The design of aviation procedures and systems must mitigate the risks of identified hazards that can reasonably be expected to occur. For illustrative purposes, some background is provided related to the *PBCS Manual* (Doc 9869). The *PBCS Manual* and other referenced standards define a technology-independent set of hazards that must be mitigated for networks to be used for ATC clearance delivery to an aircraft operator operating under Instrument Flight Rules (IFR). The identified hazards include unexpected loss of data link service, unexpected interruption of message delivery, receipt of a message intended for another party, and corruption of a message.

The rationale for these hazard categories derives from the fact that ATM is often a real-time endeavor. Incorrect delivery of a message, however, not only results in delay to the intended recipient, but raises the possibility that another recipient could execute a clearance out of context and with potentially dangerous results.

To illustrate, consider the perspective of the stakeholder for a delayed message. For an aircraft operator, a delay in an operational message (e.g., final weight and balance) may simply be a nuisance, delaying departure slightly. For ATC, a delayed clearance message delivered after that ATCO has intervened (delivered other instructions via voice) may cause confusion and raise workload for both the ATCO and the flight crew.

Credible corruption of a message's content could have a similar result in that it could lead an aircraft operator to make an unexpected, inappropriate, and potentially dangerous maneuver.

A similar approach may be taken by the new entrant community for the cases where they are already envisioned to depend heavily on non-aviation specific systems for information exchange needs. Since there is little direct regulatory control over the communication architecture and underlying systems, failures in communications can be expected, and thus, they would be allocated the appropriate probability in the fault tree and appropriate mitigations would be incorporated to reduce the risk to acceptable. The hazards created with a loss or degraded performance of a communication system require mitigation through industry-agreed procedures or the use of alternative means.

A similar approach to the analysis of hazards and hazard effects should be undertaken with any new system or a new application of existing systems.

5.4 Cybersecurity

As aviation continues its digitalization journey, cyber threats increase. Stakeholders generally agree that secured data communication paths are needed through a layered approach considering all participants in the system (defense in depth). The challenge is in defining cybersecurity measures that cover end-to-end communications (i.e., aircraft, subnetworks, service providers, airlines, ASPs) while maintaining acceptable level of A/G communication performance.

The goal of cybersecurity controls and processes in this context is to reduce the risk of unauthorized interactions with the system to an acceptable level, and support the response to, and recovery from such interactions while maintaining acceptable levels of safety and performance. Enhanced digital connectivity creates new cyber threat vectors (i.e., failure modes) for connected systems, which would be a new input to safety assessments during standard making processes.

The assessment must consider the aircraft's full data supply chain to include the ground network elements relevant to the end system that is being protected (e.g., FMS or ATSU automation).

Significant use of COTS technology is expected to speed the deployment of new capabilities. Protection of high assurance applications on a COTS device will be required unless mitigated elsewhere in the architecture.

As this concept moves forward, focus should be on global solutions that are sufficiently flexible to address current and future threats cyber threats and risks, while avoiding point solutions that may be less optimal in terms of cost and effectiveness, and may create cascading problems in other areas. Along these lines, ICAO is working towards the development of ICAO policies, provisions and guidance material to facilitate interoperable digital trust, as well as the development of holistic regulatory and organizational processes to integrate cyber threat and risk assessment and management into aviation processes, including safety, security and air navigation efficiency and capacity. States should these activities along with those from other relevant regulatory and standards-making entities.

5.5 Data Integrity

Data integrity requirements are based on safety assessment of the effects of undetected data failures in the context of the intended use. The assessment results will identify the failure effects of hazards and can be used to support an analysis of the impact on the crew.

For example, an altitude crossing restriction is sent to an aircraft, but it is corrupted along the way, resulting in an altitude error. The crew has no means to cross-check the altitude restriction, so they will fly to it as received. This creates a situation of reduced vertical separation with aircraft crossing the same waypoint. Intervention by an ATCO would be required, resulting in a significant increase in workload for both the ATCO and aircrew, reducing safety margins.

In order to protect against these types of faults, error detection and correction techniques must be employed end-to-end at the application layer with sufficient robustness to meet the integrity requirement.

If the data is encapsulated by a trusted source (e.g., ATM automation system) using a suitable error detection method and unpacked at a trusted end system (e.g., FMS), the intervening system integrity requirements are lessened. For example, data may pass through a system element with lower integrity (e.g., EFB, cabin Wi-Fi router, subnetwork routers) on its way to the FMS. This applies only to the data integrity requirement. Requirements for availability, continuity, and transition time/latency must still be met.

5.6 Human Interface

With the exception of future machine-to-machine applications, some amount of human interaction is required. Therefore, the integrity of the device(s) used by the crew will need to be considered in the context of potential failures and expected crew response.

Table 5 ties hazard classes from the Operational Safety Assessment Matrix (Table 4) to those used in airworthiness approval context.

Table 5. Hazard Classifications

Hazard Class	**1**	**2**	**3**	**4**	**5**
ARP 4761 Safety Assessment Process	Catastrophic	Hazardous	Major	Minor	No effect
Aircraft-level impact	Loss of hull	Significant damage	Increased crew workload	Minor impact to workload	No impact
Risk mitigation	Design Assurance Level (DAL) A	DAL B	DAL C	DAL D or via operational mitigation as appropriate to function. No DAL.	Not required
Integrity requirement (error rate/flight hour)	$<10E^{-09}$	$<10E^{-07}$	$<10E^{-05}$	$<10E^{-03}$ (if operationally	N/A

Hazard Class	1	2	3	4	5
				mitigated, failure is assumed and that mitigation must be predefined)	

Some examples for reducing major safety effects include the following.

- **Introduction of Preventive Means into the Application Itself** – Application design is set up to integrate some specific software mechanisms to reduce some major risks to an acceptable level.

- **Definition of Mitigation Mechanisms** – Application operations expect some specific actions to cross-check features whose safety effect is major so that it can be reduced to minor.

Today, there are two methods to approve onboard equipment to ensure safety of operations: (1) as part of the aircraft TC (or STC), or (2) through an operational authorization. Depending on the intended function and resulting risk assessment, one or both can be used. Details for both methods are provided below.

1. **Airworthy System** – System elements serving important aircraft functions as defined in ARP 4761 and ARP 4754. Risks are significantly mitigated by conformance to published performance specifications (e.g., TSO/ETSO), and development-assurance objectives identified for that aircraft function (via performance system safety assessment). These elements also require continued airworthiness instructions (e.g., repair, overhaul, return to service testing). The artifacts from these processes become part of the aircraft type design.

2. **Operationally Approved System** – System elements generally providing important operational functions. Risk is mitigated by conformance to published performance specifications (e.g., Advisory Circular (AC) 120-76) and to evaluation expectations published in Federal Aviation Administration (FAA) Order 8900.1. Risk is further mitigated by a requirement for comprehensive backup identified and available prior to granting of program approval/authorization. This is now formally referred to as "Operational Authorization" in the United States and as "Ops Approval" in other parts of the world. Continued airworthiness instructions are not required due to the presence of the required backup.

5.7 G/G Performance

The data communications landscape has been profoundly influenced with the internet and the capability it provides. However, there are still significant system design considerations to be made when planning a network with the necessary robustness to conduct operations.

As a basis for any critical data communication system, considerations must be given to a variety of risks affecting performance. These include availability, continuity, transition time/latency, and integrity. Examples of these considerations are outlined below.

- Any single event could disable the network due to lack of physical separation caused by manmade or natural phenomena.
- Concentration of services into one provider or lack of visibility in subcontracting from suppliers can lead to hidden risks or neutralize mitigation efforts if a critical service is provided by a single supplier.
- Dynamic reconfiguration is useful in network resiliency but needs to be managed in a way to not degrade performance.
- The variability of non-deterministic performance needs to be managed such that the performance requirements for the network are met at the appropriate probability (e.g., 95%, 99.9%).
- The ability for faults to cascade or propagate broadly throughout the network requires mitigation in the system design. Concentration of critical infrastructure resources or capabilities that can lead to widespread outages due to a single fault should be avoided.

Performance of leased network circuits is dependent on each individual telecommunication provider's security procedures and risks. Security faults could allow the degradation of pathways in a single telco provider, however, more complicated attacks may use one telco provider with weak security to attack another telco provider with stronger security and influence routing and performance of the path on the entire aviation ecosystem. Security must be managed at an end-to-end service level with contributions at the application, network, and subnet layers. All layers need to coordinate to ensure requirements are met.

Monitoring and reporting of performance are necessary to ensure performance and safety requirements are being met. Monitoring capability is required to: (1) measure system performance, (2) detect outages/integrity issues, and (3) detect latent failures (loss of redundancy) as well as any other items critical to the safety case. In response to an identified deviation of merit from the required performance, actions for redress to restore compliance would be undertaken and accomplished within a specified time. Failure to restore compliance would result in the flight no longer being eligible for the functions, applications, or operations requiring the performance. In a manner similar to an aircraft that loses the capability for Reduced Vertical Separation Minimum (RVSM) compliance in flight and is given an operational clearance consistent with its new (lower) performance, actions would be taken to amend the flight's clearance/operation.

5.8 A/G Subnetwork Domain Performance

Significant effort is going into CA for use by stakeholders (e.g., passenger, crew, airline operations) with many A/G systems in various states of deployment. All of these systems consist of some network of Radio Frequency (RF)-based transceivers and a ground backhaul network. Many of the considerations for G/G network performance apply here, along with the addition of RF link considerations.

The RF link can be a choke point for any data communications. The types of messages and data flowing over the link and the need for preemption should be considered. Large, low-priority data packets will tend to hold up higher priority messages at this choke point without a preemption scheme, potentially impacting performance.

The use of mobile wireless spectrum for new or existing applications should take into consideration the fact that this is unprotected spectrum and faces a higher risk of interference.

5.9 Interoperability

Given that the CA concept can include solutions where a performance-based subnetwork is used in conjunction with an aviation specific network (e.g., VHF Data Link (VDL)-2), due consideration needs to be given to interoperability with existing communication systems. This may include being connected to two networks simultaneously.

There are currently several subnetworks approved for various applications, including VDL-0, VDL-2, HF Data Link (HFDL), and Satellite Communications (SATCOM) (i.e., Inmarsat, Iridium). The primary role of the CSP, among others, is to manage the tracking of an aircraft across a subnetwork to ensure timely delivery of message traffic. Given the number of new satellite-based communications systems envisioned, it is reasonable to expect some portion will pursue performance capabilities to support aviation applications beyond simply providing passenger connectivity. This may cause the list of available subnetworks to grow considerably. Additionally, airlines will want their traffic routed cost-effectively, so some business rules-based routing algorithms may be needed. Finally, there may be geopolitical considerations on the use of certain systems over certain states. This future state will greatly complicate the issues of interoperability.

The management of traffic routing and subnetwork utilization currently is transparent to the ATSU automation systems. As complexity grows, this transparency should be maintained.

Experience with the use of CPDLC when aircraft cross the continental to oceanic airspace divide illustrates the challenges with current Aircraft Communications Addressing and Reporting System (ACARS) subnetwork management. This was designed to minimize cost for Aircraft Operational Control (AOC)/AAC traffic by strongly preferring VHF subnetworks (not to maximize performance for ATS traffic). With a potentially more complex subnetwork environment in the future, due consideration should be given to maximizing performance for ATS traffic while continuing to minimize cost for AOC/AAC traffic.

Conditions for supporting improved subnetwork management include the following.

1. Airborne terminal (radio) providing additional information on the link quality to the CSP to allow for anticipated handoffs.

2. Improved airborne communication system capability to detect communication issues based on communication analysis (e.g., expired timers, retransmissions).

3. Improved algorithms for the CSP to monitor aircraft performance and proactively switch an aircraft to another available media without loss of RCP.

The Aeronautical Telecommunications Network (ATN)/IPS standards as detailed in the ARINC Project Paper 858 and Minimum Aviation System Performance Standards (MASPS) documents currently under development by Radio Technical Commission for Aeronautics (RTCA) and European Organisation for Civil Aviation (EUROCAE) have placeholders for multi-link considerations. Primary interoperability work will be required to smoothly integrate with legacy systems.

5.10 Human Factors

Human factor considerations need to be made in part to the role the human plays in system integrity as well as system operation. In today's CPDLC regulations, there are requirements for the flight crew and ATCO to validate any clearance or clearance request received. Because this check is required, it can be assumed it is given some weight in meeting the communication system integrity requirement.

In a TBO environment, the route information can be more complex (i.e., more waypoints) and can be described by latitude/longitude coordinates. Without published information available to directly compare against, there will need to be considerations on how the flight crew and ATCO can validate the clearance. The flight crew requires a means to validate that the uplinked information is correct and can be flown. ASPs will require an independent means to ensure that clearances comply with separation minima, terrain considerations, minimum vectoring altitudes, and other requirements.

5.11 New Functions and Media

5.11.1 New Functions

There is a myriad of potential new functions for CA. These will emerge over time and the required performance of A/G communications will be aligned with the needs of the specific function.

As described earlier, the general process of analyzing, classifying, and mitigating hazards is followed anytime data communications are applied to a new application.

5.11.2 New Media Types

The CA concept also envisions some functions using voice communications, which could change to data communications in the future. An analysis of the existing function using voice would need to be performed to inform the requirements for substitution of a data communications subnetwork. This type of media change has already been done with low-impact functions (e.g., frequency changes in enroute airspace).

5.12 Transition and Mixed Environment

The transition of ASPs, airframes, and aircraft operators to take advantage of these new opportunities will occur over an extended period and not in a uniform fashion. Technical considerations and implications for this mixed environment and the extended transition include the following.

- Appropriate standards and system support (e.g., aircraft and ground automation systems) to ensure data communications occur through a pathway matching the performance, interoperability, and regulatory requirements of the operational function or capability being executed.

- A regulatory framework that can adapt the use of non-aviation specific development and approval methodologies.

- Identification for the aircraft, FOC, and ATSU of the pathways available to each of the necessary global standards to support interoperability.

- Mechanisms built on the standards described above which do not impose burdens on the human actors to ensure the "correct" pathway is used in real time for a given function or capability. *Note:* Use of the term "correct" is meant to describe a pathway—aviation-specific or commercial—whose end-to-end performance meets the requirements of the given function.

6 Standardization Needs

6.1 A/G Interoperability Aspects

Given that a legacy (or existing) CA will remain in service for 30 years and, likely, will not be upgraded without a tangible financial benefit, it is prudent to consider a mixed environment for some time. In order to always be connected, the standards landscape should consider seamless subnetwork management with new and legacy A/G subnetworks, management of functions supported on available subnetworks, and interoperability in a mixed environment (i.e., airborne and ground-based systems). The CA concept envisions loosely coupled architectures that allow aircraft, networks, subnets, and ground systems to evolve at different rates. To meet that objective, standardization and regulatory processes need to evolve to reflect the increasing cadence of change in the telecom market.

6.2 Importance of Interoperability and Standardization

It is expected that the A/G connectivity environment for ATS will operate in a mixed mode for an extended period of time. Aircraft equipage, ATSU automation upgrades, and rollout of new subnetworks will inevitably occur on differing time scales.

Interoperability is critical to achieving widespread adoption of these capabilities. The methods for achieving interoperability need to account for airlines' desire to operate their fleets efficiently, transparent to the A/G subnetworks in use. One means of achieving interoperability is to standardize CA services without reference to the underlying data link technology. Such standards would include service functional descriptions, end-to-end performances, and operational safety assessments without any reference to the communication path, enabling stakeholders or CSPs to select the best data link technology for the service. Automation systems and aircraft need to operate seamlessly with adjacent FIRs and varying types of A/G subnetworks available.

7 Regulatory Considerations

7.1 Overview

A fundamental premise of the CA concept is that, provided expected performance is assured, the use of COTS technologies and services to provide a data communications capability is required to keep pace with AUs' demand for connectivity. Access to data (i.e., SWIM and data communications) is key to TBO, and the demand for connectivity will grow over time as more applications are developed. The expectation is that commercial technologies will enable improved capabilities to be adopted faster and at a much lower cost to the industry than a technology created to a prescriptive technical standard. In order to support this concept, regulations need to support means of compliance with sufficient flexibility to allow new technologies to be brought forth for approval and at a pace consistent with commercial technologies.

To fully realize the benefits of the CA concept, global, cross-border operations are envisioned. To support the States in this environment, they should be supported by global standards and regulatory guidance across all necessary areas.

7.2 Ground and Air Networks

There is an understanding among stakeholders that reliance on commercial communications infrastructures will rise as our reliance on data increases. To compensate, monitoring, reporting, and qualification requirements can be considered to support the required system performance. An operational authorization approach should be considered for these services. An aircraft user will determine what mix of network and subnet services to which it subscribes (circumscribed by what is needed to ensure they meet interoperability constraints) and the user seeks operational authorization for that service bundle.

7.2.1 Aircraft Avionics

The CA concept does not envision changes to the integrity or certification methods for aircraft avionics. The allocation of functions may change between avionics and COTS equipment, but the resulting architecture maintains acceptable integrity commensurate with the safety objectives.

7.2.2 A/G Communications Systems

Significant work has been done in the industry on defining performance requirements of A/G communication systems (e.g., *PBCS Manual*) to support ATS. Creation of advisory material should be considered by the regulator to document the required performance levels of communications solutions. The complexity of the A/G subnetwork under consideration will drive the level of scrutiny necessary in the approval process, but the general process of operational authorizations used today should still apply.

Considerations also need to be made for regulatory support for interoperability between aircraft and ATSU automation systems. As stated earlier in this document, a key tenet of CA is that it is always connected. Mixed equipage of aircraft and variability in FIR capabilities should be considered. Regulations should also support innovative network management concepts to the CA objectives.

Additionally, current safety services operate over protected spectrum, as defined by ICAO and the ITU radio regulations. This includes VHF, HF, parts of the C-band (for Aeronautical Mobile Airport Communication Systems (AeroMACS)), and L-band SATCOM. Many of the IP data links do not operate in these frequency bands. If safety information will be exchanged over these links, regulators may need to provide additional guidance as there may be new performance requirements necessary.

Data communication systems envisioned for CA are primarily created in whole or in part for non-aviation markets. Considerations should be made about what performance guarantees, if any, can be made by the suppliers. Business volume from aviation relative to non-aviation markets may limit the level of investments in networks to supply services beyond a “best efforts” level.

7.2.3 EFB and Application Considerations

The success of COTS technology is the speed with which new capabilities can be brought to the flight deck. Performance-based standards for COTS technology will enable broader applications in the area of data communications. Since many of the envisioned use cases require some form of human interface, a reasonable path to operational authorization (as described below), will continue to be required so as to not negate the efficiencies and value gained when implementing the CA capabilities described in this concept. Safety is essential, so considerations need to be made of hazards and associated impacts of new applications of COTS technology.

Operational authorizations have proven effective thus far. They consist of a combination of design considerations for fault mitigation, testing, operational trials, and operational mitigations. This concept and methodology should be embraced in future applications.

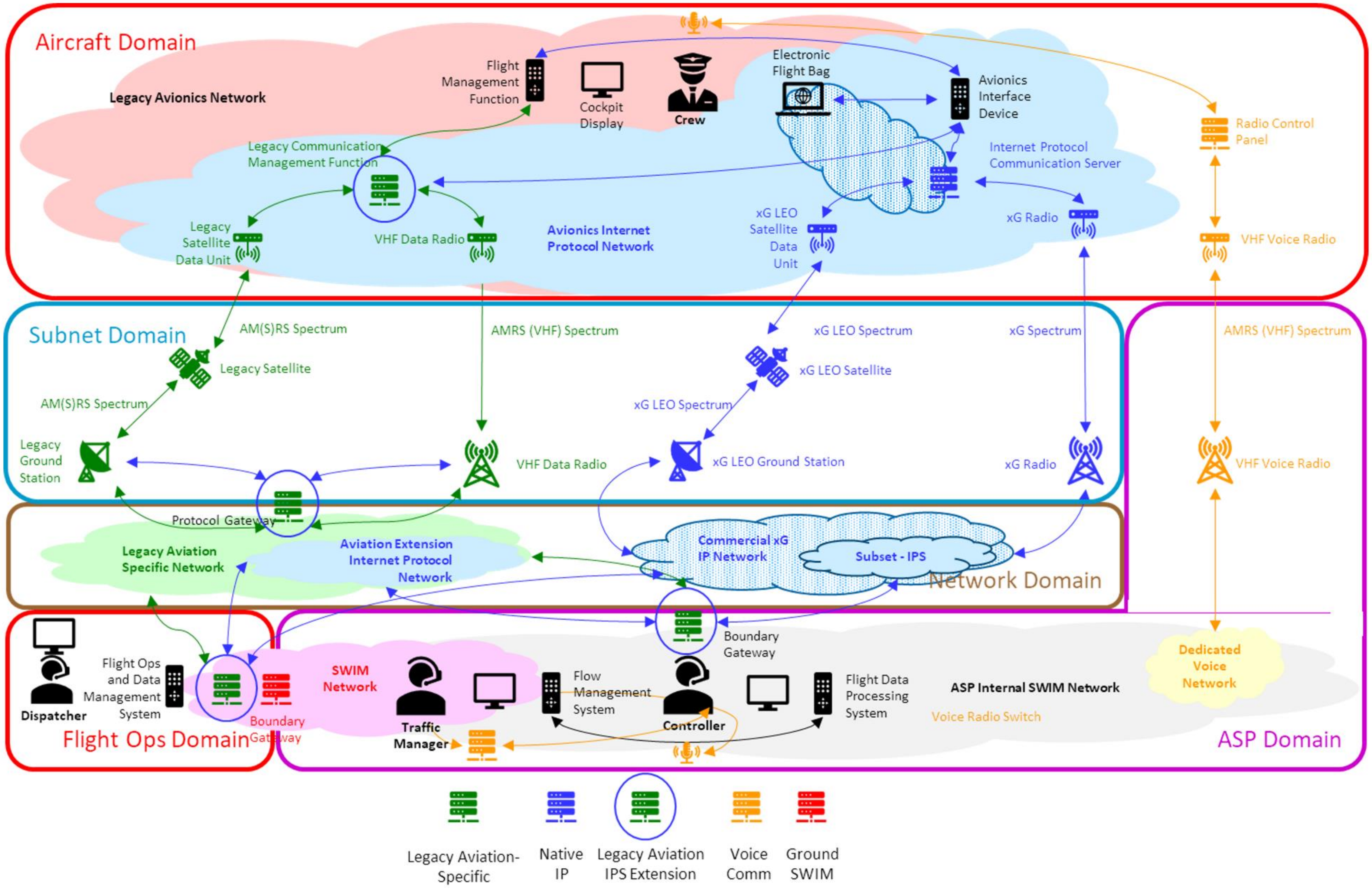
Appendix A Example Communication Paths

An example of the alternative communication paths available to the ATM system with CA is provided in Figure 14. A basic assumption is that voice communications between the ATCO and flight crew will remain available as they are today. The figure also illustrates a gradual evolution of communications paths as follows.

- **Traditional** – In the traditional exchange, aviation-specific paths are described between the flight deck and both flight operations and ATC. These include the use of dedicated aviation-specific networks and associated aviation-specific spectrum for both terrestrial and satellite-based communications to the flight. Onboard the aircraft, dedicated design-assured receivers provide the data to a communication management function, allowing further distribution across the relevant design-assured avionics systems. Present-day CPDLC applications represent an example using traditional communications paths.

- **Transitional** – Initial implementation of IP-based exchanges are expected to occur through the application of the IPS layered atop the traditional aviation-specific paths described above.

- **Connected Aircraft (CA)** – The CA is expected to leverage commercial pathways and subnetworks for connectivity to the aircraft. A subset of these may elect to adopt layered IPS standards for applications requiring such assurance on information exchanges. Connectivity to the flight deck via commercial pathways will leverage commercial receivers, in turn providing data for operationally approved applications and possibly across boundary gateways to design-assured avionics systems.



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969 *Figure 14. Example of Alternative Communication Paths in the CA*

Appendix B Glossary

Airline Administrative Control (AAC) – Provides relevant administrative information such as the passenger information list, which contains information such as passenger connections, available seats, etc.

Aeronautical Operational Control (AOC) – Communication required for the exercise of authority over the initiation, continuation, diversion, or termination of flight for safety, regularity, and efficiency reasons.

Aeronautical Telecommunications Network (ATN) – A global inter-network architecture that allows ground, Air/Ground (A/G), and avionic data subnetworks to exchange digital data for the safety of air navigation and for the regular, efficient, and economic operation of Air Traffic Services (ATS).

Aircraft Communications Addressing and Reporting System (ACARS) – Digital data link system for transmission of short messages between aircraft and ground stations via air band radio or satellite. ACARS as a term refers to the complete air and ground system, consisting of a service provider and aircraft/ground equipment.

Air Traffic Management Service Provider (ASP) – A generic term meaning variously, air traffic services unit, air traffic flow management unit, and/or Flight and Flow – Information for a Collaborative Environment (FF-ICE) services unit.

Air Traffic Services Unit (ATSU) – A generic term meaning variously, air traffic control unit, flight information center, or air traffic services reporting office.

Airspace Users (AUs) – Organizations operating aircraft and their pilots, which includes the aircraft, airborne platform, flight crew, and flight operators.

Commercial off-the-Shelf (COTS) – These are products that are packaged solutions, which are then adapted to satisfy the needs of the purchasing organization, rather than the commissioning of custom-made, or bespoke, solutions.

Controller-Pilot Data Link Communications (CPDLC) – A means of communication between controller and pilot, using data link for ATC communications.

Data Link – For the purposes of this document, a data link is a means of digital communication between the ground and the airborne platform.

Electronic Flight Bag (EFB) – An electronic information system, comprised of equipment and applications for flight crew, which allows for storing, updating, displaying, and processing of EFB functions to support flight operations or duties.

Internet Protocol (IP) – A network level protocol (part of the internet protocol suite) governing the exchange of information across network boundaries.

Internet Protocol Suite (IPS) – A set of ICAO, Radio Technical Commission for Aeronautics (RTCA)/European Organisation for Civil Aviation (EUROCAE), and Airlines Electronic

Engineering Committee (AEEC) technical documents using COTS IP standards that are profiled specifically for aviation safety communications, including both ATS and Aircraft Operational Control (AOC) messaging.

Minimum Aviation System Performance Standards (MASPS) – Specific characteristics that are useful to designers, installers, manufacturers, service providers and users of systems intended for operational use within a defined airspace.

Minimum Equipment List (MEL) – A list which provides for the operation of aircraft, subject to specified conditions, with particular equipment inoperative, prepared by an operator in conformity with, or more restrictive than, the Master Minimum Equipment List (MMEL) established for the aircraft type.

Required Communications Performance (RCP) Specification – A set of requirements for ATS provision, aircraft capability, and operations needed to support performance-based communication within a defined airspace.

Required Communication Technical Performance (RCTP) – An RCP allocation that specifies the maximum technical time for relevant parts of the unit's system, aeronautical station's system, the network systems, and the aircraft system, for which there is no human contribution to the communication transaction performance.

Service Provider – An organization or entity providing a service. In this document, this refers to ATM Service Providers (ASPs) or vendors that provide network or other value-added services. This is distinct from an information provider.

Trajectory Based Operations (TBO) – Represents a shift from clearance-based to trajectory-based control. Aircraft will fly negotiated trajectories and ATC moves to trajectory management. The roles of pilots/controllers will evolve due to the increase in automation support.

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Appendix D Acronyms

Acronyms used throughout this document are provided in Table 6.

Table 6. Acronyms

Acronym	**Definition**
3D	Three-Dimensional
4D	Four-Dimensional
4DT	Four-Dimensional Trajectory
AAC	Airline Administrative Control
AAM	Advanced Air Mobility
AC	Advisory Circular
ACARS	Aircraft Communications Addressing and Reporting System
ACD	Aircraft Control Domain
ADIF	Aircraft Data Interface Function
ADIRU	Air Data Inertial Reference Unit
ADS-C	Automatic Dependent Surveillance – Contract
AEEC	Airlines Electronic Engineering Committee
AeroMACS	Aeronautical Mobile Airport Communication System
A/G	Air/Ground
AID	Aircraft Interface Device
AISD	Airline Information Services Domain
AMDAR	Aircraft Meteorological Data Relay
AOC	Aircraft Operational Control
ARP	Aerospace Recommended Practice
ASP	ATM Service Provider
ATC	Air Traffic Control
ATCO	Air Traffic Controller
ATIS	Automatic Terminal Information Service
ATM	Air Traffic Management
ATMRPP	ATM Requirements and Performance Panel
ATN	Aeronautical Telecommunications Network
ATS	Air Traffic Services
ATSU	Air Traffic Services Unit
AU	Airspace User
BVLOS	Beyond Visual Line of Sight

Acronym	Definition
CA	Connected Aircraft
CAI	Continued Airworthiness Instruction
CDM	Collaborative Decision Making
CNS	Communication, Navigation, and Surveillance
COTS	Commercial off-the-Shelf
CPDLC	Controller-Pilot Data Link Communications
CSP	Communication Service Provider
DAL	Design Assurance Level
DO	Document
EFB	Electronic Flight Bag
ETSO	European TSO
EUROCAE	European Organisation for Civil Aviation
FAA	Federal Aviation Administration
FF-ICE	Flight and Flow – Information for a Collaborative Environment
FIR	Flight Information Region
FMS	Flight Management System
OCC	Operational Control Center
GATMOC	Global ATM Operational Concept
G/G	Ground/Ground
HAPS	High-Altitude Platform System
HF	High Frequency
HFDL	High Frequency Data Link
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
IP	Internet Protocol
IPS	IP Suite
ITCZ	Intertropical Convergence Zones
ITU	International Telecommunications Union
IUEI	Intentional Unauthorized Electronic Interactions
MASPS	Minimum Aviation System Performance Standard
MEL	Minimum Equipment List
MMEL	Master Minimum Equipment List
NOTAM	Notice to Air Missions
PANS	Procedures for Air Navigation Services

Acronym	**Definition**
PBCS	Performance-Based Communication and Surveillance
PED	Portable Electronic Device
RCP	Required Communications Performance
RCTP	Required Communication Technical Performance
RF	Radio Frequency
RPIC	Remote Pilot in Command
RSP	Radio Surveillance Performance
RTCA	Radio Technical Commission for Aeronautics
RVSM	Reduced Vertical Separation Minimum
SAE	Society of Automotive Engineers
SATCOM	Satellite Communications
STC	Supplemental Type Certificate
SWIM	System Wide Information Management
TBO	Trajectory Based Operations
TC	Type Certificate
TSO	Technical Standard Order
TSOA	TSO Authorization
UAS	Unmanned Aircraft System
VDL	VHF Data Link
VHF	Very High Frequency
WG	Working Group
WMO	World Meteorological Organization