D2.2.200 PJ14-W2-76 Integrated CNS and spectrum - CNS Evolution Roadmap and Strategy

Deliverable ID:	**D2.2.200**
Dissemination Level:	**PU**
Project Acronym:	**PJ.14 W2 I-CNSS**
Grant:	**874478**
Call:	**H2020-SESAR-2019-1**
Topic:	**ESAR-IR-VLD-WAVE2-12-2019**
Consortium Coordinator:	**LEONARDO**
Edition date:	**8th November 2022**
Edition:	**00.05.04**
Template Edition:	**02.00.05**

EUROPEAN PARTNERSHIP

Co-funded by the European Union

Authoring & Approval

Authors of the document

Beneficiary	Date
EUROCONTROL	8/11/2022
ESSP	8/11/2022
NATS	8/11/2022
ENAIRE	8/11/2022
AIRBUS	8/11/2022

Reviewers internal to the project

Beneficiary	Date
AIRBUS	8/11/2022
DSNA	8/11/2022
ENAIRE	8/11/2022
ESSP	8/11/2022
INDRA	8/11/2022
NATS	8/11/2022
DFS	8/11/2022
LEONARDO	8/11/2022

Reviewers external to the project

Beneficiary	Date
IATA	8/11/2022
EBAA	8/11/2022
Air France / KLM	8/11/2022
Skyguide	8/11/2022
DFS	8/11/2022

Approved for submission to the S3JU By - Representatives of all beneficiaries involved in the project

Beneficiary	Date
EUROCONTROL	8/11/2022
ESSP	8/11/2022
NATS	8/11/2022

ENAIRE	8/11/2022
INDRA	8/11/2022

Rejected By - Representatives of beneficiaries involved in the project

Beneficiary	Date

Document History

Edition	Date	Status	Beneficiary	Justification
00.00.01	29/06/2017	Version 1	EUROCONTROL	First version
00.01.01	06/10/2017	Updated version 1	EUROCONTROL	Comments from SJU
00.02.01	22/12/2017	Draft version 2	EUROCONTROL	Comments from EUROCONTROL WG NSG, COM SG and SUR SG, but also the SJU
00.02.02	16/03/2018	Version 2	EUROCONTROL	Further Comments from EUROCONTROL WG NSG, COM SG and SUR SG and IATA
00.03.00	30/08/2019	Version 3	EUROCONTROL	Update of the document following the development of the EATM Master Plan
00.03.01	02/10/2019	Version 3.1	EUROCONTROL	Update of the document following SJU comments
00.04.01	30/08/2021	Version 4.1	EUROCONTROL	First update of solution 76
00.04.02	01/09/2021	Version 4.2	EUROCONTROL	Second update following Solution 76's member contributions
00.04.03	31/10/2021	Version 4.3	EUROCONTROL	Update following final comments from Solution 76 on v4.
00.04.04	12/11/2021	Version 4.4	EUROCONTROL	Update following review from PJ14 SLs on v4.
00.04.05	22/12/2021	Version 4.5	EUROCONTROL	Update following SJU comments on 4.4
00.05.00	30/08/2022	Version 5.0	EUROCONTROL	First draft version 5

00.05.01	01/09/2022	Version 5.1	EUROCONTROL	Draft version 5 for EUROCONTROL internal review
00.05.02	28/09/2022	Version 5.2	EUROCONTROL	Draft version 5 for external review
00.05.03	28/09/2022	Version 5.3	EUROCONTROL	V5.2 update following a first set of comments received during review
00.05.04	8/11/2022	Version 5.4	EUROCONTROL	Update following comments during the final review

PJ.14 W2 I-CNSS

INTEGRATED COMMUNICATION, NAVIGATION AND SURVEILLANCE SYSTEM

This CNS Evolution Roadmap and Strategy is part of a project that has received funding from the SESAR3 Joint Undertaking under grant agreement No 874478 under European Union’s Horizon 2020 research and innovation programme.

Abstract

Communication, Navigation and Surveillance (CNS) systems provide the infrastructure and services, which are essential for Air Traffic Management (ATM). CNS mainly enables efficient navigation and safe separation in all phases of flight. Although current CNS systems are mature and globally providing a good service, they are still relying on a modular approach and all facing technological transition phases to reach the objectives of the SESAR Concept of Operations in terms of quality of service, cost effectiveness and environmental impact. All the ATM elements will require an underlying supporting infrastructure including communication, navigation and surveillance capabilities that are adapted to support the concept elements in an efficient way.

PJ.14 W2 I-CNSS – INTEGRATED COMMUNICATION, NAVIGATION AND SURVEILLANCE SYSTEM is dealing with these infrastructures. PJ.14-W2-76 D2.1.200 CNS Evolution Roadmap and Strategy will provide a global view of the future Communication, Navigation and Surveillance services, with the associated paths for systems integration. The solution will identify synergies across the domains, contributing to CNS services and systems roadmap with mature or maturing candidate system designs and specifications. The solution aims to provide an in-depth analysis of a future set of CNS services delivered by an appropriately “integrated as much as possible” system of system being resilient, safe, cost and spectrum-wise efficient.

The description and analysis of CNS infrastructure and systems short term, mid-term and long term evolution will bring opportunities to re-evaluate the ATM costs by identifying CNS cross-domains commonalities while maintaining redundancies where appropriated and required. Particular focus on the civil-military interoperability, with the identification of interoperability targets to support performance-based compliance, also aims to improve the overall interoperability. A specific focus on the validation of CNS information data sharing needs between ATM and military entities will be addressed, and the integration and the fusion of such information by both entities assessed. Relying on strategic directions determined by the description of future ATM/CNS challenges, this document proposes a CNS roadmap aiming to CNS architecture and services convergence while highlighting the critical path to make it achievable.

Aligned with Global Air Navigation Plan[1] (GANP) Aviation System Block Upgrades (ASBU) and the associated technology roadmaps, the CNS Evolution Roadmap and Strategy will contribute to the update of the European Air Traffic Management Master Plan by providing a phased vision of CNS and spectrum evolution.

Executive summary

Communication, Navigation and Surveillance are key enablers to ATM operations. Although current CNS systems are mature and providing an efficient and safe support to air navigation, they are mainly based on legacy technologies that will need to evolve. New entrants like RPAS, the pressure on the aviation spectrum, the evolution of the air navigation towards 4D trajectory management are driving the CNS evolution. CNS being at the crossroad of ATM operations, such an evolution needs to be planned in a coordinated and stepped approach.

The development of this roadmap took as inputs relevant strategic documents such as FlightPath 2050, IATA Vision 2050, the ICAO Global Air Navigation Plan and the European ATM Master Plan, and resulted from the combination of a top-down and a bottom-up approach. The top-down approach considered the SESAR vision for the evolution of ATM and in particular, the essential operational changes brought by the CNS infrastructure. This vision foresees the evolution of CNS towards a service-based approach as described in PJ.14-W2-76 D2.1.100 CNS service assessment and a performance-based approach as presented in PJ.14-W2-76 D2.1.300 CNS Performance-based, enabling the de-coupling of CNS services provision from air traffic services and ATM data services. The bottom-up approach identified the CNS systems being developed. Given that developing, standardizing and deploying a system in aviation requires more than a decade, the identification of the current development provides a fair view of the short to mid-term evolution.

The combination of the top-down and bottom-up approach led to the definition of a CNS target architecture, the development of a transition path, and the identification of the CNS rationalisation opportunities. The CNS target architecture will be composed of three layers: performance-based CNS applications supporting the operational services, a backbone of recent and global technologies, in the form of secure CNS services, and minimum operational networks (MON) of the legacy infrastructure providing a back-up or and efficient support to the backbone. The development of a transition path towards that target architecture identified a 2025 rendezvous with the deployment of an efficient multi-datalink capability, the composite surveillance and the use of dual-frequency and multi-constellation GNSS. Along to the transition path, legacy systems can be rationalised, most of the rationalisation being enabled by this 2025 rendezvous.

The version 3 of this roadmap has been widely reviewed by the CNS community at both technical and decision-taking level through the EUROCONTROL working groups (Navigation Steering Group, Communication Steering Group, Surveillance Steering Group, Joint CNS Stakeholder Platform, Agency Advisory Board), the SJU agreement with airspace users, and the 2018 CNS symposium (an event organized by EUROCONTROL and bringing together 350 participants from the CNS community:

---

[1] The latest edition of GANP is an online version and can be accessed via the link (https://www4.icao.int/ganpportal/)

Industry, ANSPs, Airlines, Institutions, Research institutes….). Finally, the version 3 of this roadmap has been used as input for the development of the 2020 edition of the European ATM Master Plan and provided as input to the European Commission CNS advisory group.

The version 4 of this roadmap is an update of the previous version, which did not modify any of the key elements and foreseen date for the implementation of new technology. As such, this version 4 is fully aligned with the 2020 edition of the European ATM Master Plan. However, this version improves the overall context by providing an updated annex on drones and spectrum, and by better considering the airborne and cyber-security aspects through dedicated annexes.

As a conclusion, this roadmap recommends the further development of the integrated CNS concept, considering Communication, Navigation and Surveillance as one domain, and the need for a program management approach under the proper governance, ensuring a seat to all stakeholders.

Note for the reader

The initial version of this roadmap has been developed in 2018 and has been widely reviewed by the CNS community during the CNS Symposium organized by EUROCONTROL on October 2018. Following the agreement reached during the symposium, the core content of this document has been updated and fully incorporated into the 2020 Edition of the European ATM Master Plan. Additional content (mainly annexes) has been developed in the subsequent version of this document, but the core content (key implementation technology and dates) remained unchanged, ensuring a full alignment between this document and the 2020 Edition of the European ATM Master Plan.

Following the development of the European ATM Master Plan Edition 2020, DGMOVE established a CNS Advisory Group to develop recommendations aiming at achieving a more comprehensive, reliable and accurate planning for CNS implementation; proposing incentives for voluntary implementation complemented by smart(er) regulations; improving management and governance; and considering human dimension aspects. As a result, the group suggested the following twelve recommendations:

1. Translate the Master Plan's CNS roadmap into a 'CNS evolution plan' with short, medium and long-term objectives, priorities and decision points.
2. Improve cost-efficiency through rationalisation, including decommissioning of CNS facilities, maintaining robustness while ensuring safety and security.
3. Implement CNS infrastructure applying a technical performance[2] based approach in a way that is simple and cost-efficient.
4. Conceive an integrated CNS evolution maximising synergies and addressing security for Communication, Navigation and Surveillance services.
5. Develop a long-term EU strategy and policy to improve aviation spectrum efficiency as a driver of the CNS evolution.
6. Reduce the greenhouse gas emissions of the CNS infrastructure to maximise aviation's contribution to achieving European net zero carbon emissions targets.

---

[2] If not otherwise specified, this term refers in this report to the technical performance of CNS systems (e.g. accuracy, availability, latency, integrity,…) and should not be confused with the definition in the ATM performance and charging scheme in the SES (i.e. safety, capacity, environment, and cost-efficiency).

7. Demonstrate operational and technical interoperability and scalability[3] of the infrastructure before deployment.
8. Develop robust CNS implementation business cases involving stakeholders at the earliest possible opportunity.
9. Ensure smart use of incentives to support stakeholders in implementing the CNS evolution plan.
10. Apply a smart(er) approach when developing technical CNS regulations to support the implementation of the CNS evolution plan.
11. Establish a holistic CNS programme management to ensure successful implementation of the CNS evolution plan using or adapting existing entities to maximum effect.
12. Consider the importance of the human dimension aspects related to the evolution of the CNS infrastructure.

As per recommendations 1) and 11), the content of the European ATM Master Plan Edition 2020, hence this document as they are fully aligned, should be translated into a detailed CNS action plan which should be maintained and followed up by a CNS program manager.

---

[3] Scalability is defined here as a system's ability to increase or decrease in performance and cost in response to changes in the operational requirements.

Table of Contents

List of Tables

List of Figures

1 Introduction

Communication, Navigation and Surveillance infrastructures remain the corner stones for any future development in ATM and UTM. The evolutions of the C, N and S infrastructures have been widely addressed in international and European strategic documents such as the EU Aviation Strategy, Flight Path 2050, the ICAO GANP, the European ATM Master Plan, the Airspace Architecture Study and a Strategic Research and Innovation Agenda (SRIA). However, these evolutions are mostly considered separately for each domain whereas the interdependencies and interconnections between the CNS current and future technologies are requiring a more global approach. The synergies as well as the common failure modes between existing and future CNS systems are gradually being addressed by the CNS community and regrouped under the term "Integrated CNS" (iCNS). In this integrated approach, it will also be necessary to ensure that military systems can interact with the network centric environment in place and remain interoperable with civil systems. In parallel, cost, spectrum requirements and business cases will drive a rationalization process of the infrastructure including a seamless phase-out of legacy systems and smooth transition to the use of new more performant technologies and/or related CNS services.

While ensuring full consistency with other relevant strategic group and documents, the objectives of this deliverable are:

1. To identify the CNS Evolutions drivers.
2. To provide a long term vision for the future CNS objective infrastructure.
3. To provide a short, mid and long term CNS transition path.
4. To identify CNS rationalisation opportunities.
5. To identify recommendations for the European CNS community in order to support and facilitate the CNS evolution and to build-upon a consolidated strategy.

2 Integrated CNS concept

The C-N-S concept comes from the early days of aviation and remains an important safety principle. Developed during the days of single systems, the logic is that while one part of CNS can have a complete failure, the other two parts enable, as a minimum, safe landing of aircraft. This has led to functions such as the designation of one specific SSR transponder code to indicate loss of communication. With increasing levels of traffic, a significant failure of one of the CNS elements is no longer an option. This is why each CNS element has increased its level of reliability and safety by adding redundant and diverse systems or multiple system layers. Both the safety philosophy and the increasing complexity of CNS have led to Communication, Navigation and Surveillance developing their systems independently, without much consideration of other CNS evolutions. Because of the current mix of digital and analogue technologies, performance-based concepts and the introduction of GNSS in multiple areas of CNS, the traditional, single system CNS safety concept is becoming difficult to maintain. Therefore, a comprehensive review of CNS is necessary, considering the following issues:

1) In many cases, systems and safety engineering for a particular CNS technology supporting a particular application must make performance assumptions about other CNS elements. This can lead to situations where assumptions are not consistent or interdependent across CNS. To consistently maintain independence of CNS elements (where possible), systems and safety engineering approaches need to be compared and evaluated at an integrated CNS level. Where not possible (such as when using a single technology to support multiple CNS elements), an integrated assessment is required which considers all related system layers.
2) While redundant systems are an essential ingredient for a robust CNS infrastructure, considering CNS as independent silos may also lead to excessive redundancy and associated cost. To optimize the provision of CNS, the safety requirements for CNS redundancy for a diverse set of airspace users' needs to be balanced against cost efficiency. This should enable a more cost-efficient provision of CNS while maintaining the required margins for operational safety and continuity of operations.
3) System evolution to meet evolving operational needs in one area of CNS will increasingly impact the development in other areas of CNS, in particular when it comes to efficient use of spectrum. While CNS was traditionally also separated into distinct frequency bands, CNS band sharing will continue to increase. Therefore, the development initiative in all areas of CNS should be evaluated in terms of overall CNS impact and optimized where possible.
4) New threats or issues (cyber security, RPAS) are impacting all areas of CNS, traditionally comprised of fully open systems to maximize interoperability. These developments need to be evaluated in a consistent manner to ensure successful integration of future capabilities in CNS.

The Integrated CNS concept has been developed in the SESAR program in order to manage the CNS concept's change and to address the existing and upcoming CNS challenges: integrated CNS is about considering the C, N and S domains as one. So far, C, N and S contribution to the airspace concept were mainly considered in isolation. A harmonized view of these contributions across CNS would improve the overall CNS efficiency. Concerning the CNS applications, this concept would integrate the individual C, N and S Performance-Based concepts into a harmonized CNS Performance-Based framework. Concerning the CNS infrastructure, this concept would imply that one domain could be used as a support for another domain. Ultimately, the infrastructure might be integrated into one single system providing the C, N and S services, but such a system would need to meet safety requirements, and ensure full interoperability during the interim deployment phase. This evolution is not foreseen at the time of this writing. This integrated approach will enable a coordinated cross-domain evolution, the identification of cross-domain opportunities but would also address potential common mode failure through the identification of an appropriate level of mitigation and redundancy.

Within the SESAR 2020, the integrated CNS concept is tackled by the PJ.14-W2-76 solution, which brings together expertise from the C, N and S domains and provides the main deliverables described below.

CNS Roadmap and Strategy

The seamless integration of new entrants, such as unmanned air systems, and the continued evolution of traffic levels, airspace user equipage and operational applications will require the ATM system to acquire a higher level of automation and connectivity between the air and the ground. This connectivity will need to evolve from a fully open infrastructure towards a more secure environment. The use of new technologies will also enable the implementation of key concepts such as trajectory-based operations (TBO), and reduce the environmental impact and the ATM costs while accommodating the transition and a judicious rationalisation of the legacy systems.

The foreseen CNS evolution from an analogue to an increasingly digitalised CNS infrastructure, which could be characterized as a CNS performance step change, will only be adopted by airspace users and Air Navigation Service Providers (ANSPs) through a coordinated and stepped approach, bringing equitable costs and benefits to users and providers, and allowing for regional differences. This stepped approach needs to be coordinated through the development of a CNS Roadmap and Strategy, with the aim to fully coordinate CNS equipment upgrades. In order to ensure a common strategy and convergence with other relevant strategic documents, this roadmap has been based on the European Commission’s vision on aviation - Flightpath 2050, the ICAO Global Air Navigation Plan and the European ATM Master Plan.

Performance-Based CNS

A well-accepted CNS concept is “performance-based”. However, “performance-based” can have a variety of different meanings. In performance-based standards, the intent is to write requirements which focus on what needs to be achieved operationally, without being overly prescriptive about how the performance should be achieved or how the related functions should be implemented. This enables innovation in product design and has been aviation standards practice for many years. Some in ICAO consider the term performance-based standards to mean that external industry standards should be relied upon as much as possible, with ICAO only setting the most high-level requirements in SARPS. Then there is performance-based technology, where the choice of the actual sensors or systems used remains flexible. This is also called “technology agnostic”. An underlying idea is to allow a mix and match of different technologies to maximize the available capabilities. This has been applied for example to navigation and surveillance systems, where different layers and diverse systems support the same main function in a very robust way. However, in safety certified systems subject to economic constraints, there are limitations to how open approaches can be; normally there is a limited list of standardized systems which can be used. Also, it must be ensured that performance-based technology does not lead to both air and ground systems having to be equipped with all possible systems in the sense of excessive redundancy.

Performance-based Communication, Navigation and Surveillance are being developed, allowing the ATM/CNS to evolve from system-based operations toward the delivery of CNS services. Integrating these existing concepts under a harmonized Performance-Based CNS framework, including appropriate performance metrics would maximize the cross-domain opportunities and synergies and allow for the support of various airspace concepts. A unified Performance-Based CNS concept would also enable a better understanding of the CNS environment, currently perceived by the airspace users and the service providers as a complex system.

The development of a Performance-Based CNS framework could also support flexibility for ANSPs and could enable them to define their own CNS service delivery model. Finally, such framework could enable the rationalisation of the airborne systems by customizing the required airborne equipage to the aircraft and the local specificities but also to the operator business models.

The above discussion illustrates that the term “performance-based” can have diverse objectives, challenges and benefits. It would appear useful to first investigate and describe the various interpretations of performance-based. Then, where beneficial, these concepts could be harmonized to ensure a more optimize CNS service provision. However, there is a long way to go towards the harmonization and unification of the individual C, N and S Performance-Based concepts and this project has set a more reasonable objective: it shall pave the way toward this integration by describing the three concepts, assessing theirs differences and similarities and finally by identifying recommendations toward a future unified concept. The detailed analysis of this concept is presented in the PJ.14 W2 deliverable D2.1.300 CNS Performance-based.

CNS Robustness

The current CNS infrastructure is using multiple radio links based on open standards. Due to their operational suitability, the use of space-based CNS systems is increasing enabled by performance-based concepts. All radio systems are vulnerable to interference and may also be subject to cyber-attacks; the impact of interference on space-based systems could become very significant. CNS resiliency and robustness will need to specifically mitigate those vulnerabilities by a combination of short and long term technical and operational measures, based on a reasonable level of technical and operational resiliency and an efficient service status reporting mechanism toward enforcement authority and ANSPs.

Developing a robust and secure CNS infrastructure is a long way off. This project will focus on the systems which are foreseen to be at the core of the future CNS infrastructure, namely GNSS, ADS-B and Datalink. The robustness analysis will further develop the measures that may reduce the occurrence of radio-interference or jamming. Based on a combination of residual system risks and performance-based metrics, the project will aim to develop analysis methods to help determine what level of redundancy and robustness is appropriate taking into account the full breadth of CNS system elements.

Global interoperability

The global evolution of ATM/CNS systems as foreseen by the CNS Roadmap and Strategy requires cooperation between civil and military authorities.

The interoperability challenges have to be addressed fostering the optimum utilisation opportunities of CNS capabilities, CNS rationalisation, technology convergence and synergies, including reliance on a performance-based environment as the basis to promote the concept of performance equivalence for military and unmanned systems. This will be beneficial for all stakeholders in terms of best practices, capitalization on expertise, and reduction of work duplication in a cost-efficiency and safety context.

However, in this project, the activity on global interoperability will focus on the identification of the information exchange requirements between the civil and military organisations.

3 SESAR Vision

By 2040, an increasing number and variety of air vehicles will take to Europe's skies. The SESAR vision aims to deliver a resilient and fully scalable ATM system capable of handling growing air traffic of diverse manned and unmanned air vehicles in all classes of airspace, in a safe, secure, sustainable manner. The vision builds on the SESAR target concept and primarily on the notion of trajectory-based operations (TBO), which enables airspace users to fly their preferred flight trajectories, delivering passengers and goods on time to their destination as cost efficiently as possible. This will be enabled by a new architecture captured under the notion of "digital European sky", which is detailed in the latest edition of the European ATM Master Plan:

The digital European sky

By 2040, increasing numbers of aerial vehicles[4] (conventional aircraft and unmanned aircraft, such as drones) will be taking to Europe's skies, operating seamlessly and safely in all environments and classes of airspace. Trajectory-based free-route operations will enable airspace users (civil and military) to better plan and execute their business and mission trajectories[5] within an optimised airspace configuration that meets safety, security and environmental performance targets and stakeholder needs. The system infrastructure will progressively evolve with the adoption of advanced digital technologies, allowing civil and military ANSPs and the Network Manager to provide their services in a cost-efficient and effective way irrespective of national borders, supported by secure information services. Airports and other operational sites (e.g. landing sites for rotorcraft and drones) will be fully integrated at the network level, which will facilitate and optimise airspace user operations in all weather conditions. ATM will progressively evolve into a data ecosystem supported by a service-oriented architecture enabling the virtual defragmentation of European skies. Innovative technologies and operational concepts will support a reduction in fuel and emissions while also mitigating noise impact, in support of the EU's policy of transforming aviation into a climate-neutral industry. Performance-based operations will be fully implemented across Europe, allowing service providers to collaborate and operate as if they were one organisation with both airspace and service provision optimised according to traffic patterns. Mobility as a service will take intermodality to the next level, connecting many modes of transport, for people and goods, in seamless door-to-door services.

---

[4] Traditional aircraft will be complemented by new entrants such as very low-level drones, military medium-altitude long-endurance unmanned aircraft systems, automated air taxis, super-high-altitude (FL600+) operating aircraft, next generation supersonic aircraft and electrically propelled aircraft.

[5] Meaning that aircraft and drones can fly their preferred trajectories.

3.1 Offering improvements across ATM

It is widely recognised that to increase performance, ATM modernisation should look at the flight as a whole and not in segmented portions. Mindful of this, the SESAR vision embraces the entire ATM system, offering improvements at every stage of the flight. The latest edition of the European ATM Master Plan lists the following improvements:

- Enabling high network capacity and resilience
- Improved flight trajectories, minimising the environmental footprint of aviation
- Improved airport performance and access
- Enabling higher airborne automation
- Improved ANS operations productivity
- Optimal use of ANS infrastructure and use of scarce resources
- Increased global interoperability and enhanced collaboration
- Enhanced safety and security

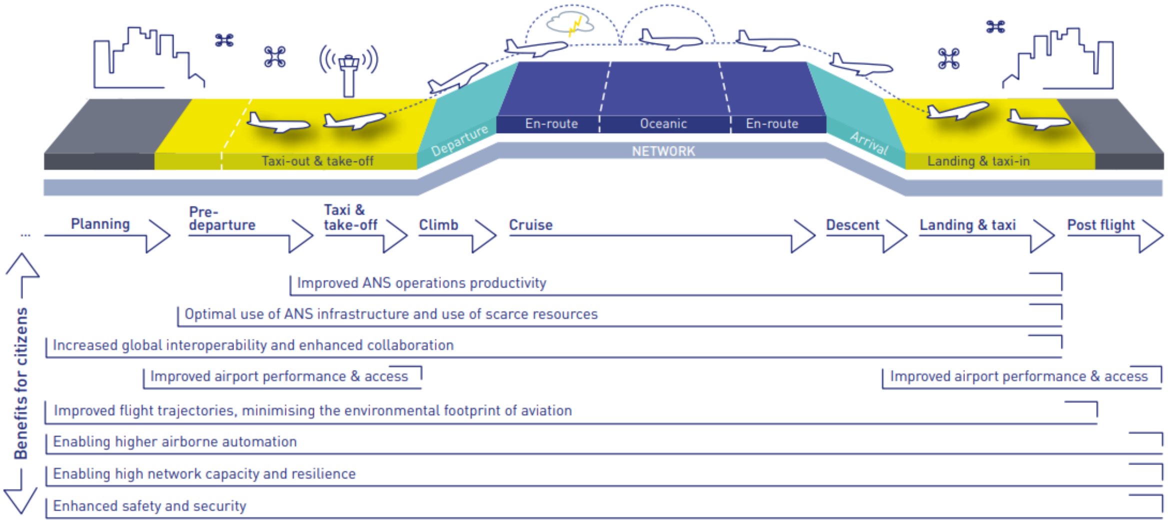

Figure 1: Improvements at every stage of flights

3.2 Embracing the digital transformation of aviation

Digital transformation is not a goal in itself, but the means to accelerate the roll-out of the SESAR vision. The desired change is profound and goes far beyond the narrow understanding of "going paperless" or "replacing analogue with digital". A "digitally transformed aviation" will use targeted data and information through automated and connected solutions to improve the overall performance of the system from a safety, efficiency and cost perspective. Aviation will take full advantage of advanced digital technologies to generate new services, optimise current ones while delivering a better experience and benefits to all stakeholders.

Considering the fast pace of technology development outside ATM and the amount of high-risk/high gain research that could be undertaken in the digital sector (autonomy, artificial intelligence (AI), fast prototyping, etc.), there is a need for an agile and an open approach to collaboration together with higher levels of coordination to keep the pace and reduce time to market.

3.3 Essential Operational Change: CNS infrastructure and services

The CNS domain evolutions will be driven by a service-based approach described in PJ.14 Wave 2 deliverable "D2.1.100 CNS service assessment" and a performance-based approach described in PJ.14 Wave 2 deliverable "D2.1.300 CNS performance-based". This will enable the decoupling of CNS service provision from air traffic services, ATM data services. This change will lead the European ATM system to be more flexible and resilient, allowing scalability.

Through a service-based approach, the CNS services will be specified through contractual relationships between customers and providers with clearly defined, European wide harmonised services and level of quality. This approach will create business opportunities for affordable services with a strong incentive for service providers to compete resulting in cost-efficient services. The progressive introduction of a CNS service-based approach will enable the virtualisation of ATM (consisting in decoupling the provision of ATM data services from ATS) and will enable ANSPs to make implementation choices on how new services are provided. A CNS service-based approach should provide a strong incentive for service providers to cooperate across national boundaries, to optimise the use of technologies as well as the geographical distribution of equipment (and hence optimise spectrum use). It will also provide a better environment for the integration of new CNS services – such as space-based automatic dependent surveillance broadcast (ADS-B) and satellite communications.

The performance-based CNS approach sees an evolution from system/technology-based operations, where systems/technologies are prescribed, towards the delivery of performances-based services, which specify the ambition to be achieved within a specific environment. It is anticipated that this service-based and performance-based approach will favour potential technological/functional synergies across the Communication (COM), Navigation (NAV) and Surveillance (SUR) domains, taking advantage of common system/infrastructure capabilities for the ground, airborne and space segments. From a service standpoint the boundaries between the different domains will disappear progressively as the infrastructure moves to an integrated "digital" framework. It will be the most cost effective for the providers and users. Technologies will evolve over time without requiring the operations themselves to be revisited, as long as the requisite performance is provided by the system.

4 CNS Evolution

4.1 CNS objective infrastructure

The objective or long-term CNS infrastructure should include a backbone of recent and global technologies, supported by Minimum Operational Network of legacy infrastructure.

Performance-based application and CNS services as a backbone

Performance-based Communication, Navigation and Surveillance are being developed, allowing the ATM/CNS to evolve from system-based operations towards the delivery of CNS services. The future integration of these existing concepts under a harmonized Performance-Based CNS framework, including appropriate performance metrics will maximize the cross-domain opportunities and synergies and allow for the support of various airspace concepts. Equally, the concept of Performance-Based Operating Minima will allow the airspace users to maximize their access to the airport by applying reduced minima based on their on-board specific equipment.

Performance-based applications will be supported by a backbone of recent and global technologies, in the form of secure CNS services. Security requirements need to be implemented to mitigate cyber-threats. The technologies foreseen are:

- The implementation of SWIM concept, allowing for an exchange of information across all ATM systems.
- A wide-band and robust digitalised voice and data communication, grouping multiple technology in a seamless way under the multilink concept.
- A robust and accurate positioning and timing service through the use of multiple GNSS constellations providing dual-frequency signals, augmented with ABAS, SBAS and GBAS.
- A global ADS-B coverage based on ground and space networks of receivers, feeding the surveillance chain with the accurate aircraft position and other aircraft derived data but also optimizing the use of the legacy infrastructure through the composite surveillance concept.
- Specific aircraft capabilities tailored to the targeted operations, such as Combined Vision System or advanced navigation capabilities.

Minimum Operational Network of legacy or modernized infrastructure as support

“Minimum Operating Network” could be defined by “A fair rationalisation of the legacy infrastructure down to a point where it can still operate as a backup or provide an efficient support”. The term “Minimum Operating Network – MON” has been first introduced by the US FAA to describe the evolution of their VOR network. A good example of MON is the French strategy for CAT I approaches. Their strategy is use GNSS-based approaches supported by a minimum number of ILS CAT I selected in a way so that most of the instrument runway ends are closer than 30 minutes of flight from an ILS CAT I equipped airfield. This strategy led to the decommissioning of a large number of ILS CAT I, while retaining a minimum capability for contingency in case of wide-spread GNSS failure.

Following this approach, the backbone defined above will be supported by minimum operational network of legacy or modernized technologies:

- Voice VHF communication as a back-up to datalink or air-ground voice-over-IP communication, or to support specific operations.
- An Alternative means of Position, Navigation and Timing (A-PNT) to mitigate possible GNSS loss or degradations due to interferences or space weather events.
- ILS CAT I and CAT II/III on a reasonable number of airports to provide a back-up to GNSS-based landing.
- Composite surveillance systems that combines ADS-B surveillance with layers of independent cooperative (SSR, MLAT) and/or non-cooperative (PSR, video) surveillance, as necessary.

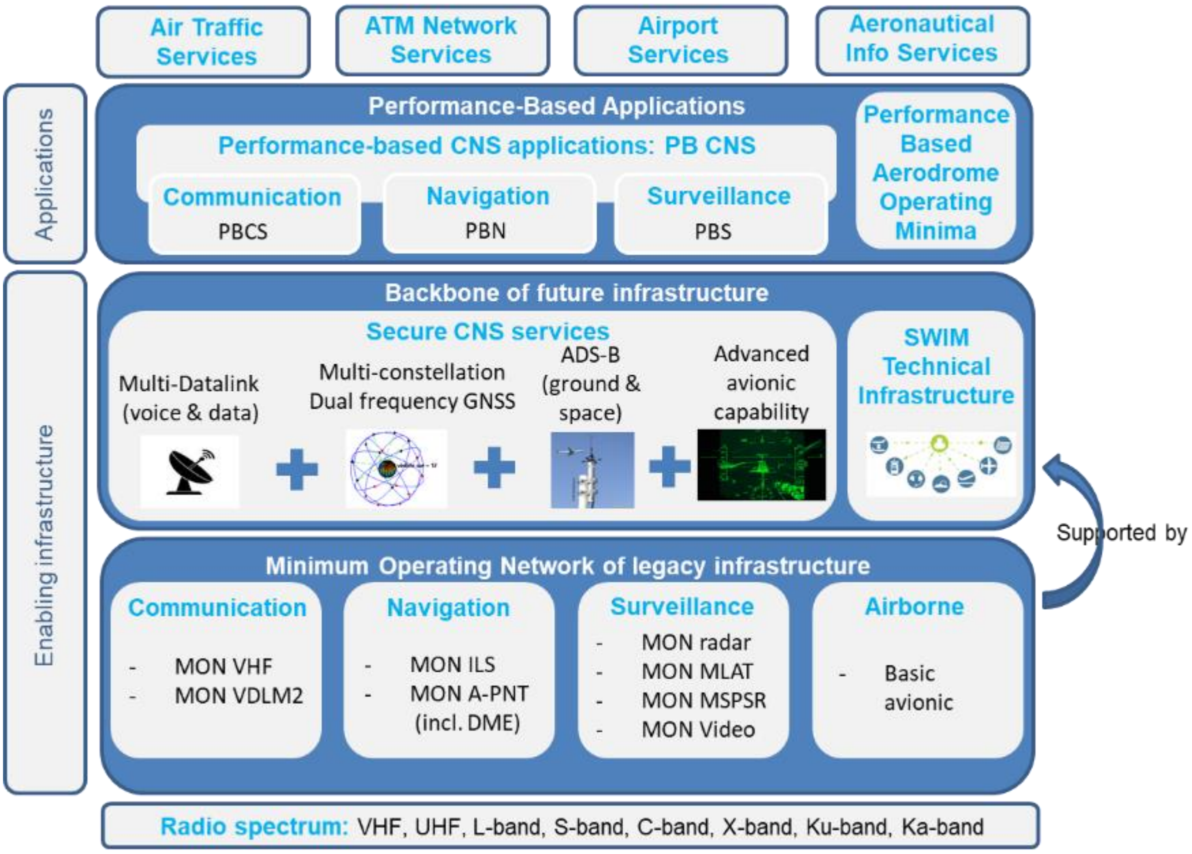

Figure 2: CNS objective infrastructure

4.2 CNS Transition path

The transition path provides a phased description of the required operational evolution, the underlying technologies changes, the rationalization opportunities and the spectrum challenges.

Given that the objective of this section is to provide an integrated view of the CNS evolution, the operational and technological views provided in this section are not structured in the usual

Communication, Navigation and Surveillance domain. Instead, the operational evolutions are organized according to the ATM key features defined in the European ATM Master Plan: optimized network services, advanced air traffic services and high performing airport operations. Concerning the underlying technologies, the evolution will be grouped under the following functional domains: aircraft trajectory negotiation, clearance and exchange; aircraft positioning and identification for oceanic, remote, polar, continental and terminal areas; and the aircraft positioning and guidance for airport access.

4.2.1 From now to 2025

4.2.1.1 Operational view and CNS services

Optimised ATM network services: airspace design and procedures

- **ATM route Network Collaborative Management** will improve the quality and the timeliness of the ATM route network information shared by all ATM stakeholders.
    1. Improves the network performance, capacity and flight efficiency through exchange, modification and management of trajectory information
    2. Includes enhanced Short Term ATFCM Measures, Collaborative NOP, Calculated Take-off Time to Target Times for ATFCM purposes, Automated Support for Traffic Complexity Assessment: the development of the IP ground network (PENS) supports this evolution
    3. The AFTN messaging application is going to be phased out and replaced by AMHS in this phase in Europe.
- **Global Surveillance** will enable ATFM improvements through a better predictability of trajectories thus increasing capacity.

Advanced air traffic services

- **Voice communication** will remain the primary means for the control of aircraft.

- **Free Route airspace** will continue its implementation above FL 305 (or lower in some areas) either with new implementation from current BRNAV/RNAV 5 airspace or by increase of the free route area using cross-border free route activities.

- **ATS routes for oceanic airspace** will be PBN (RNAV 10 and/or RNP 4)

- **ATS routes for en-route (continental) and transition** will end being all based on RNAV 5

- **PBN terminal procedures** will allow reducing fuel consumption and environmental impact in descent/arrival/initial climb phases:
    1. At least one RNAV 1 SID or/and STAR for those instrumental runway ends where there are SID or/and STAR routes
    2. RNP 1 SID or/and STAR, including altitude constraints and/or RF leg functionalities, instead of RNAV 1, where beneficial due to traffic density/complexity or terrain features
    3. RNAV 1, RNP 1 and RNP 0.3 procedures (e.g. Low Level Routes and PinS procedures) for rotorcraft operations

- Implementation of applications that would enable a **higher level of automation**, such as:

    1. **Controller-Pilot Data-Link Communication** (CPDLC) based on ATN B1 will complete its implementation supported by mandate according to EC 29/2009 and as a complementary air traffic control means.

    2. **Trajectory exchange** (ADS-C Extended Projected Profile **EPP**) that would pave the way for future enhanced automation within ATM, especially advance trajectory de-confliction and conformance monitoring.

- **Airborne Separation Assistance System** (ASAS) would be supported through continued deployment of a set of Airborne Surveillance applications based on ADS-B:

    1. **ATSA-AIRB** application which is already operational provides a traffic display that identifies the surrounding aircraft and enhances the flight crew situational awareness. It will supplement out the window and/or voice radio communication on surrounding aircraft.

    2. **In-trail procedures**: In-Trail Procedure (ITP) which is already operational enables aircraft to change altitude in procedural airspace on a more frequent basis by allowing a climb-through or descend-through manoeuver past a reference aircraft, in compliance with a longitudinal separation minima based on distance using ADS-B In-Trail Procedure.

    3. **Flight-deck Interval Management** (FIM): Interval Management (IM) which is expected to be initially deployed by 2025, is a collection of airborne functions that along with appropriate procedures is designed to support a range of operations whose goals are accurate inter-aircraft spacing.

- Regarding **safety nets**, the following is operational or already mature for implementation:

    1. **Hybrid and Extended Hybrid ACAS** is an updated version of ACAS II aiming at the use of ADS-B to reduce the RF impact from ACAS. ACAS is an aircraft safety net system based on Secondary Surveillance Radar (SSR) transponder signals.

    2. **TSAA for non ACAS equipped aircraft and rotorcraft**: Traffic Situation Awareness with Alerts (TSAA) is an application that is intended to reduce the number of mid-air collisions and near mid-air collisions involving general aviation aircraft and rotorcraft. TSAA provides voice annunciations to flight crews to draw attention to Target Aircraft and also adds visual cues to the underlying basic traffic situation awareness. The TSAA application passively uses ADS-B surveillance information to provide the flight crew with indications of nearby aircraft in support of their see-and-avoid responsibility. TSAA provides alerts but does not coordinate with the intruding aircraft and therefore do not provide resolution advisory. Overall, this application can improve safety without having a negative impact on spectrum.

- **Accommodation of all types of UAS operations** (Low level Flight Rules, VFR/IFR and High-level Flight Rules). The UAS accommodation will require ad-hoc coordination between ATC/ATM and the UAS operator and the initial UTM/U-space.

High performing airport operations

- **Generalisation of RNP approach procedures with vertical guidance** for all instrument runway ends:
  1. Implementation of RNAV APCH procedures to LNAV, LNAV/VNAV and LPV minima (according to EU regulation 2018/1048 – PBN IR).
     - Approach operations to the lowest possible LPV minima (provided that the service coverage is appropriate and fleet equipage is sufficient).
     - RF legs where beneficial due to traffic density/complexity.
  2. Where the implementation of RNP APCH procedures with vertical guidance (LPV, LNAV/VNAV minima) is excessively difficult due to terrain, obstacles or air traffic separation, only LNAV will be implemented. In addition, RNP AR APCH will be implemented where beneficial.

- **First implementations of GBAS operations** that include automatic approach, landing (**down to CAT IIIB minima**) and roll-out, and guided take-off. The use of GBAS instead of ILS in LVP will allow taking advantage of the removal of the ILS CSA.

- Initial implementation of **enhanced arrival and departure procedures** supporting **Continuous Climb and Descent Operations**. Some examples of possible implementations of enhanced arrival and departure procedure are listed below:
  1. RNP transition to xLS using RF legs
  2. Established on RNP AR: Established on RNP AR APCH' is a procedure for simultaneous parallel independent approaches that considers aircraft on RNP-AR APCH to be established on the approach procedure.
  3. Point in space procedures: Point in Space (PinS) are approach and departure procedures fully tailored for helicopter operations and include both an instrument and a visual segment.
  4. Simultaneous Non-Interfering operations (SNI) are instrument flight procedures designed to enable helicopters to operate to and from airports without conflicting with fixed-wing traffic or requiring runway slots.
- Implementation of applications that would enable a higher level of automation, such as D-TAXI: a datalink exchange of taxi clearance and route, possibly combined with the display of the taxi route on an airport moving map. D-TAXI is actually a standardised ATS-B2 airport application, which should naturally be deployed over an airport data link such as AeroMACS or Commercial Technologies (see section below)[6].

---

[6] AeroMACS as based on the Wimax obsolete technolgoey is currently being proposed at ICAO and various groups for being adapted to commercial technologies such as 5G: this is called 'AeroMACS2' and is being discussed at the time of writing. Furthermore using Commercial Technologies as such is also the object of discussion and active research, including in SESAR PJ14 solution 61 'Hyper Connectected ATM' lead by Airbus.

- Departure Management

  1. Improved departure flows, taking multiple constraints and preferences into account, maximising the traffic flow on the runway by setting up a sequence with minimum optimised separations. **Airport — Collaborative Decision Making (A-CDM)** establish pre-departure sequences, taking into account multiple constrains.

  2. Automatic determination of optimal surface movement plans (such as taxi route plans) involving the calculation and sequencing of movement events and optimizing resource usage (e. g. de-icing facilities). **Advanced Surface Movement Guidance and Control Systems (A-SMGCS)** provide optimised taxi-time and improve predictability of take-off times by monitoring of real surface traffic and by considering updated taxi times in departure management.

- **Time-Based Separation (TBS)** for final approach:

  1. TBS enables to minimise the impact of strong headwinds on landing rates and thereby reducing delays and cancellations.

  2. TBS is using time intervals instead of distances to separate aircraft in sequence on the final approach to a runway. It can for example be implemented by providing equivalent distance information to be displayed to the controller taking account of prevailing wind conditions. TBS support tools considers radar separation minima, Wake Turbulence Separation and the effect of the prevailing headwind.

- **Airport Safety Nets and Surface Movement Planning and Routing support**

  1. **Airport safety nets** consist of the detection and alerting of conflicting ATC clearances (‘CATC’) to aircraft and deviation of vehicles and aircraft from their instructions, procedures or routing (‘CMAC’) which may potentially put the vehicles and aircraft at risk of a collision. It includes both the Runway and Airfield Surface Movement area.

  2. The system integrates air traffic controller instructions with other data such as flight plan, surveillance, routing, published rules and procedures, if available.

  3. The routing and planning functions of **Advanced Surface Movement Guidance and Control Systems (A-SMGCS)** provide automatic generation of taxi routes, with the corresponding estimated taxi time and management of potential conflicts.

- **Airborne Separation Assistance System** (ASAS) would be supported through continued deployment of a set of Airborne Surveillance applications based on ADS-B:

  1. **Enhanced Visual Separation on Approach** (ATSA-VSA): Clearances to maintain own visual separation on approach are used in current operations. The VSA application which is already mature for implementation provides the additional support of a traffic display that plots and identifies the preceding aircraft.

  2. Implementation of **CDTI Assisted Visual Separation** (CAVS): similar to VSA, the CAVS is used to assist the flight crew in acquiring and maintaining visual contact with a

preceding aircraft (designated traffic) but the operation can be continued if the visual contact with the preceding aircraft is lost.

3. **ATSA-SURF** enhance the flight crew's traffic situational awareness on the airport surface or when arriving/departing to/from an airport by providing a traffic display that locates and identifies the surrounding aircraft and overlays their position on the airport map. The traffic display supplements the out-the-window scan for both taxiway and runway operations.

4. **SURF IA** uses indications highlighting situations (traffic or runway) of interest to anticipate possible future risk of collision and Alerts. It operates relative to all ADS-B equipped entities.

- Initial implementation of **Performance-Based Aerodrome Operating Minima (PBAOM)**: Modern regional and business aircraft are increasingly equipped with additional systems like HUD, EVS, auto-land, etc. These aircraft can safely operate to lower RVR and/or DH or operate to traditional minima with less reliance on ground facilities. The higher performance capabilities of new and improved avionics have mitigated some of the performance requirements of the ground-based navigation equipment. The minima will be predicated upon the combined capabilities of the ground and airborne facilities, i.e. the resulting performance for providing guidance during the instrument and visual segments of the approach and landing, hence the concept "Performance-Based Aerodrome Operating Minima (PBAOM).

- **Remote tower:** the use of video surveillance combined with ADS-B or other surveillance technologies allow the control of small to mid-size airport remotely which will provide air traffic services in a cost-efficient way.

4.2.1.2 Underlying technology and solutions

Trajectory negotiation, clearance and exchange

The trajectory will continue to be mainly negotiated between the pilot and the air traffic controller through voice communication. As a complementary communication means, datalink will be increasingly used. The supporting infrastructure will be composed of:

- A/G Voice communication:
    1. ***VHF 25kHz and 8.33kHz*** spacing in continental airspace
    2. ***HF*** in oceanic, remote or polar airspace
    3. ***SATCOM class C and B*** in oceanic, remote or polar airspace but also gradually in continental airspace

- A/G Data communication:
    1. ***VDLM2*** in continental airspace
    2. ***HF*** in oceanic, remote or polar airspace

3. ***SATCOM class C and B*** in oceanic, remote or polar airspace but also gradually in continental airspace

4. AeroMACS on the Airport Surface, for Airport and/or ATN/OSI Services

5. **4G (LTE)** in General Aviation airspace for non-safety critical services, as studied by SESAR2020 Project FACT.

- G/G Data and Voice communications

    1. Migration to the Internet Protocol IP Backbone (pan-European network service - **PENS)** for both for voice and data. Since this is a technical migration, current applications such as AFTN/AMHS, OLDI, surveillance distribution, etc maintain largely the same way of working, transparently for operational users.

    2. Communications beyond national borders (e.g. in the FAB concept) is being supported by network-based ground data and voice telecommunications relying on **NewPENS evolution**.

    3. **Voice over IP** is used purely on the ground, both for telephony and radio signalling and digital voice transmission.

Aircraft position and derived data for oceanic, remote, polar continental and terminal area

- **Aircraft:**

    1. An **RNP on-board aircraft position backed-up by RNAV sources**: GPS L1 augmented by ABAS and SBAS will be primarily used, complemented by inertial systems where available/required and backed-up by an optimised VOR and DME network. The optimised DME network might require a slight increase in the number of DME. On-board Navigation System might be required to support procedure with defined Fixed Radius paths.

    2. Although the **Dual-Frequency Multi-Constellation GNSS** infrastructure is planned to be introduced by 2025, most of the traffic is expected to keep using GPS L1. A broadcast of the **GPS L1 on-board aircraft position** to the ground and to other aircraft for all areas through ground- and space-based ADS-B. Aircraft will also acquire the position of surrounding aircraft (ADS-B in).

    3. The airspace Users will continue to be equipped with “future proof” technology with both **Mode S ELS/EHS and ADS-B capabilities**. The aircraft which are not covered by any regulatory obligations for equipage may equip on voluntary basis. Provisions preventing transmission and use of misleading Surveillance data will be implemented. Furthermore, in addition to the current avionic capabilities to support “ADS-B In” applications (ITP, AIRB, SURF, VSA), improved avionics capabilities enabling initial operations of CAVS, , SURF IA and IM applications will be available.

- **Ground ATS surveillance sensors:**

    1. **Independent and cooperative surveillance sensors** (mainly Mode S secondary radar and/or WAM) used as a main mean of surveillance

2. A **ground or space-based ADS-B** layer covering the whole airspace used as a main or complementary mean, depending on the airspace.

3. Where required a **non-cooperative surveillance layer** (PSR or MSPSR) ,

4. The other components of the ground Surveillance chain, namely the Surveillance Data Fusion the Surveillance Data Distribution and the Surveillance Data Analysis will be enhanced to address the characteristics of the new Surveillance environment. This includes the new types of sensors (MSPSR, video etc.), new types of targets (incl. RPAS) and a drastically increased number of Surveillance data Users. **Continuous Performance Monitoring** will be available to address deviations or anomalies and trigger associated mitigation and corrective actions.

5. The **Performance-Based Surveillance (PBS)** will be specified and standardised at European and ICAO level, linking a first set of operational applications, airspace types and separation minima with SUR safety and performance requirements in a technology agnostic way. The first group of applications being addressed by PBS is for 2, 2.5, 3 and 5 nm separation in various traffic densities (low, medium and high).

Aircraft position and guidance for airport access

- **Aircraft:**

  1. Approaches with minima higher than 250 ft will be **mainly GPS L1 based**: ABAS (LNAV and LNAV/VNAV using barometric VNAV) and/or SBAS (LPV)

  2. 3D Approaches with minima higher than 250 ft will start to evolve from **a mix of GPS L1 based (SBAS/GBAS) and ILS towards mainly GPS L1** based approaches (SBAS/GBAS).

  3. **Some CAT II** (200 ft>DA/H ≥100ft) approaches with **GBAS CAT I** airborne and ground equipment (**with SBAS integration** to support CAT II on CAT I) will be available. Approaches down to CAT II/III (DA/H≤200 ft) will be **mainly based on ILS**, complemented by some GBAS approaches enabled by GAST D (GPS L1 based) ground subsystems.

  4. Although the **Dual-Frequency Multi-Constellation GNSS** infrastructure is planned to be introduced by 2025, most of the traffic is expected to keep using GPS L1.

  5. **Enhanced Flight Vision Systems and Synthetic Vision and Guidance Systems** will initiate a decrease of minima for a limited number of approaches (see EASA CS AWO May 2022 for more details).

- **Ground ATS surveillance sensors:**

  1. Where required, **Surface Movement Radar (SMR), MLAT or** ADS-B will support the control of the aircraft.

  2. **Video surveillance**: This technique uses video cameras to detect target positions. This technology can be used as a standalone or as complementary primary surveillance

source, and is the perfect candidate for remote towers, as it also provides a virtual vision of the airport.

3. Where required and depending on local assessment, large airport may need to acquire **a detection capability of non-cooperative UAS**. The technology could be based on dedicated radars or RF signal analysis, coupled with video/electro-optical systems and supported by high-end software enhanced by the use of machine learning/artificial intelligence.

4.2.1.3 Rationalization opportunities

- The decommissioning of ILS CAT I will start.
- The decommissioning of NDBs and some VOR will start.
- The decommissioning of Mode A/C Radar will continue as well as the clustering of sensors, the extraction of only the DAPs which are operationally used as well as switch to using ADS-B based DAP/ADD data instead of Mode S BDS extraction, use of more efficient mix of sensors etc.
- The wider deployment of ADS-B will also improve ACAS (Extended) Hybrid Surveillance which has a very high potential for spectrum efficiency (up to 40% reduction of RF congestion).
- The use of remote tower may allow the rationalisation of some control towers although control towers are usually not considered as part of the CNS infrastructure.

4.2.1.4 Short Term CNS Spectrum Perspective

For Communication systems, there is increasing pressure for both voice and data Communication, in particular due to the increasing data volume of ATN protocol (IDRP) and Airline Operational Communications (AOC). It is therefore essential that the Multilink Future Communication Infrastructure concept advances, including the development of LDACS and the broader implementation of AeroMACS, alongside with the use of SATCOM.

For Navigation systems, in addition to advancing the rationalization of NDB, the rationalization of VOR is essential. While VOR does provide important residual capabilities, with the implementation of PBN it will increasingly transition to a back-up system[7]. VOR rationalization enables the implementation of GBAS while removing channel pairing constraints for DME, which will increasingly be implemented as a non-associated aid to support PBN in a network fashion to support both RNAV1 and RNAV5 at altitude. Protection of the DME is essential to ensure robust back-up to GNSS outages while enabling sharing in a compatible way with LDACS, while maintaining compatibility with the ongoing implementation of GNSS on the L5/E5 frequency and without interference from non-aviation systems. The evolution of ILS services towards a Minimum Operational Network will still need to be protected from radio broadcast below 108 MHz.

---

[7] For details see ICAO Annex 10, Volume I, Radio Navigation Aids, Attachment H.

For Surveillance systems, careful management and monitoring of 1030/1090 MHz radio traffic load is essential, while maintaining safety and primary radar capabilities.

Potential Radio Frequency Interference from 5G services to RADALT are a concern for both Navigation and Surveillance applications and careful monitoring of 5G implementation (and forthcoming services – 6G, 7G…) must ensure suitable mitigation measures are implemented as required.

4.2.2 From 2025 to 2030

4.2.2.1 Operational view and CNS services

Optimised ATM network services: airspace design and procedures

- **Initial SWIM** (iSWIM) ground-ground applications (AIS/MET, later Flight Objects) will start replacing some of the current ground-ground message-exchange flows supported by AMHS and OLDI), based on bilateral or multicast distribution of messages such as flight plans, NOTAMS, METARS, flight plan updates, coordination and transfer messages etc… If compared with the time scale involved in the previous evolution of those systems (i.e. the AFTN migration to AMHS), this next step is likely to take a similar if not longer amount of time. Note that iSWIM is not likely to completely replace Messaging systems at this time scale, due to the number of various operational needs.
- **Initial Trajectory Information sharing (EPP) supported by iSWIM** is related to the above considerations of iSWIM, but this time involving the aircraft itself for trajectory exchange on the air-ground link, before sharing the trajectory on the ground with ground-SWIM. The concepts have been the object of trials in the SESAR 1 project “PEGASE”, continuing in the SESAR2020 DIGITS project and PJ38 ADSCENSIO project.

Advanced air traffic services

- In the upper airspace (above FL 305 or lower in some specific area), collaboration between ANSPs across Europe may provide a **European-wide cross-border free-route airspace** allowing the airspace user to plan for direct routes between airports.

- **ATS routes for oceanic** airspace will remain PBN (RNAV 10 and/or RNP 4).

- **ATS routes for en-route (continental) and transition** will be all based on RNAV 5.

- **PBN optimized terminal procedures** allow reducing fuel consumption and environmental impact in descent/arrival phases:

    1. RNAV 1 SID/STAR implementation will progressively be extended to all SID/STAR to instrument runway ends where there are SID or/and STAR

    2. RNP 1, including altitude constraints and/or with RF leg functionalities, SID and STAR should be implemented instead of RNAV 1 where beneficial due to traffic density/complexity or terrain features
    3. RNAV 1, RNP 1 and RNP 0.3 procedures (e.g. Low Level Routes and PinS procedures) for rotorcraft operations

- **Voice communication** will remain the main means of communication between controllers and pilots, as used to control the trajectory of aircraft.

- Implementation of applications that would enable a **higher level of automation**, such as:

    1. **Advanced Controller-Pilot Data-Link Communication** (CPDLC) based on ATS-B2 will now support an increasing share of the complete pilot-controller communications,

allowing for more automation on ground. Note that ATS-B2 is based on EUROCAE ED228 Rev A published in 2016, and the ED228 Rev B is expected to be issued in 2023.

2. **Trajectory exchanges** combined with **advanced air traffic control HMI** will enable accurate prediction of air traffic conflicts and propose optimized intervention to the air traffic controller.

- **Initial Airborne Separation (ASEP)** applications will be implemented and pave the way toward future more demanding **Airborne Separation Assistance System** (ASAS) applications:
    1. Continuation of the implementation of **Flight-deck Interval Management** (FIM)
    2. **In-trail procedures** will be fully deployed.
- **Enhanced safety nets**:
    1. ACAS X is the next generation of Airborne Collision Avoidance System that will be tailored for different airspaces users.
    2. The use of enhanced surveillance Downlink Aircraft Parameters (DAP) will allow the development of enhanced safety nets, such as consistency check of the on-board QNH setting.
- **Integration of LFR and IFR UAS operations; accommodation of VFR and HFR UAS operations.** The integration will require coordination with some level of automation between ATC/ATM and the UAS operator and the initial UTM/U-space for LFR and IFR UAS operations. Ad-hoc and specific procedures may remain for VFR and HFR UAS accommodation.

High performing airport operations

- **ILS CAT I** procedures will be **progressively replaced by RNP approaches based on SBAS** that can be operated down to 200 ft minima (provided that the service coverage is adequate and fleet equipage is sufficient).
- **Implementation of optimised low visibility operations using GBAS CAT II/III at large airports**.
- Further implementation of **enhanced arrival and departure procedures**. Some examples:
    1. Closely Spaced Parallel Runways operations using staggered thresholds (CSPR-ST) to optimise wake vortex separations between the aircraft.
    2. Increased Second Glide Slope (ISGS): a glide path with a higher glide slope between 3.0° and 4.49°, in addition to the standard 3° glide slope. The two slopes are active at the same time on a runway.
    3. Secondary Runway Aiming Point (SRAP): a glide path anchored to a shifted touch down point with respect to the standard threshold. The two runway thresholds are active at the same time on a runway.
    4. Increased Glide Slope to a Second Runway Aiming Point (IGS-to-SRAP).Adaptive Increased Glide Slope (A-IGS): an airborne on-board functionality that calculates the best descent glide slope (limited to 3.5º) in accordance to the local conditions (e.g. wind, aircraft mass, temperature, etc.) on the basis of the lower published glide slope.

- Completion of the **Performance-Based Aerodrome Operating Minima (PBAOM)** implementation

- **Enhanced safety nets**: **Approach Path Monitor (APM)** is intended to warn the controller about increased risk of controlled flight into terrain accidents.

- **Remote tower**: will continue its deployment in small to mid-size airport or as a contingency mean for large size airport.

4.2.2.2 Underlying technology and solutions

Trajectory negotiation, clearance and exchange

Although the negotiation of trajectory between the pilot and the controller will continue to use voice communication, a significant share of the communication will be supported by data communication. The supporting infrastructure will be composed of:

- Voice communication:

    1. **VHF 8.33 kHz and a Minimum Operating Network of VHF 25 kHz** in continental airspace: although VHF 25 kHz communication is expected to be largely rationalized by this phase there will likely remain offset carrier (CLIMAX) airspace sectors based on 25 kHz channel spacing.
    2. A limited use of **HF** in oceanic, remote or polar areas;
    3. Potentially **LEO Satellite VHF voice communications** in oceanic and remote areas
    4. **SATCOM class B** in oceanic, remote or polar airspace but also gradually in continental airspace

- Air-Ground data communication will be supported by an IP-based **multilink concept** managing multiple digital data links working in parallel according to Quality of Service requirements imposed by operational applications. Multilink will have its Initial Operation Capability in this phase and will manage:

    1. ***VDLM2***[8] in continental airspace
    2. ***SATCOM class B*** in oceanic, remote or polar airspace but also gradually in continental airspace
    3. ***LDACS:*** an L-Band technology based on a cellular concept in support of continental (line of sight) data communications. LDACS is an ATN/IPS subnetwork developed for

---

[8] Whether VDLM2 will be included in the Internet Protocol based multilink system is of writing yet not confirmed; at a minimum, a "connection less" version of VDLM2, without the X.25 Subnetwork adaptation as used in the current ATN/OSI, shall be envisaged.

ATS Baseline 3, which will have an Initial Operational Capability in this phase. As it comes into Initial Operational Capability in this phase, LDACS is also supporting ATS Baseline 2 services.

4. ***AeroMACS:*** a C-Band technology and an ATN/IPS subnetwork for use at airports. It is based on the Wimax technology (IEEE 802.16), of which AeroMACS is a profile and is expected to be used in the airport area.

5. Commercial communication using technologies non-dedicated to aviation (e.g. Mobile telephony systems such as 4G, 5G or further evolutions, and additional commercial solutions) **may** complement dedicated technologies (LDACS and/or AeroMACS). They may replace those technologies for non-safety-of-life communications and are arguably not to be integrated in the multilink concept discussed so far. This point is very much in discussion at the time of writing this report particularly in SESAR2020 PJ14 solution 61 'Hyper Connected ATM'.

- New radio and antennas generation: the use of **software defined radios** will ease the transition and the deployment of new datalink protocols. Equally the use of **multiband antennas** will increase the communication flexibility while reducing the need for hardware installation on aircraft.

- G/G communications

  1. The initial deployment of **G/G SWIM** (based on **Service Oriented Architecture** SOA) will continue in replacement of more and more flows still using messaging technologies. Depending on the type of application supported by this, the relevant SWIM profile will be used, with corresponding requirements on the underlying network, being NewPENS or even public Internet if the safety case allows and other considerations require it, taking into account security requirements.

Aircraft position and derived data for oceanic, remote, polar continental and terminal area

- **Aircraft:**

  1. An **RNP on-board aircraft position backed-up by RNAV sources**: GPS L1 or GNSS DFMC augmented by ABAS and/or SBAS will be used, complemented by inertial systems where available/required and backed-up by a **Minimum Operating Network (MON) DME and VOR**. An RF on-board function might be required to fly certain terminal procedures (e.g. some RNP AR departures but not only, other PBN procedure may benefit from RF).

  2. A broadcast of the **GPS L1 or GNSS DFMC on-board aircraft position** to the ground and to other aircraft for all areas through ADS-B and space-based ADS-B. Aircraft will also acquire the position of surrounding aircraft (ADS-B in).

  3. During this Phase, the equipage of all mandated fleet with "future proof" technology (**Mode S ELS, EHS and ADS-B**) will have been completed. Voluntary equipage of non-mandate fleet will have reached significant levels, allowing an improved datalink capacity and backwards compatibility. Furthermore, regarding "ADS-B In" applications, avionics with advanced Airborne Spacing and Separation capabilities will

be available. The full deployment of ADS-B will further increase the benefits from future ACAS (Extended Hybrid but also ACAS X) in terms of performance and spectrum efficiency.

- **Ground ATS surveillance sensors:**

  1. A **ground or space-based ADS-B** layer covering the whole airspace widely used operationally.
  2. **Where required, one or two independent cooperative surveillance layers** (mainly mode S secondary radar and/or MLAT).
  3. In terms of Non-Cooperative Surveillance, Multi-static PSR (MSPSR) technology and RPAS specific surveillance technologies addressing safety and security issues will be deployed.
  4. The Surveillance Data Fusion the Surveillance Data Distribution and the Surveillance Data Analysis with the already available enhancements will be widely deployed. Real-time continuous performance monitoring will be available.
  5. The Performance-Based Surveillance (PBS) standardised at European and ICAO level together with a European rationalisation plan aiming at cost and spectrum efficiency, will be the basis for ground system deployment.
  6. **The UAS IFR integration will induce a larger number of targets** and the ground surveillance chain may require some adaptation to increase its capacity.

Aircraft position and guidance for airport access

- **Aircraft:**

  1. Approaches with minima higher than 250 ft will be **SF GNSS and DFMC GNSS based**: ABAS (RAIM and H-ARAIM) and/or SBAS, using barometric VNAV for LNAV/VNAV and SBAS for LPV.
  2. **CAT I approaches will be mainly L1 GNSS and DFMC GNSS** based approaches (SBAS/GBAS) backed up by a **Minimum Operating Network of ILS CAT I.** The use of CAT I systems may be extended towards lower minima (most likely 150 ft) based on PBAOM.
  3. **CAT II/III approaches will be mainly based on ILS**, complemented by GBAS GPS L1 or first DFMC GBAS CAT II/III systems. Possibly, approaches down to CAT II based on DFMC SBAS (which may need some additional airborne equipment) may be introduced.
  4. **Enhanced Flight Vision Systems (EFVS), Synthetic Vision and Guidance Systems (SVGS), and Combined Visions Systems (CVS)** allow operational credit in the frame of PBAOM towards lower minima.

- **Ground ATS surveillance sensors:**

1. Where required, a M**inimum Operating Network of Surface Movement Radar (SMR) and MLAT** complemented by ADS-B will support the control of the aircraft.

2. **Video surveillance**: This technique uses video cameras to detect target positions. This technology can be used as a standalone or as complementary primary surveillance source, and is the perfect candidate for remote towers, as it also provides a virtual vision of the airport.

3. Where required and depending on local assessment, large airport may continue to deploy **a detection capability of non-cooperative UAS**. The technology could be based on dedicated radars coupled with high-end software enhanced by the use of machine learning/artificial intelligence.

4.2.2.3 Rationalization opportunities

- The decommissioning of NDBs will continue towards a full decommissioning.

- The decommissioning of VOR will continue towards a Minimum Operating Network. The Minimum Operating Network of DMEs will remain similar to the network optimised in the previous timeframe.

- The decommissioning of PSR, SSR mode A/C and mode S radars will continue. Surveillance Data Fusion, radar mode S clustering and Composite surveillance will optimize the use of all available sensors and spectrum. The use of more efficient mix of sensors will intensify.

- The decommissioning of terrestrial navigation aids that only support non-precision approach and ILS CAT I will continue. A Minimum Operational Network of ILS CAT I is expected at key airports (e.g. where CAT II/III facilities are not in close proximity).

- The use of remote tower may allow the rationalisation of some control tower, although control towers are usually not considered as part of the CNS infrastructure.

4.2.2.4 Mid Term CNS Spectrum Perspective

For Communication, initial deployment of LDACS should commence and allow offloading VDLM2 traffic.

For Navigation, new GNSS receivers will likely include a data downlink of Radio-Frequency interference status which likely needs to be accommodated on a Surveillance link (ADS-B or other downlink still under discussion). While DME compatibility needs to be maintained, A-PNT studies should lead to first conclusions on a possible long-term successor to DME and its impact on the L-Band.

Transition to a new generation of radio-altimeters in 4200 to 4400 MHz should be initiated to further facilitate 5G (or 6/7G) implementation.

For Surveillance, both ADS-B In and Out, e.g., ACAS X and phase modulation technique, would take into account the complex cooperative surveillance framework and optimise the use of 1030/1090MHz frequencies.

CNS Systems integration should increasingly accommodate cyber security, such as comparing positions from different sensors to mitigate the risk of radio-frequency spoofing – with potential Communication support for some security features.

4.2.3 2030-2035 and beyond

4.2.3.1 Operational view and CNS services

- **Voice communication** will start being largely replaced by data communications as the regular means for the control of aircraft but will remain in use for emergency and any other specifics needs, either in analogue or digital form. Traffic forecasts predict a continued increase in air traffic, meaning that even if most communications are realised by data exchanges, voice communications will not become insignificant. These qualitative considerations must be further detailed in voice/data traffic models for the future.

- **Messaging applications** will exchange ground/ground information related to AIS/MET, Flight Objects, etc, supported by general messaging and SWIM technologies.

- **Trajectories exchanges and 4 D applications** supported by emerging technologies (such as Artificial Intelligence, Big Data management…) combined with **advanced air traffic control HMI** will enable accurate prediction of air traffic conflicts and propose optimized intervention to the air traffic controller with **a high level of automation**. In particular:

    1. **Controller-Pilot Data-Link Communication** based on ATS Baseline 3 (B3) will be the primary means of communication to control the aircraft. Operational applications to be part of B3 are still not yet defined, although an initial estimate of performance requirements from these applications on the Future Communications Infrastructure (FCI) has been proposed in SESAR 1 Project 15.2.4, SESAR 2020 PJ14.02.04 and continues in SESAR 2020 Wave 2 PJ.14-W2-77 FCI services.

    2. Although timescales are vague at this stage due to the fact that further work is needed for the proof of concept, "**sectorless ATM**" may be introduced. This is a "revolutionary[9] concept for air traffic management in upper airspace. It envisions en-route air traffic control without conventional sectors. One controller will be assigned several aircraft regardless of their location and will guide these aircraft during their entire flight in upper airspace. This new concept promises a significant increase in capacity and controller efficiency. Furthermore, this aircraft-centred approach provides more flexibility fewer handovers and enables user preferred routes".

- **Airborne Separation (ASEP)** applications will be implemented:

    1. **Advanced Interval Management**: Advanced-IM will include additional scenarios, and will address operations such as dependent staggered arrivals, paired approach…

- **Self-separation application**, including autonomous aircraft operations, using associated Flight Rules and supporting functionality such as Conflict Detection and Resolution. This could apply

---

[9] http://www.dlr.de/fl/Portaldata/14/Resources/dokumente/veroeffentlichungen/Sectorless_ATM_flyer_web.pdf

to specific parts of the airspace e.g. en-route and be linked to a Performance-Based CNS scheme.

- **Enhanced safety nets** will be fully deployed (ACAS X for instance).
- **Exclusive use of PBN since 2030 from en-route down to CAT I**:
  - ATS routes for oceanic airspace will be PBN (mainly RNP 4)
  - PBN terminal procedures will be RNAV 1 or RNP 1 for aircraft operations, and RNAV 1, RNP 1 and RNP 0.3 for rotorcraft operations.
  - RNP approaches based on SBAS and/or ABAS that can be operated down to CAT I minima (provided that the service coverage is adequate and the fleet equipage is sufficient). ILS and GBAS CAT I equipment only allowed post 2030 for contingency and areas where SBAS service coverage is not met.
- **CAT II/III operations mainly supported by GBAS (in the long term mainly DFMC GBAS)**. In order to provide a non-GNSS based contingency, ILS CAT II/III PA might be available at certain aerodromes.
- **Integration of LFR, VFR and IFR UAS operations; accommodation of HFR UAS operations.** The integration of a larger number of vehicles will require coordination with a higher level of automation between ATC/ATM and the UAS operator and the UTM/U-space. Ad-hoc and specific procedures may remain for HFR UAS accommodation.

4.2.3.2 Underlying technology and solutions

The **Performance-Based CNS (PBCNS)** concept will be standardised at European and ICAO level. This concept could define ATM applications, which would be supported by performance-based Communication, Navigation and Surveillance applications. In term of technology, a multilink and robust datalink, GNSS DFMC and ADS-B would be the backbones of this concept.

Trajectory negotiation, clearance and exchange

The negotiation of trajectory between the pilot and the controller will mainly use data communication and voice communication infrastructure will start to be rationalized toward an initial minimum operating network. The supporting infrastructure will be composed of:

- **Multilink Data communication** managing **LDACS** in continental airspace, **AeroMACS** on the airport, **SATCOM class B and A**[10]**,** and potentially **VDLM2** and/or **VHF Satellite data communications** (to be confirmed). Commercial communication using technologies non-dedicated to aviation may complement dedicated technologies (LDACS and/or AeroMACS).
- Voice communication will be used as a back-up and for emergency or any other specific needs through the use of a **Minimum Operating Network of VHF** 8.33 and 25 kHz systems, potentially

---

[10] To be confirmed whether both Class A and Class B can be operating in the same airspace due to the RCP gap.

complemented by VHF Satellite voice communications. VHF 25 kHz will arguably still be in use, in the case of 8.33 kHz exemptions (sectors with offset carrier, CLIMAX). **Digital voice** over LDACS or Satcom Class A will be introduced, channel allocation will be reviewed to take into account the spectrum required for transmission of the digital voice stream. Furthermore, end-to-end **Voice over IP** A/G signalling would then be introduced as well, with an impact on the above spectrum requirements.

Aircraft position and derived data for oceanic, remote, polar continental and terminal area

- **Aircraft:**

  1. An **RNP on-board aircraft position backed-up by RNP sources**: GNSS DFMC augmented by ABAS and SBAS will primarily be used, complemented by inertial system where available/required and backed-up by an RNP A-PNT (A-PNT is a generic term that encompass all possible candidate for alternative Position, Navigation and Tiiming: like LDACS-NAV, enhanced DME, multi-DME, mode N, visual/terrain navigation…). An RF on-board function might be required to fly certain terminal procedures (RNP AR departures).

  2. A broadcast of the **GNSS DFMC and its RNP back-up** on-board aircraft position to the ground and to other aircraft for all areas through ADS-B and space-based ADS-B. Aircraft will also acquire the position of surrounding aircraft (ADS-B in).

  3. Equipage with a higher performance ADS-B standard (v3) will continue. Furthermore, regarding “ADS-B In” applications, Airborne Separation (ASEP) avionics use will expand further. Limited self-separation will be first possible in oceanic, remote and polar areas and will expand further and gradually in other areas.

- **Ground ATS surveillance sensors:**

  1. The use of the **broadcast aircraft on-board position through ADS-B** based on the GNSS DFMC position and its RNP back-up allow the use of ADS-B for more demanding ground Surveillance applications.

  2. **Clustered mode S radar and MLAT** under the composite surveillance concept will complement the infrastructure.

  3. Where required for security reasons, **a non-cooperative surveillance layer**

  4. The Surveillance Data Fusion the Surveillance Data Distribution and the Surveillance Data Analysis with the already available enhancements will be widely deployed. Real-time continuous performance monitoring will also be widely available.

  5. **The UAS VFR/IFR integration will induce a larger number of targets** and the ground surveillance chain may require some adaptation to increase its capacity.

Aircraft position and guidance for airport access

- **Aircraft:**

  1. Approaches with minima higher than 250 ft will be **mainly DFMC GNSS based**: ABAS (LNAV/VNAV using barometric VNAV or LPV using V-ARAIM) and/or SBAS (LPV)
  2. **CAT I approaches will be mainly DFMC GNSS based** approaches (SBAS and/or ABAS based on V-ARAIM) backed up by a Minimum Operating Network of ILS/GBAS CAT I. The use of CAT I systems may be extended towards lower minima (most likely 150 ft) based on PBAOM.
  3. **CAT II/III approaches will be progressively supported by GBAS (mainly DFMC GBAS)** at large airports **backed up by a MON of ILS CAT III**. Type B approaches down to CAT II[11] may be based on DFMC SBAS (although some additional airborne equipment may be required).
  4. **Enhanced Flight Vision Systems (EFVS), Synthetic Vision and Guidance Systems (SVGS), and Combined Visions Systems (CVS)** allow operational credit in the frame of PBAOM towards lower minima.
  5. .

- **Ground ATS surveillance sensors:**

  1. Where required, SMR, MLAT and ADS-B will be used to support the control of the aircraft.
  2. Video surveillance: This technique uses video cameras to detect target positions. This technology can be used as a standalone or as complementary primary surveillance source, and is the perfect candidate for remote towers, as it also provides a virtual vision of the airport.
  3. Where required and depending on local assessment, large airport may continue to deploy **a detection capability of non-cooperative UAS**. The technology could be based on dedicated radars coupled with high-end software enhanced by the use of machine learning/artificial intelligence.

4.2.3.3 Rationalization opportunities

- The decommissioning of ILS CAT I will continue.
- The decommissioning of ILS CAT II/III will start towards a Minimum Operational Network.

---

[11] Besides the possibility of CAT II approaches based on GBAS CAT I airborne and ground equipment using SBAS data.

- The rationalisation of analogue VHF voice will start toward a Minimum Operating Network for back-up, emergency or specific situation.
- Depending on the A-PNT solution, DME may either start to be decommissioned or will be maintained.
- Although the EU-US Air/Ground Data Communication common strategy (June 2016) do not foresee any VDLM2 phase out, an initially rationalisation toward a Minimum Operating Network can be expected by the end of this phase.
- PBCNS together with COM, NAV and SUR technological progress will allow the CNS to reach a Network optimum. Mode S radar and MLAT might be organised in a Minimum Operating Network.
- The use of remote tower may allow the rationalisation of some control towers, although control towers are usually not considered as part of the CNS infrastructure.
- The use of future ACAS systems (Extended Hybrid but also ACAS X) will be increased enabling further spectrum efficiency.

4.2.3.4 Long Term CNS Spectrum Perspective

In VHF, a clear perspective should be available on future need for both VHF Navigation spectrum for supporting the remaining ILS and VOR as well as GBAS VDB, and for VHF Communication spectrum for supporting 8.33 KHz voice and VDLM2 channels.

In the 960 to 1215 MHz L-Band, implementation of GNSS L5 and a complementary DME network should be mature, while having a clear view on the needs of cooperative Surveillance and the evolution of LDACS. Transition to new and more spectrum efficient L-Band NAV capabilities (A-PNT) could begin, possibly using CNS synergies (LDACS-NAV).

All SATNAV, SATCOM and SATSUR services should have adequate terrestrial back-ups including clarity on associated spectrum requirements.

4.3 CNS Roadmap

The figure below provides a graphical view of the CNS Roadmap detailed in the previous sections.

There is one arrow per technology or type of technology. Given that the technologies have been grouped under the functional domain “Trajectory negotiation, clearance and exchange”, “Aircraft positioning and identification”, and “Aircraft position and guidance for airport access”, the technological arrows have been also grouped under these functional domain. The arrow’s colour is driven by the framework under which the technology is implemented, either Performance-Based Communication, Navigation, Surveillance or in the future, CNS. These concepts are defined and clarified in the introduction of this document (see section 1). The objective infrastructure backbones have been identified using grey boxes, whereas the technologies expected to be deployed or rationalized in minimum operational network have been identified with pink boxes.

On top of the technological arrows, the applications supported by the underlying technologies have been identified. The applications have been categorized according to the ATM key features defined in the European ATM Master Plan: optimized network services, advanced air traffic services and high performing airport operations. The colour of the application label is linked with these categories.

Finally, a time reference has been added on the top of the roadmap, identifying the ~5-years block from now to 2025, 2025-2030, 2030-235 and beyond 2035. These time references should be seen as indication and not as firm implementation date. The objective of this roadmap is not to provide a project management plan on the future CNS implementation, but rather to provide an executive view on which CNS application and infrastructure should be ready by when.

The scope of the roadmap below has been limited to the Safety-Of-Life applications, therefore, some non-Safety-Of-Life applications mentioned earlier are not indicated in the roadmap (for instance the open connectivity and the application based on 3G/4G/5G networks).

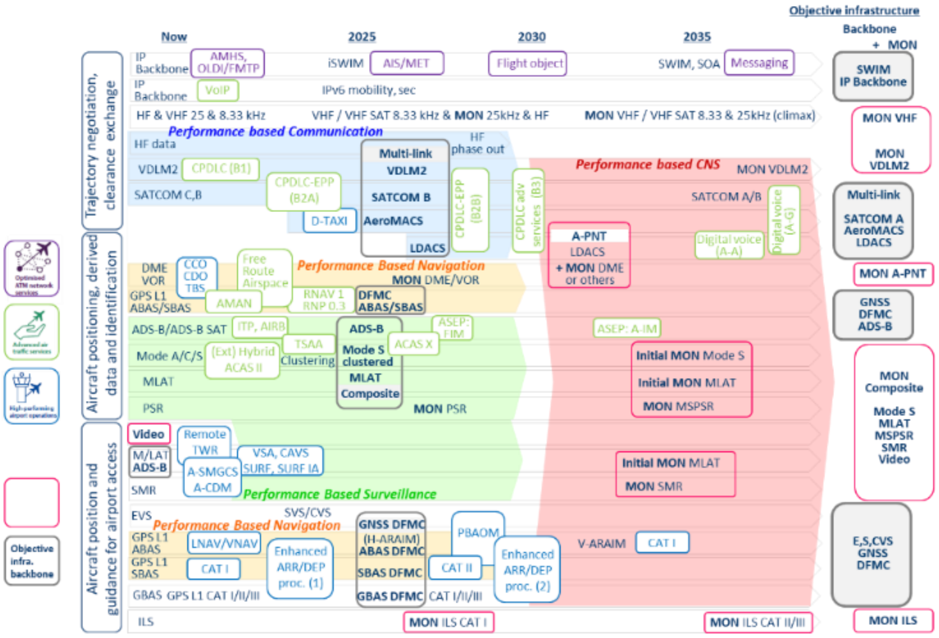

Figure 3: CNS Roadmap

4.4 CNS Rationalization opportunities summary

It is important to note that none of the CNS systems (ground-based, satellite-based, airborne) can be removed without providing alternative solutions to single point failures and any new CNS technology will not be approved for deployment without being safe, secure and resilient. Work is ongoing to determine what can be considered a suitable level of system of systems redundancy required to provide both safety and continuity of operations, while exploring when system redundancy can be considered excessive or unnecessary. Having said that, some rationalization opportunities are already foreseen and the table below provide a summary of the CNS Rationalization opportunities and spectrum optimisation. The decommissioning potential is indicated in percentage of the current infrastructure. In other word, the number of ILS CAT I is not expected to vary between 2025-2030 and 2030-2035.

Infrastructure		Now to 2025	2025-2030	2030-2035	Objective infrastructure
Communication	VHF voice		Initial MON VHF 25kHz voice	Initial MON VHF 8.33 & 25kHz voice	MON VHF voice.
	VDLM2			Initial MON VDLM2	MON VDLM2
	HF		MON HF	Full decommissioning	Full decommissioning
Navigation[12]	NDB	Initial decommissioning. Potential: 30%-100%	Full decommissioning. Potential: 100%	N/A	N/A
	VOR	Initial MON VOR. Decommissioning potential: 0-60%	MON VOR. Decommissioning potential: 60%	MON VOR. Same as previous timeframe	Full decommissioning. Potential: 100%
	DME	Initial MON DME. Decommissioning potential: 5% or less	MON DME. Decommissioning potential: 5% or less	MON APNT: Depending on technical solution, DME may or may not be decommissioned	MON APNT: Depending on technical solution, DME may or may not be decommissioned

---

[12] NDB / VOR / DME figures based on detailed SESAR 1 Studies (State Reports)

	ILS CAT I	Initial MON ILS CAT I. Decommissioning potential: 0-20%	MON ILS CAT I. Decommissioning potential: 20% to 50%	MON ILS CAT I. Decommissioning potential: 20% to 50%	MON ILS CAT I. Decommissioning potential: 20% to 50%
	ILS CAT II/III	N/A	N/A	Initial MON ILS CAT II/III. Decommissioning potential: 0-10%	MON ILS CAT II/III. Decommissioning potential: 10%
Surveillance	SSR Mode A/C	Continuation of the decommissioning. Potential: 30-100%	Full decommissioning. Potential: 100%	N/A	N/A
	SSR Mode S	N/A	Initial MON SSR Mode S. Decommissioning potential: 0-25%	MON SSR Mode S. Decommissioning potential: 25%	MON SSR Mode S. Decommissioning potential: 25%
	PSR MSPSR/ SMR	N/A	MON PSR	MON PSR/SMR	MON MSPSR/SMR
	MLAT	N/A	N/A	N/A	MON MLAT. No decommissioning potential.
	Spectrum optimisation	ACAS (Extended) Hybrid: up to 40% reduction of RF congestion	ACAS X, Mode S clustering and passive acquisition offer additional spectrum benefit (50% to 80%).		

Table 1 CNS Rationalization Opportunities and Spectrum Optimisation

The figure below provides a graphical view of the CNS rationalisation opportunities. Only the infrastructure that may be rationalised and the rationalisation period are shown. For instance, SSR Mode S are not expected to be rationalized before 2025.

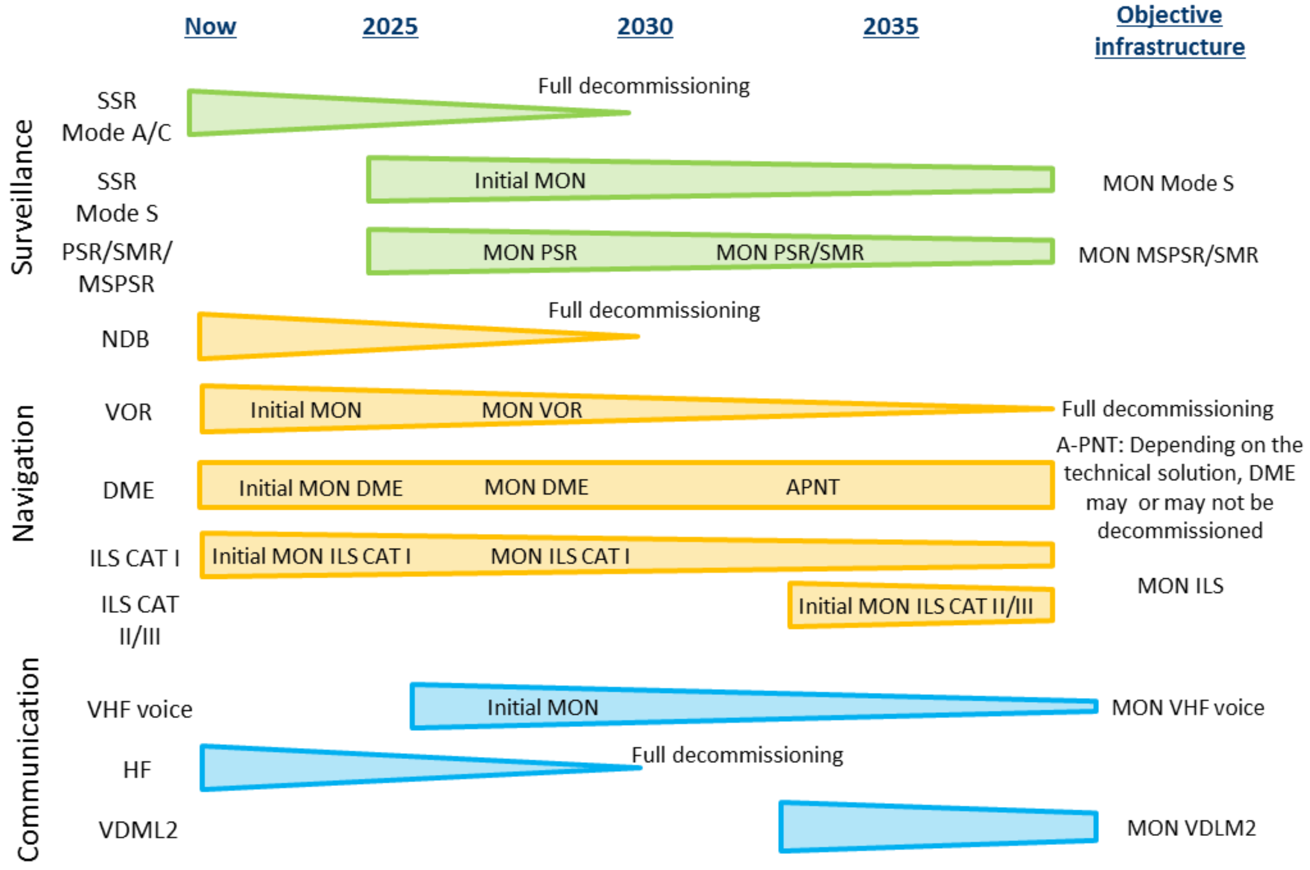

Figure 4: CNS rationalisation opportunities

HF Communication Systems, which includes both Voice and Data (HF Data Link HFDL), are considered for full decommissioning on the indicated timescale: this is still to be confirmed in view of other developments on satcoms mentioned above, both commercially and technically. Indeed, HFDL and HF suffer from poor quality and throughput, but have been the natural backup solution to satcoms in remote regions. Providing the same or higher level of service at reasonable costs will confirm this decommissiong of HF. Timescames may also be different for HF voice and HFDL.

5 CNS strategy and recommendations

5.1 2025 Milestone and its challenges

The roadmap detailed in the previous chapter identified a key milestone: the “2025 Rendezvous” where Multi-datalink, Composite SUR and DFMC GNSS are expected. These key elements will allow the evolution towards a more integrated approach and CNS performance based environment but will also unlock the potential rationalisation opportunities identified. Some challenges in the implementation of this key milestone can already be identified.

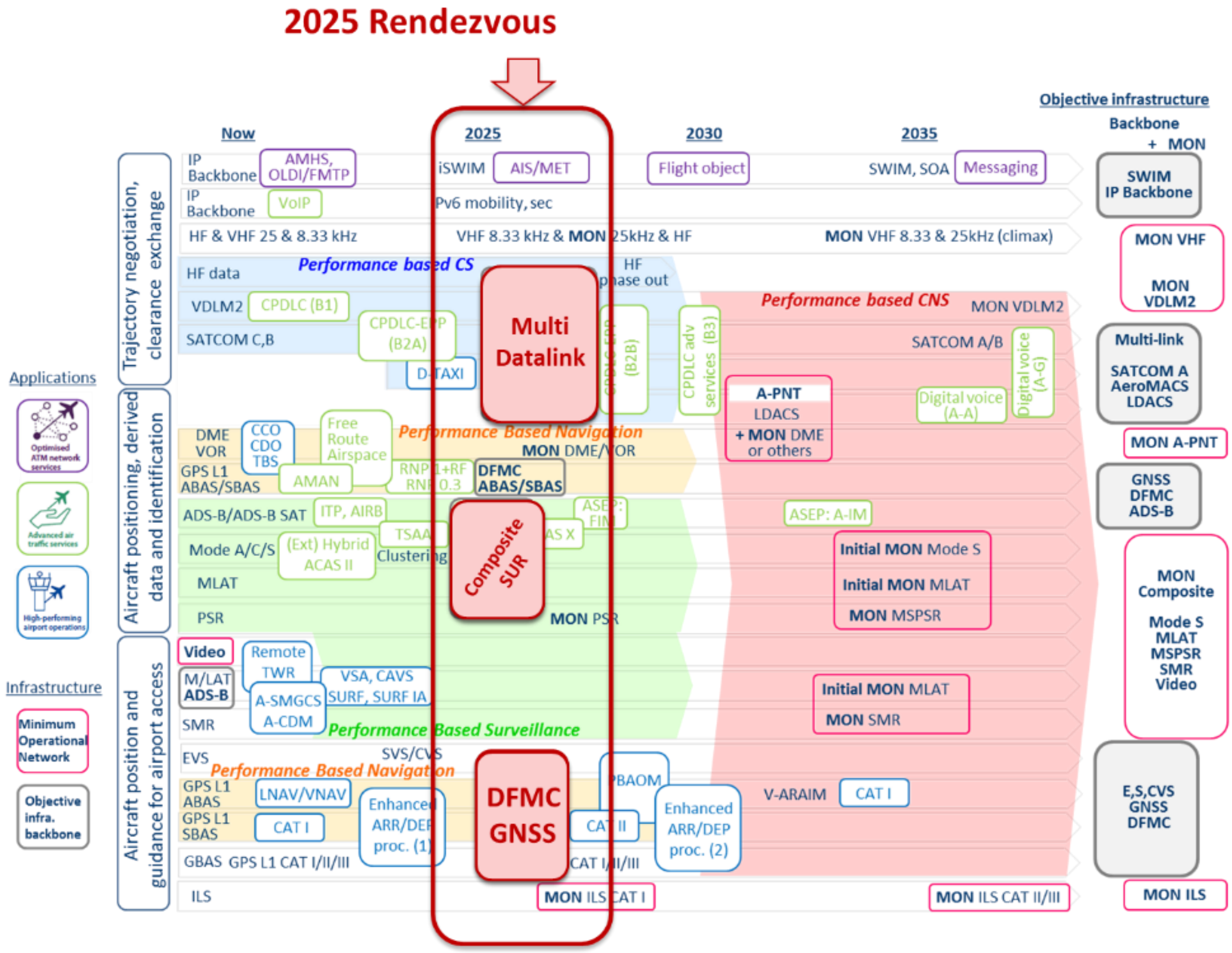

Figure 5: CNS Roadmap and the 2025 milestone

Multi-Datalink Challenges

The following points are identified as potential risks and challenges for Multi-Datalink (also called Multilink). Note that implementation risks considered for each of the single-link scenarios (LDACS, SATCOM CLASS A – also called SATCOM Next Generation NG or IRIS) are also applicable to the Internet Protocol Suite ATN (ATN/IPS) Multilink scenario.

- Security of the global mobility backbone, which is a common infrastructure shared by all datalink technologies involved in the ATN-IPS Multilink concept. In case the backbone is compromised, this will also have an impact on the single-link access networks. However, solution PJ14-W2-77 has been addressing the security of the backbone.
- **Delay of ATN/IPS standardisation: ATN/IPS Multilink solution is applicable only if all functionalities and network elements standardised by ICAO for ATN-IPS implementation are available.**
- Financial risks for the Airspace Users:
    - the need to equip multiple (at least 2) different radio access technologies on board the aircraft
    - late deployment , meaning costly retrofitting (in addition to forward-fitting) to reach the critical mass of users (e.g. lack of Boeing forward-fit programme for ATN over SATCOM)
    - this risk is amplified by the current recovery of airspace users from the last two major crisis: COVID-19 and the Ukrainian War.
- "Fragmentation":
    - ground deployment in Europe vs. pan-European deployment (e.g., if some ANSPs are not supporting SATCOM use, or AUs/ANSPs delay investment in LDACS)
    - deployment takes place over a transition phase, lasting for years and during which new technologies become available for use in different regions with different timelines
- **Spectrum Compatibility constraints impacting availability of frequencies in L-band for LDACS deployment**

Composite Surveillance Challenges

The following points are identified as potential challenges for the composite surveillance:

- Availability of specifications and standards for composite surveillance systems and their interfaces to support harmonised implementation;
- Management of inconsistencies between data extracted from different surveillance technologies;
- Performance variation between surveillance technologies;

- Different level of airborne surveillance equipage (Mode A/C, Mode S ELS, Mode S EHS, ADS-B) across the aircraft fleet;

- Efficient deployment of composite systems to improve situation on the 1090 MHz frequency band;

Dual-Frequency-Multi-Constellation Challenges

2025 is the target for DFMC GNSS Standards and Recommended Practices to be published and applicable in ICAO Annex 10, Volume I, and for the publication of the EUROCAE / RTCA DFMC GNSS MOPS receiver standard. All four constellations and their new signals, as well as DFMC SBAS (supporting EGNOS V3 procurement and implementation) are already included in Annex 10 Amendment 93, which will become applicable in November 2022. Advanced RAIM (ABAS) and SBAS navigation data authentication are expected to follow in the subsequent amendment. DFMC GBAS is under development. DFMC GNSS MOPS are on an intense development path, strongly supported by industrial contracts for completion by 2025. However, this MOPS only covers GPS and Galileo signals, and SBAS and ARAIM in terms of augmentations (some work on BDS is starting; for GLONASS, only a GPS/GLONASS single frequency MOPS standard has been completed). Therefore, 2025 represents an Initial Operational Capability (IOC) by which the avionics industry can start to offer certified DFMC GNSS receivers for integration into aircraft.

While this is certainly a significant step which introduces more robust and capable GNSS positioning, velocity and time for aircraft use, this is currently a pure navigation development. Several major interrelated uncertainties can be anticipated:

- Industry uptake: The introduction of GPS L1 ABAS capability into aircraft required roughly 20 years, despite very clear operational benefits (global, highly accurate navigation). Given that the 2025 DFMC GNSS milestone is a partial one (not covering all core satellite constellations and not all augmentations), and currently anticipated benefits are less significant, the avionics and aircraft manufacturing industry may not push the incorporation of these capabilities strongly. They may instead wait for a future time when more DFMC GNSS elements have been included in standards.

- Application development: GPS L1 position, velocity and time outputs are used for many non-navigation applications. This includes standardized applications such as ADS-B and Enhanced Ground Proximity Warning systems, as well as many non-standardized applications – the latter is especially true for applications using the GPS-provided UTC time. So far, none of the communities outside of navigation have taken into account new DFMC GNSS capabilities in their developments. One exception and example is initial work to standardize GNSS interference detection, and downlink GNSS interference status using a future version of ADS-B. Whether this will ultimately be agreed for inclusion in multiple and interdependent NAV and SUR standards is uncertain. Any such developments impact the cost and complexity of the DFMC GNSS integration, resulting benefits, remaining vulnerabilities, etc. – both in the positive or negative direction.

- Multi-Constellation CAT III GBAS development are still under discussion with trade-off between multiple options being analysed:

   1. GAST F as initially developed by SESAR with an airborne processing robust to signal interruption
   2. GAST X as initially proposed by industry (ICCAIA) with an airborne processing more complex but also potentially more extensible
   3. GAST D+ as an intermediate steps to combine multiple constellation into a single frequency CAT III system

- Recovery from COVID 19 and Ukrainian War crisis: the aviation domain is still in the recovery phase from these crisis and this recovery may induce delay in any new development and deployment of technology

In terms of impact on the CNS landscape, this means that any effort to right-size or adapt complementary or residual CNS infrastructure is subject to the same schedule and scope uncertainties.

5.2 Recommendations

EUROCONTROL CNS Symposium 2018

To reach the operational, technological and human goals set out for the CNS domain through the long-term roadmap, it appears as urgent to take this domain in consideration and to dedicate proper effort. As outcomes of the CNS Symposium organized by EUROCONTROL on October 2018, and the feedback received from stakeholders at World ATM Congress 2018 & 2019, the following recommendations were identified:

1. **Strong leadership and a program management approach is required with the proper governance**: a seat to all stakeholder should be ensured.
2. **Generate trust:** confidence on the roadmap implementation is needed for investment plans
3. **Costs need to be compensated with benefits**. Route charges need to evolve in order to better distribute the benefit from CNS evolution and to better reflect what is being used by Airspace Users.

In particular, these recommendations could be detailed as:

1. **To challenge and change the way spectrum is considered in aviation and to establish a proper spectrum management approach.** This approach should ensure spectrum availability for future aviation operations by developing an agreed spectrum long-term view and strategy and by improving the collaboration between strategic policy makers, CNS development and spectrum experts.
2. **To tackle the security challenges, including cyber-security** of evolving from fully open C-N-S services to a fully secured CNS service.

3. **To support standardisation**, considering that an average of 10 years is necessary to develop a standard, this would alleviate the risk to have technology ready for the long-term objective but not implementable due to lack of associated standards.

4. **To strengthen the civil-military collaboration in strategic development** to achieve a full and seamless interoperability.

5. **To prioritize the CNS development** on the following critical areas:
   - Support the development of an efficient and high bandwidth datalink system: AeroMACS for surface operation, LDACS for continental operation, SATCOM for oceanic or remote operation at first. SATCOM could be extended to continental operations over time, where its capabilities are able to meet the appropriate requirements in a denser airspace
   - Study the potential use of a next generation datalink system for CNS services
   - Support the development of future IP-based communications
   - Support the development of DFMC GNSS for all phases of flight associated with the implementation of PBN procedure and precision approach down to CAT III
   - Support the development of an Alternate Position Navigation and Timing (A-PNT) system that would meet the performance requirements, would be spectrum and cost efficient, and would provide backward compatibility and support legacy systems
   - Support the development of Performance-based Surveillance applications
   - Support the development of efficient Surveillance systems capability (ADS-B, MSPSR etc.) enabling ground and airborne applications
   - Support the development of integrated CNS Performance-Based concept

6. **Develop incentive programmes** to break the vicious circle of airspace users not equipping because procedures do not exist and ANSPs not developing procedures because airspace users are not equipped. These programmes should be inclusive, available for all and realistic in terms of required resource to claim them. An appropriate indicator of the relevance of such programme may be the consistency between the level of use of the network and the level of access to them.

7. **Support the CNS rationalisation** to ensure a timely decommissioning of legacy system, both on the ground and in the cockpit

European Commission CNS Advisory Group

The content from this document has been fully incorporated in the ATM Master Plan Edition 2020. Following the development of this edition of the Master Plan, DGMOVE established a CNS Advisory Group to develop recommendations to ensure the best possible management and implementation of the CNS infrastructure. The CNS Advisory Group has identified the following key issues that hamper successful CNS implementation:

- Pan-European CNS deployment is slow.
- The CNS infrastructure redundancy layers and geographic locations are not optimised.

- The variety of airspace users' needs and constraints prevents efficient and timely deployment.
- CNS infrastructure is not sufficiently spectrum-efficient, and is not sufficiently protected against security threats.
- CNS interoperability requirements and compliance demonstration have not been fully addressed. The lack of harmonized compliance framework resulted into additional delays, duplication of efforts, and costs for airspace users and ANSPs.
- There is a lack of European wide CNS Programme Management addressing the full life cycle of the CNS infrastructure.

The CNS Advisory Group has developed the following recommendations, aimed at achieving a more comprehensive, reliable and accurate planning for CNS implementation; proposing incentives for voluntary implementation complemented by smart(er) regulations; improving management and governance; and consider human dimension aspects:

13. Translate the Master Plan's CNS roadmap into a 'CNS evolution plan' with short, medium and long-term objectives, priorities and decision points.
14. Improve cost-efficiency through rationalisation, including decommissioning of CNS facilities, maintaining robustness while ensuring safety and security.
15. Implement CNS infrastructure applying a technical performance[13] based approach in a way that is simple and cost-efficient.
16. Conceive an integrated CNS evolution maximising synergies and addressing security for Communication, Navigation and Surveillance services.
17. Develop a long-term EU strategy and policy to improve aviation spectrum efficiency as a driver of the CNS evolution.
18. Reduce the greenhouse gas emissions of the CNS infrastructure to maximise aviation's contribution to achieving European net zero carbon emissions targets.
19. Demonstrate operational and technical interoperability and scalability[14] of the infrastructure before deployment.
20. Develop robust CNS implementation business cases involving stakeholders at the earliest possible opportunity.
21. Ensure smart use of incentives to support stakeholders in implementing the CNS evolution plan.
22. Apply a smart(er) approach when developing technical CNS regulations to support the implementation of the CNS evolution plan.
23. Establish a holistic CNS programme management to ensure successful implementation of the CNS evolution plan using or adapting existing entities to maximum effect.
24. Consider the importance of the human dimension aspects related to the evolution of the CNS infrastructure.

---

[13] If not otherwise specified, this term refers in this report to the technical performance of CNS systems (e.g. accuracy, availability, latency, integrity,…) and should not be confused with the definition in the ATM performance and charging scheme in the SES (i.e. safety, capacity, environment, and cost-efficiency).

[14] Scalability is defined here as a system's ability to increase or decrease in performance and cost in response to changes in the operational requirements.

6 References

The following documents were used to provide input, guidance or further information:

- ✓ European ATM Master Plan, Edition 2020
- ✓ ICAO Global Air Traffic Management Operational Concept, Doc 9854, First Edition 2005
- ✓ Flightpath 2050 Europe's Vision for Aviation - Directorate-General for Research and Innovation/Directorate-General for Mobility and Transport, European Union, 2011
- ✓ IATA Vision 2050, Singapore, February 2011.
- ✓ EUROCONTROL Challenges of Growth, 2013 Edition
- ✓ Roadmap on Enhanced Civil-Military CNS Interoperability and Technology Convergence, Edition 2.0, EUROCONTROL, 17 October 2013;
- ✓ ICAO Procedures for Air Navigation Services ATM Management, Doc 4444, 2016
- ✓ NATO Military Position on Mode S - MCM-197-04, 7 October 2004, distributed under AC/92(CNS)N(2004)0006, 21 October 2004;
- ✓ NATO Position on Automatic Surveillance-Broadcast (ADS-B), AC/92-D(2011)0002, 11 April 2011;
- ✓ ICAO EUR Regional Supplementary Procedures (SUPPS) – Doc 7030, 5th Edition Amendment No 9, 25/04/2014;
- ✓ EUROCONTROL Specification for ATM Surveillance System Performance Volume 1 & Volume 2 - Appendices, Edition 1.1, September 2015;
- ✓ SESAR WP15.04.01 D09-002 Evolution of the Surveillance Infrastructure, Edition 2.00, 26/04/2012;
- ✓ SESAR WP15.02.04 D03 FCI Operational Concept (updated), Edition 01.01, 09/03/2016;
- ✓ SESAR WP 15.2.6-D104 SATCOM Mission Requirements
- ✓ ICAO Aeronautical Telecommunication Network (ATN) – Doc 9896 - Manual for the ATN using IPS Standards and Protocols, Edition 2.0, 2015;
- ✓ NATO Position on Using Tactical Data links to Interface with Civil Data link Requirements, document AC/92(EAPC)D(2013)0002, 14 January 2013;
- ✓ SESAR WP15.03.01 D04 SESAR Navigation Baseline, Edition 1.00, 20/09/2013;
- ✓ SESAR WP15.03.01 D09 SESAR Navigation Baseline and Roadmap,
- ✓ SESAR WP15.03.04 D04 Configuration Report, Edition 1.00.00, 23/03/2011;

- ✓ SESAR WP15.03.04 D08 GNSS Baseline Report, Edition 2.00.00, 25/02/2014;
- ✓ NATO Position on Future Use of TACAN, AC/92-D(2011)0005, 23 June 2011;
- ✓ SESAR WP-B.04.03-D95-ADD Step 1, V00.02.02, 30/04/2015,
- ✓ SESAR WP-B.04.03-D97-ADD Step 2, V00.03.01, 05/01/2015,
- ✓ Single Sky Committee 59 (15-16 Dec. 2015), Agenda item 6, “Discussion paper on the need for a European ATM Communication Infrastructure Strategy”
- ✓ SESAR WP15.01.06 D04-01 SESAR Aeronautical Spectrum Strategy and Vision, Edition 1.02, 08/10/2015
- ✓ SESAR WP15.01.06 D04-02 Spectrum Strategy Band-by-Band, Edition 1.01, 08/10/2015
- ✓ SESAR WP15.01.06 D05 Implementation of the SESAR Aeronautical Spectrum Strategy & Vision, Edition 1.01.01, 07/10/2016
- ✓ SESAR WP15.01.06 D32 SESAR Spectrum Compliance Process, Edition 1.02, 14/07/2016
- ✓ SESAR Deployment Programme edition 2018, 19 December 2018
- ✓ SESAR WP15.01.07 D04 CNS Technology Assessment, Edition 1.00, 30/06/2016
- ✓ ICAO PBN Manual (Doc 9613) Edition 5
- ✓ ICAO Annex 10 Volume I Amendment 92
- ✓ ICAO European Air Navigation Plan (Doc 7754) volume III, 4 December 2020
- ✓ Commission Implementing Regulation (EU) 2021/116 of 1 February 2021 on the establishment of the Common Project One supporting the implementation of the European Air Traffic Management Master Plan provided for in Regulation (EC) No 550/2004 of the European Parliament and of the Council, amending Commission Implementing Regulation (EU) No 409/2013 and repealing Commission Implementing Regulation (EU) No 716/2014.
- ✓ Commission Implementing Regulation (EU) 2018/1048 of 18 July 2018 laying down airspace usage requirements and operating procedures concerning performance-based navigation.
- ✓ ICAO Performance-Based Aerodrome Operating Minima (PBAOM) Concept of Operations

Appendix A Spectrum context and challenges

The availability of spectrum resources for civil aviation is a highly critical need and requirement. Without adequate spectrum, which is the backbone of our ATM/CNS system, civil aviation would not operate. Most of the spectrum used by aviation is allocated to "protected" frequency bands that are afforded special regulatory measures in the International Telecommunication Union (ITU) Radio Regulations (safety status to protect the safety and regulatory of flight).

Spectrum management is the process of ensuring the availability of appropriately protected spectrum and the development and regulation of the use of radio frequencies to support's operational and technical requirements. Assignment of spectrum is a sovereign responsibility within a State, and State radio administrations will remain responsible for spectrum policy and regulation.

The availability of suitable radio spectrum is essential for meeting the global demand for safe, efficient and cost-effective air transport, particularly for enabling the provision of CNS. However, the ATM/CNS domain also has an increasing need for additional spectrum for the implementation of emerging technologies such as digital future communications systems.

A.1 Spectrum challenges

In 2014, the European Commission released to the European parliament and the Council a report on the radio spectrum inventory (COM (2014) 536 final, 01/09/2014).

This EU spectrum inventory was created as part of the radio spectrum policy programme (RSPP) in order to give effect to the principle that spectrum should be used and managed efficiently. The main objective was to identify frequency bands where efficiency of existing spectrum use could be improved in order to accommodate spectrum demand in support of Union policies, to promote innovation and to enhance competition.

The main key findings to sustainably satisfy spectrum demands were to invest time and resources in identifying and developing sophisticated spectrum sharing concepts as such as:

- Licensed shared access assignment
- Increase in spectrum re-use and spectrum sharing between operators within the existing networks and spectrum allocations.

This increasing spectrum demand and sharing consideration is not trivial to implement in aeronautical spectrum and consequently requires that aviation exercises great care especially when sharing between aeronautical and non-aeronautical services having fundamentally different radio regulatory regimes is proposed. In particular, especially given the ever increasing demand for spectrum for mobile telecommunications applications, aviation must intensify its efforts to ensure an appropriate balance between safeguarding interference free operation of radio services while engaging to the utmost possible in increasing spectrum efficiency of aeronautical or aeronautically used spectrum allocations.

In comparison with other industry like telecommunications, aviation systems and infrastructure evolve at a slow pace. Technologies first standardized in the 1960-70s are still in use because the technical and financial effort to develop, certify and install a new technology is very significant. As a result, some of the aviation systems may be seen as not being spectrum efficient enough by other industries (this is further discussed in section A.5). While aviation has been improving the way spectrum is used in many ways (reduction of channel bandwidth, adding new modulation to improve channel capacity, improved frequency assignment planning practices, reallocation or extension or sharing of frequency bands), these efforts are not considered to be sufficiently ambitious by other spectrum users. Therefore, spectrum efficiency improvement must become an inherent driver in the evolution of CNS services.

The objective described above has also been recognized at the European Union level through the work of the “CNS Advisory Group”, which has agreed, among others[15], recommendation number 5 to “Develop a long term EU strategy and policy to improve aviation spectrum efficiency as a driver of the CNS evolution”. The recommendation highlights the following needs:

- To deploy CNS systems that are spectrum-efficient and more resistant to interference.
- To reduce spectrum congestion through rationalisation of less spectrum-efficient systems as a priority. The rationalisation of infrastructure proposed in recommendation 2 to improve cost-efficiency would also contribute to improve spectrum-efficiency.
- To ensure that the appropriately protected aviation spectrum is and remains available to accommodate the CNS evolution plan, including existing and new operations, entrants and systems, while preserving aviation safety when sharing spectrum with non-safety-of-life systems.

Meeting these needs should lead to CNS avionics that ensures safe operation in spectrum proximity with other systems (e.g. Limiting downstream side-effects caused by interference affecting GNSS) that protects safety-of-life services without hindering developments in other industries (e.g. safe operation of Radio altimeters and deployment of 5G stations). Recently adopted amendments to ICAO Annex 10 and the current work in progress in the ICAO RPAS Panel on the C2 link technical solutions is potentially adding some additional pressure on current CNS systems or on the aeronautical spectrum:

- Terrestrial and Satellite communications in the 5030-5091 MHz band
- Satellite communications in the L band
- FSS

The following, the figure below provides an executive overview of the spectrum allocation per band and per domain. Most of the challenges identified above are concentrated in the VHF band and in the L band.

---

[15] CNS Advisory Group Report Final Draft 27 April 2021, European Union DG MOVE

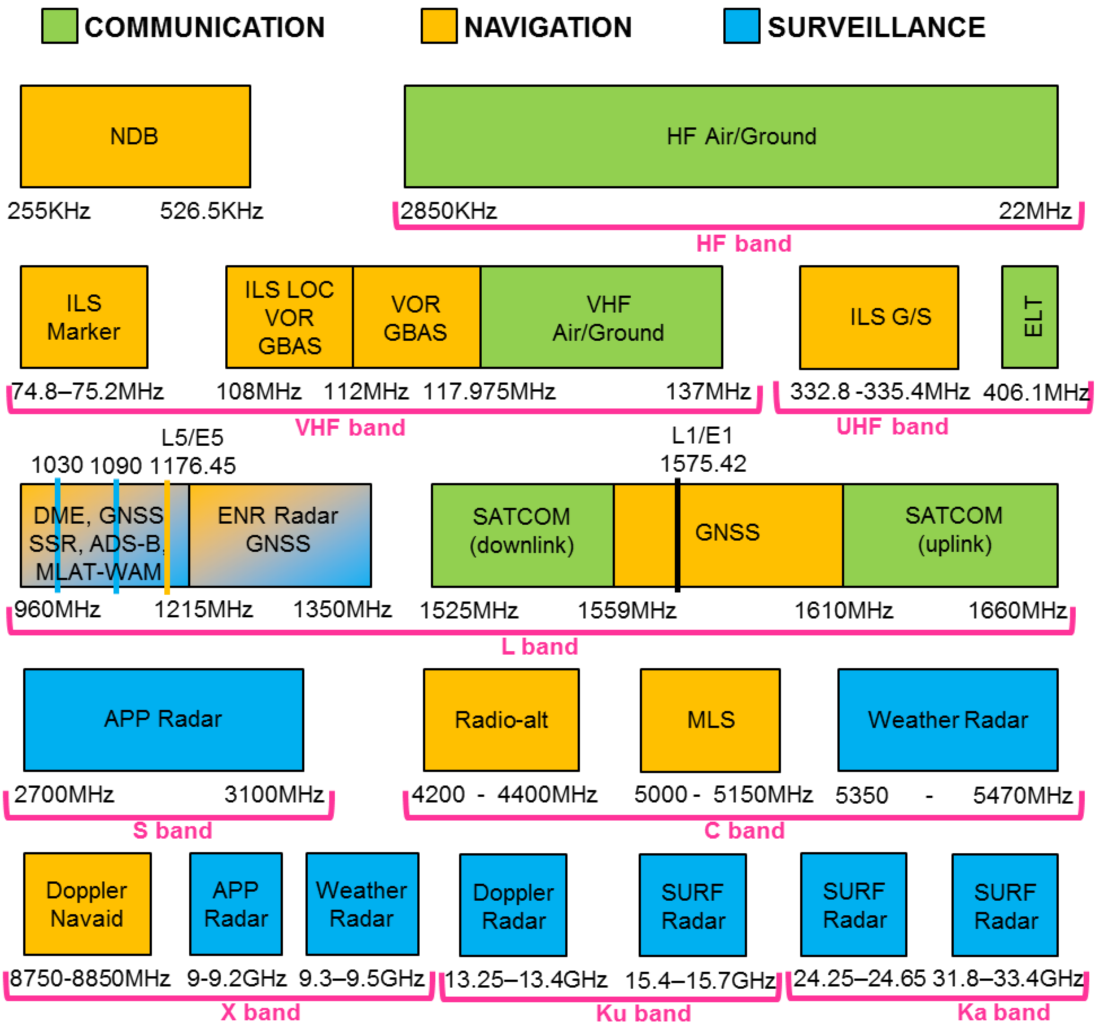

Figure 6: Aviation spectrum allocation

This current spectrum situation is being dealt with through the process of frequency management. Despite the transition to 8.33 KHz VHF COM channels, the system which is most under pressure in terms of reaching saturation is VHF COM. This limits, for example, the opening of new ATC sectors, which is essential to accommodate more traffic capacity. In navigation, DME channels are also close to saturation. In surveillance, pro-active management of interrogation load on the SSR frequency pair 1030 / 1090 MHz has become necessary to avoid loss of aircraft tracks. While spectrum management is primarily a top-down discipline with the aim to accommodate new demand, frequency management is a bottom-up discipline that deals with the allocated spectrum in a manner that is as responsible as possible. However, if certain CNS services reach their capacity limits, spectrum management needs to ensure that solutions can be found quick enough. Therefore it is important that any spectrum evolution planning takes into account both of these processes.

A.2 ICAO Spectrum position

The ICAO Position to the ITU World Radio Conference (WRC) aims to protect aeronautical spectrum for all radiocommunication, radiolocation and radionavigation systems used for ground facilities, space vehicles and on-board aircraft. The continuous increase in air traffic movements as well as the additional requirement for accommodating new and emerging applications technologies and entrants such as unmanned aircraft systems (UAS) or security protections is placing an increased demand on CNS services. Even when spectrum demand linked to air traffic movements is decreasing, another source of significant pressure is the need to operate flights in the most efficient possible way in terms of keeping environmental emissions to a minimum. This will require more cooperative system which exchange more collaborative data to achieve such objectives and hence, more real time data exchange. While some of this demand can be met through improved spectral efficiency of existing radio systems in frequency bands currently allocated to aeronautical services, the challenge lies in accommodating a transition to a new technology, during which both the legacy and new spectrum allocations is required. With technology implementation cycles on the order of 20 years, this makes switching to a fundamentally new technology very difficult. At the same time, it should not be expected that aviation will obtain additional spectrum allocations to accommodate such transitions.

The ICAO Position for the ITU WRC is further supported by policy statements and detailed technical references in the ICAO Handbook on RF Spectrum[16]. It includes the ICAO Spectrum Strategy and identifies Spectrum requirements in order to support efficient aircraft operations in the long term. It was developed on the basis of current global and regional plans for implementing CNS systems until 2035 and consistent with the Technology Roadmaps of the GANP. The Spectrum Strategy aims to enable advancement of technological developments and innovation in CNS through the development of ICAO SARPS as necessary. In addition to that, the ICAO Spectrum Vision identified the need to secure the long-term availability of suitable spectrum, as even with new technologies development the total system development and deployment cycle takes from 20 to 25 years on a global scale. This time frame includes a concept/technology definition, system development, transition from existing system to a new one while performing safety-of-life RF band prioritization and reallocation among other CNS systems, as currently almost all the bands are fully occupied and actively used. The Spectrum Vision includes next statements:

- Establish and maintain agreed spectrum strategy
- Improve collaboration
- Long-term view
- Holistic CNS and Spectrum approach (CNSS)
- Financial decision making

As an outcome, it is important to highlight that vision and strategy realization requires a high level of collaboration between States as an "*Assignment and use of spectrum is a sovereign issue within a State, and State radio administrations will remain responsible for spectrum policy and regulation*".

The short-term Spectrum Strategy is driven by the World Radio-communication Conferences (WRC) and the ICAO position is agreed with all contracting States through the State letter process. For the next WRC, the draft position is contained in "Draft ICAO Position on items of interest to aviation on the agenda of the International Telecommunication Union (ITU) World Radio-communication

---

[16] ICAO Doc 9718 Handbook on Radio Frequency Spectrum Requirements for Civil Aviation. Volume I ICAO Spectrum strategy, policy statements and related information, 2nd edition 2018)

Conference 2023 (WRC 2023)[17]". It has been reviewed by States and approved by the ICAO Council during the sixth meeting of its 223rd Session, held on 14th of June 2021 and published in August 2021 as ICAO State Letter 2021 / 037. It contains both actions for new allocations (for example, relating to sub-orbital vehicles, space-based VHF, improvement of FSS regulatory status to support RPAS C2 links, allocations in the HF band) as well as areas of concern where aviation seeks to ensure that there will be no undue impact. This relates especially to the demand for spectrum by International Mobile Telecommunications (IMT).

In support of the safety aspects related to the use of radio frequency spectrum by aviation, Article 4.10 of the Radio Regulations states, "ITU Member States recognize that the safety aspects of radionavigation and other safety services require special measures to ensure their freedom from harmful interference; it is necessary therefore to take this factor into account in the assignment and use of frequencies." In particular, compatibility of aeronautical safety services with co-band or adjacent band aeronautical non-safety services or non-aeronautical services must be considered with extreme care in order to preserve the integrity of the aeronautical safety services. However, this can only be ensured if aviation entities participate in their State's delegation to the ITU WRC, in line with ICAO Assembly resolution A38-6 (*Support of the ICAO Policy on radio frequency spectrum matters*).

The ICAO position provides recommendations on the upcoming WRC-21 agenda items relevant for aviation. The main objectives, can be summarized as:

- Ensure that all frequency bands used by aviation will be safeguarded
- Maintain global protected safety spectrum
- Consider and accommodate that frequency bands used by civil aviation are also used for military aviation operations
- Spectrum may be required for new aviation related technologies, but aviation takes the challenge to accommodate increasing demand (such as IFR RPAS) within the band described in Annex 10 Volume V.

The ICAO position for the ITU WRC provides a basis for regional coordination, including Europe. In addition to the WRC position, ICAO also issues State letters on spectrum matters of particular urgency. Two recent examples are State letters concerned with radio frequency interference (RFI) to GNSS and the potential for RFI between new 5G services and radio altimeters in the 4200 to 4400 MHz band.

The ICAO State letter on GNSS RFI is based on papers submitted by affected States and organizations to the 40th ICAO Assembly. The letter asks all States to mitigate the risk of GNSS RFI by applying already published ICAO guidance (commonly known in the GNSS community as the GNSS RFI Mitigation Plan and developed by EUROCONTROL)[18]. The GNSS radio frequency mitigation plan is presented in the

---

[17] ICAO State Letter 2020 / 103, Ref E 3/5-20/103

[18] ICAO State Letter 089 (2020), "Strengthening of communications, navigation and surveillance (CNS) system resilience and mitigation of interference to global navigation satellite system (GNSS), Ref AN7/5-20/89, International Civil Aviation Organization, 28 August 2020

Appendix F of ICAO GNSS Manual[19]. Most of the RFI challenges of GNSS are linked to military activities near zones of conflict, as illustrated in a recent EUROCONTROL Think Paper[20]. While the political realities surrounding GNSS as a shared civil / military utility will be difficult to change, they underline the continued need for robust multi-sensor navigation, in particular using Distance Measuring Equipment (DME) allocated to the 960 to 1215 MHz ARNS frequency band. While DME is often considered not to be spectrum efficient, it provides a significant robustness against RFI.

A different issue is the potential for RFI between new 5G technologies and radio altimeters, as explained in ICAO State Letter 2020 / 022[21]. In this case, RADALT operated in an environment with space allocations in adjacent bands, however, when global terrestrial allocations to IMT were introduced at ITU in particular in the 3400 to 3800 MHz range, insufficient studies were conducted on RADALT due to the frequency separation of 400 MHz appearing to be a sufficiently large frequency separation to not have any adverse impact. The compatibility issue is exacerbated by both insufficient filtering of currently fielded RADALT equipment (used in low visibility landing and other safety critical applications) as well as the use of advanced antenna technologies by 5G.

These two practical examples of spectrum challenges underline the importance of globally coordinated engagement in aviation spectrum matters. They are also acknowledged in the EC CNS recommendation on spectrum in section A.1.

A.3 SESAR Spectrum Strategy

In the European ATM Master Plan[22] the update view on SESAR spectrum strategy is presented. The main aim of the strategy is to secure the long term availability of suitable radio spectrum to meet all of Europe’s future objectives for aviation through cooperative engagement at global level by next activities grouped into short-term and long-term strategies summarized in the Table below.

Short-term	Long-term
Periodical assessment of the saturated bands and investigation of optimum use of the available spectrum (e.g. the L band), at pan European level	Adoption of a holistic approach consistent with the performance-based approach to COM, NAV and SUR
Review of the current use and improvements with regard to efficiency (e.g. VDLM2), at pan European level	Transformation of the current reactive process to deal with threats to a proactive process, supported by a long term view and improved collaboration with all aviation stakeholders

Table 2 SESAR Short and Long-term Spectrum Strategies

---

[19] ICAO Doc 9849 Global Navigation Satellite System (GNSS) Manual, 3rd edition 2017

[20] EUROCONTROL Think Paper #9: “Radio frequency interference to satellite navigation: An active threat for aviation?” Available at https://www.eurocontrol.int/event/eurocontrol-stakeholder-forum-gnss.

[21] Potential safety concerns regarding interference to radio altimeters, ICAO SP74/1-21/22, 25 March 2021

[22] European ATM Master Plan. Edition 2020

With the aim to ensure cohesion and coordination between spectrum management and the overall CNS strategy, and associated to these conclusions one of the main recommendation is "to have a long-term vision of how aviation spectrum should be conducted in Europe" with the following requirements:

- Ensuring sufficient and suitable spectrum availability for existing and future CNS systems
- Minimising the likelihood of incompatibility
- Guaranteeing freedom from in-service interferences
- Assessing the operational impact on other aeronautical systems in case of sharing
- Making appropriate provisions through ITU processes
- Ensuring the collection of evidence-based data at appropriate stages of project development and, following validation, developing an appropriate action plan to secure spectrum supportability.

The next steps may support in fulfilling the requirements described above:

1) CNS infrastructure rationalization (as it is described in the Chapter 4.4 of this document)
2) Increase of civil-military synergy
3) Transition to the performance-based approach in CNS
4) Move towards the satellite-oriented CNS services provision while ensuring contingency by using optimized ground infrastructure
5) Development and deployment of integrated CNS (iCNS) functions in a single technological solution (fully or partially) while avoiding the risk of single-point failure modes.

A.4 Network Manager Spectrum position

In accordance with the article 2 and 3 of the Annex-II of Network Manager (NM) Implementing rule (Commission Regulation (EU) No 677/2011), the network manager provides recommendations to the European Commission regarding network related spectrum aspects. In accordance with the NM Collaborative Decision Making (CDM) arrangements, these recommendations are regularly presented to the National Frequency Managers at the Radio Frequency Function Group meetings (joint with the ICAO EUR Frequency Management Group FMG) and to the EUROCONTROL Communication Navigation and Surveillance (CNS) Infrastructure Team (joint with EASA also known as the Joint CNS Stakeholder Platform, JCSP).

The aviation spectrum, particularly the protected spectrum is a critical resource that is vital to maintain the network capacity. Past events have shown that when aviation spectrum suffers interferences, it can have an immediate impact on the network capacity that can be reduced by up to 70%. This would include local restrictions, for example, if a certain airport cannot support low visibility operations due to RFI to RADALT, then this quickly has a ripple-effect on the entire network. Therefore, the CDM processes of the network manager seek to address all aviation spectrum aspects, not only those with a direct impact on network operations.

This collaboration is achieved through the Common European Aviation Position (CEAP)[23] on spectrum. It is aligned with the ICAO position discussed in A.2 but underlines items of particular importance to Europe, and enables coordination on such items with the European Radio Regulatory Forum, the CEPT. The current CEAP draft has been developed by the ASCG (Aeronautical Spectrum Consultation Group) in March 2021 and is currently undergoing consultation.Similar to the ICAO process discussed in A.2, the network manager working arrangements also permit escalation of spectrum issues of particular importance. Concerning GNSS RFI, the Network Management Board (NMB) endorsed at its 28th meeting on 8 July 2020 “further action to raise awareness of the impact of GNSS RF interference on aviation in the eastern Mediterranean region through collaboration with EASA, ICAO and the ITU” (agenda item 2.7, CNS Monitoring Report, item c), leading to a number of further mitigation actions at various levels.

Similarly, the NMB also endorsed a recommendation prepared by the NDTECH (Network Directors of Technology) meeting, which discussed the topic of possible RFI from 5G to RADALT at NDTECH/3 and supported the proposed actions in a working paper[24]. The paper recommendations provide a basis for cooperation among European actors in dealing with this issue.

A.5 CNS Spectrum Efficiency

It is often claimed that aviation is not using spectrum efficiently. However, it appears that so far, no attempts have been made to quantify this. As part of this project in Wave 1, a CNS Spectrum Efficiency (PJ14-01-01) study was undertaken by LS telcom. The Final project Report can be provided on request. This is done to serve two objectives:

1) To be able to have a more fact-based discussion of aviation spectrum use. The normal metrics typically applied only to telecommunication systems are refined to take into account aviation CNS system specificities.
2) To enable CNS system development in a way which formally considers the increase of spectrum efficiency as an objective, such that new or upgraded aviation CNS systems can continue to improve in terms of spectrum efficiency.

While it is generally straightforward to quantify spectrum efficiency for aeronautical communication systems using common metrics (bits / second per Hertz), this becomes more difficult for navigation and surveillance system since the primary objective of those systems is not the transfer of data, but rather positioning and guidance. The project attempted to derive conversions such that positioning performance is expressed in terms of equivalent data rate. In some cases this led to efficiencies which were quite good (to the extent of being counterintuitive), while in others it was shown that aviation systems do lag behind compared to other, non-aviation technologies – for a variety of reasons. The project also noted that common efficiency metrics aim to optimize data rate to as high a number of users as possible, whereas in aviation, there is no point to try and achieve higher data rates when the users are distributed in space through an inherently limited number of aircraft users. In summary it was found that this is a difficult approach and that for the most part, standard spectrum efficiency

---

[23] European Aeronautical Common Position for the ITU WRC-23, ASFCG, Draft Rev 3, 24 March 2021

[24] NDTECH/3 WP to agenda item 4.3, “Possible 5G Interference to Radio Altimeters”, 12 March 2021

metrics cannot be applied in a useful way to most types of aviation CNS systems. The only way to illustrate aviation spectrum inefficiency was to use a legacy argument: the study estimated that with current state of the art technology, all CNS services could be satisfied by using only 2 x 10 MHz. In comparison, already the aeronautical L-Band uses well over 200 MHz, implying an inefficiency of a factor 10.

However, as explained in A.1, while such a situation is deplorable, it can only be improved if a realistic technology transition plan can be agreed. The study also evaluated the distribution of DME channel assignments, and found that by using a cell-based planning methodology, only half of the current DME channels could be sufficient to provide a suitable back-up network to GNSS. This was based on many simplifying assumptions. The notion of re-assigning DME channels in order to make space for new spectrum users such as LDACS, has already been captured in the ICAO spectrum handbook. The ongoing rationalization of VOR (removing channel pairing constraints and making frequency changes for DME only more feasible) could open up the possibility of a DME channel reassignment plan (similar to VHF COM block planning exercises), which could lead to facilitating transition to a more spectrum efficient system, both for new systems such as LDACS and a potential replacement for DME (which is part of the Alternative Positioning, Navigation and Timing effort, A-PNT). Further studies to evaluate the feasibility of this L-Band evolution are ongoing.

A.6 Spectrum Efficiency Study in SESAR 2020 Wave 2

The band 960–1 215 MHz (L-band) is a prime radio navigation band which is used intensively, and extensively, to support a number of aviation systems, for both civil and military purposes. One of the most spectrum consuming system in this band is Distance Measuring Equipment (DME). The military equivalent of DME is Tactical Air Navigation (TACAN), which uses the same channels as DME. DME was initially developed as an addition to VHF Omnidirectional Radio Range (VOR), but by now DME has become the only terrestrial navigation infrastructure which enables Performance-based Navigation (PBN) positioning using two or more DME ranges when GNSS is not available. Despite this independent use of DME by the Flight Management System (FMS), DME/TACAN continues to be paired with VOR or Instrument Landing System (ILS) by means of common channel plan which associate UHF with VHF frequency utilized by systems described above. The channel plan for DME/TACAN and the associated VHF aids is given in ICAO Annex 10, Volume I, Chapter 3, Table A and also includes similar pairing for the unused Microwave Landing System (MLS).

The Spectrum Efficiency study objective in SESAR 2020 Wave 2 Solution PJ.14-W2-76 Integrated CNS and Spectrum is to determine if DME channel planning could be optimized by means of change to the channel plan or improving technical parameters. As it was described above, VOR/ILS to DME pairing has been criticised as causing spectrum inefficiency, however this has never been shown, quantified or analysed. Therefore, different approaches were analysed and results presented in Technical Note paper to this deliverable:

1. limiting DOC range value to a maximum 130NM;
2. aligning Effective Isotropic Radiated Power (EIRP) values with the frequency protected Designated Operational Coverage (DOC) range assigned to DME/TACAN;
3. un-pairing DMEs from ILS and VOR;
4. utilization of Z-channel.

Appendix B Unmanned Aircraft System

Unmanned Aircraft Systems (UAS), which is a generic term that encompass Remotely Piloted Aircraft Systems (RPAS), autonomous aircraft (including driverless personal air vehicles - DPAV - Volocopter, Kitty hawk, Vahana, etc…) and model aircraft are increasingly becoming a part of our day-to-day lives. The vast range of their possible uses has created a new industry with a large economic potential. Technological developments are arriving at a much faster pace than for manned aviation. The world of manned and unmanned aircraft must be integrated in a safe and efficient way since both types of aircraft will use the same airspace.

The integration of these vehicles may impact the evolution of the CNS infrastructure and may require new CNS applications. This section provides elements on how the future UAS integration may impact the CNS evolution. This section is largely based on the UAS ATM Operational Concept[25]. Since 2020, the regulation on UAS and U-Space significantly evolved. More specifically, the Commission implementing Regulation (EU) 2021/664 sets a regulatory framework for the U-Space. This regulation "defines a minimum set of requirements for the UAS operations in certain UAS geographical zones, which should be called U-space airspace for the purposes of this Regulation. The access by UAS operators to such U-space airspace should be conditional on the use of certain services ('U-space services') that allow the safe management of a large number of UAS operations, respecting also applicable security and privacy requirements"[26]. The e-conspicuity which is demanded to all airspace users in U-space airspace[27] is a function that may require either additional spectrum, reallocation of existing aviation spectrum or more extensive use of some bands in the current aviation spectrum.

The U-Space framework is currently being complemented by the services and their requirements which will ensure the adequate safety levels for all the airspace users.

---

[25] Can be accessed via the link https://www.eurocontrol.int/sites/default/files/publication/files/uas-atm-integration-operational-concept-v1.0-release%2020181128.pdf

[26] Commission implementing regulation 5EU) 2021/664 on a regulatory framework for the U-Space - 22 April 2021

[27] Article 11 of (EU) 2021/664

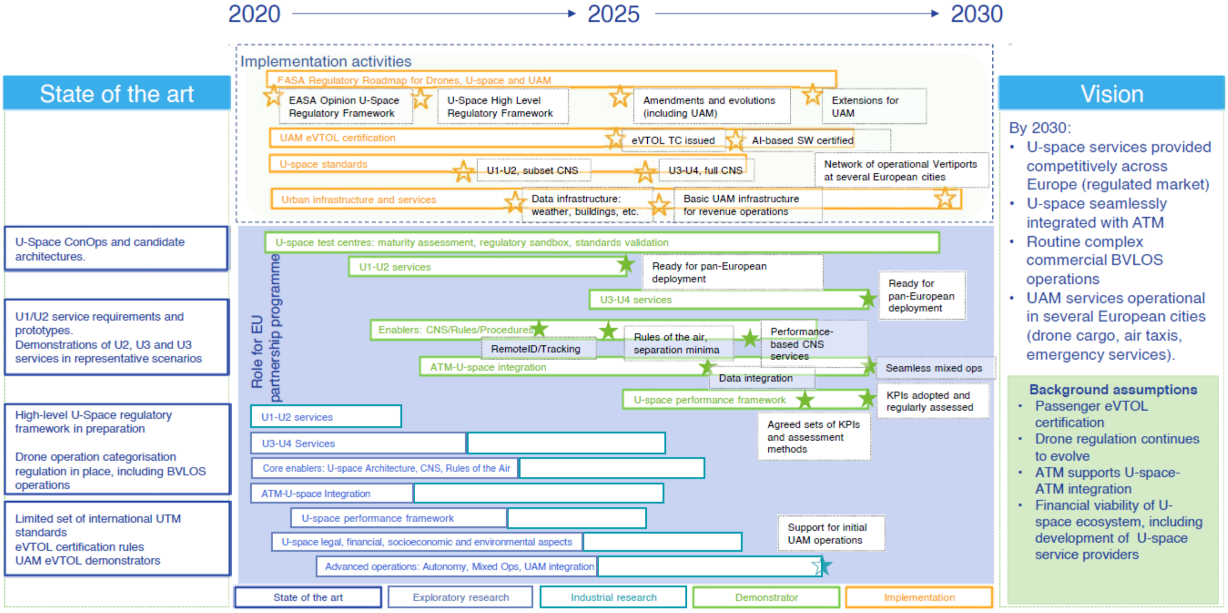

Figure 7: U-Space and UAM roadmap, SESAR 2020 PJ.20 [W2]

B.1 UAS operations

There is a wide variety of UAS types and usage, ranging from very small UAS for recreational use in limited area to long-haul large vehicle for military operations, not to mention the recent development of autonomous air vehicle for inter-city personal transportation. The easiest way to assess the impact of this large variety of new comers on the CNS evolution is to class them per type of operation and not per UAS categories or airspace classes. Three classes of operations should be considered: U space, IFV/VFR and Flight operations above FL600 (e.g. the use of High Altitude Platforms Systems - HAPS).

U space

U space will support UAS and manned aviation in the U space airspaces. Due to the difficulty of manned aviation to see and avoid small UAS, in the cases when they are not separated by airspace design the latter will have to be responsible for remaining clear of the former, supported by the U-Space Traffic information Service. Similarly, BVLOS operations (Beyond visual line of sight), when not kept apart from VLOS, will most likely have right of way over VLOS. It is expected that suitable surveillance solutions will be available for all airspace users in this airspace volume to enable this.

IFR/VFR airspace requirements

It is assumed that all UAS operating as IFR/VFR traffic within airspace classes A-G will comply with the relevant airspace requirements in the same manner as manned aircraft. Operations in the airspace where commercial transport aircraft normally operate could demand additional operational performance requirements covering speed, reaction time, turn performance, and climb/descent performance and a detect and avoid (DAA) capability. Annex 10 Volume IV is being updated in ICAO to support the development of adequate DAA systems.

High Altitude Platforms Systems: These Flight Operations above FL600

Flight operations above FL600 (and below 50km), such as the ones performed by High Altitude Platforms Systems called HAPS [28] cover all operations on manned and unmanned aircraft operating in this airspace. In order to access this airspace, UAS will need to interact with the airspace below and thus, high level flight rules must be compatible with IFR but may warrant additional requirements.

B.2 UAS integration

There are 4 main integration requirements:

1. The integration of UAS shall not imply a significant impact on current users of the airspace;
2. UAS shall comply with the existing and future regulations and procedures laid out for manned aviation;
3. UAS integration shall not compromise existing aviation safety levels nor increase risk more than an equivalent increase in manned aviation would.
4. UAS operations shall be conducted in the same way as those of manned aircraft and shall be seen as equivalent by ATC and other airspace users.

A three-step approach: from -accommodation to integration towards evolution

Presently UAS can benefit mostly from the latest FUA/AFUA techniques, and operate as IFR either through dedicated corridors (as currently done over the Mediterranean), or through creating "a dynamic segregation bubble" around the UAS, which places fewer restrictions on airspace usage. This allows for early UAS flights before the required technology, standards and regulations are in place. To fully integrate UAS as any other airspace user, a three steps approach is proposed: accommodation, integration in line with the ICAO GANP Aviation System Block Upgrades and evolution. The evolution phase will be characterised by similar requirements and modification for all manned and unmanned airspace users. The role and the deployment of U-Space in class A to C is still to be clarified in the future.

U space

U space was expected to follow a four-step approach:

- **Accommodation up to around 2020 (U-space U1):** Present VLL operations are accommodated through national rules, regulations and require harmonisation. In this timeframe the first U-Space services will be implemented to support accommodation.
- **Harmonized European accommodation in line with U space regulations 2020-2023 (U space U1 and U2):** VLL operations will be accommodated through European rules and regulations.
- **Integration around 2023 onwards (U-space U3):** With the implementation of harmonised rules and standards, and the deployment of the adequate infrastructure, small UAS will be fully integrated into VLL airspace, safely coexisting with all other airspace users.

---

[28] HAPS are aircraft, usually unmanned airships or airplanes positioned above 20 km (FL600), in the stratosphere, in order to compose a telecommunications network or perform remote sensing.

- **Fully interoperable U space and ATM (U space 4):** in the long-term future, the objective is to(reach a fully interoperable environment for all airspace user, regardless of the airspace.

The (EU) 2021/644 is updating this empiric vision with a clarification on the roles of several stakeholders, the need for several services and the anticipation of equipage requirements which may have limited technical a side effect on current CNS.

In the U-Space environment, when implemented in the U-Space volumes, the VFR and IFR operations will follow the U-Space framework regulation requirements.

When not in a u-Space environment, the UAS will be compliant with the ATM regulations.

UAS IFR operations will follow the two-step approach:

- **Accommodation from now to 2025:** Due to the current absence of regulation and industry standards, accommodation of IFR capable UAS in controlled airspace is, for the time being, mostly possible through FUA/AFUA techniques. In Europe this phase of accommodation can easily be maintained due to the relatively low number of UAS operations.

- **Integration from 2025:** It is expected that the essential SARPS, which will enable civil and military UAS to fly in non-segregated airspace, will be in place by 2023 (ASBU Block 2). With the availability of regulations, standards and relevant supporting technology UAS will, if necessary, be able to integrate as any other airspace user, when meeting the specific airspace requirements based on the principles explained above.

High Altitude Platforms Systems

Since the use of airspace above FL600 by manned aviation is currently limited to certain military operations, and since only a few UAS operators have so far expressed an interest in using this airspace, it is considered that these UAS operations may be accommodated for the foreseeable future.

B.3 UAS integration impact on the CNS infrastructure and applications

Operations in U-space airspace

The CNS infrastructure for U space is being defined by the U space regulation. Given that U space infrastructure must be efficient at low altitude, additional systems will be required. These systems will be either based on space assets or based on a large number of ground stations. Due to the large cost of such deployment, a dedicated infrastructure is quite unlikely. A realistic scenario would base the U-space CNS infrastructure on what exists today: a mix of GNSS, signal of opportunity and commercial communications.

Although UTM/U-Space and ATM are partially geographically separated, some degree of coordination will be required and the ATM CNS infrastructure will have to adapt and interface with the U-Space CNS infrastructure. Given that UAS are expected be mainly accommodated until 2023, an ad-hoc coordination will most likely take place from now to 2023. After 2023, U space UAS are expected to be mainly integrated and coordination with a high level of automation will be required.

In addition and depending on local assessment, large airport may need to acquire a detection capability of non-cooperative UAS. Such dedicated radars coupled with high-end software are being currently developed. The deployment of this detection capability will start in the coming years, when the technology becomes ready, and will most likely continue in the mid-term future.

Operations in the ATM environment

The main requirements for UAS integration apply and UAS will need to seamlessly be integrated :

- UAS will meet CNS airspace requirements;
- UAS will be able to establish two-way communication with ATC if mandated;
- UAS will remain clear of manned aircraft;
- UAS operator must be able to contact ATC (if required) in regard to special conditions such as: lost C2 Link, emergency or controlled termination of flight.

Coordination between ATM and UAS operator will be required and the ATM/CNS infrastructure will need to interface with UAS operator. Given that IFR and VFR UAS are expected to be mainly accommodated until 2025, the coordination will most likely be on an ad-hoc basis. IFR UAS are expected to be mainly integrated after 2025, and VFR UAS after 2030. The coordination’s level of automation will need to increase from 2025.

In addition, the CNS infrastructure will need to handle a larger number of vehicles and then should adapt its capacity. Given the timeline of the VFR/IFR integration, the number of vehicles are expected to grow from 2025.

High Altitude Platforms Systems (HAPS)

UAS flying at very high altitude (above FL600) will need to transit into the lower airspace for entry and exit and then to meet their CNS requirements. UAS operator will also need to inform the responsible ATC unit in case of emergency re-entry into controlled airspace and about the type of contingency procedure to be used (balloon deflating or orbiting descent).

Given that HAPS are expected to remain accommodated in the foreseeable future, the coordination is expected to be based on specific and ad-hoc procedures between ATM and the UAS operators.

Appendix C Civil-military synergies

This Appendix is based and aligned with Civil-Military CNS Interoperability Roadmap Edition 3.0 issued on 7/10/2020 (endorsed by the Military ATM Board).

C.1 The need for civil-military CNS interoperability

The evolution of the global aviation system comprises operational and technological improvements enabled by increasing levels of automation, connectivity, security, resilience, use of satellite technologies, a move towards performance based approaches and the use of more integrated, rationalised and spectrum-efficient systems.

Considering that the military play a key role in aviation, all civil aviation evolutionary plans need to fully consider relevant military requirements. Civil-military interoperability will be a fundamental element to ensure the required levels of connectivity and performance in a globally interoperable context, seamlessly accommodating military operations and training.

Increased civil-military information-sharing will require military systems to be interfaced with the underlying communications infrastructure, including relevant resilience, security and cyber protection. Concerning airborne equipage, it is recognized that some military aircraft (e.g. fighters) are weapon systems and that military avionics primarily perform warfare-related functions rather than meeting civil ATM/CNS requirements. Consequently, Military Authorities may not focus aircraft performance requirements on the needs and standards of civil ATM/CNS systems.

However, in some cases military aircraft need to operate in controlled airspace where the underlying civil infrastructure ensures the provision of two-way air-ground communication services, navigation positioning and tracking as well as surveillance and safe separation. In those cases compliance with the applicable ATM/CNS requirements or alternative ways of accommodation/handling are an absolute imperative.

There are multiple routes for compliance or accommodation. A particular option is to take advantage of dual use technical solutions, enabling the reutilisation of available military capabilities hence reducing integration and technical constraints.

Transversal aspects to consider include the need to coordinate the sharing of spectrum bands, seek more spectrum-efficient systems, address the security challenges derived from increased automation and internetworking, ensure that technical standards consider specific military requirements and resolve procurement and certification mismatches.

C.2 Military Goals

European aviation must incorporate the security and defence dimension at a level that will ensure that military aviation will continue to provide and further improve effective security and defence in Europe, in the changing context of the civil aviation sector, without prejudice to the safety of civil air traffic. As a consequence, military aviation must be be afforded due prioritization and facilitation to conduct missions that support security and defence operations.

Air operations rely heavily on the effective exchange and sharing of digital data among relevant stakeholders and operators. The military must maintain its ability to protect the confidentiality of mission-critical information. The necessary information must be shared by the competent authorities across the Air Traffic Management network. A resilient and robust data sharing network, including relevant cyber protection and cyber resilience will be essential.

C.3 Global Context

Civil-military cooperation is a subject covered by the ICAO Manual on Civil Military Cooperation (doc. 10088). This Manual contains one specific section on civil-military interoperability which sets high-level principles to be globally considered in that domain.

Recently, ICAO confirmed the intention to add a civil-military dimension to its Global Air Navigation Plan moving from coordination to collaboration. States were recommended to actively collaborate with their Military Authorities, including at the regional level, and encourage greater civil-military interoperability and usage of performance based approaches.

In Europe, the ATM Master Plan identifies as performance ambition the need to facilitate military operations through specific technological solutions and procedures, associating the military from the outset to the whole research and development lifecycle to exploit civil-military synergies. Dual-use solutions must contribute to ensuring: safety, regularity and efficiency of the global aviation system and compliance with the requirements of military air operations and training.

A number of Network Functions and tasks, undertaken by the Network Manager, entail significant civil-military implications. Concrete examples are civil-military coordination on scarce resources (RF frequencies, Mode S codes), resolution of anomalies and deficiencies affecting CNS infrastructure performance and safety and support to infrastructure optimization and deployment in terms of military impact.

C.4 Civil-Military Information Exchange Needs

Civil-military coordination supporting safety, continuity of service, security and identification of flights as well as air-picture compilation and associated collaborative decision-making (CDM) processes, call for adequate exchange of information between civil and military ATM and Air Defence units.

The provision of required information to all relevant parties at the right time and with the adequate level of quality and security, on a need to know basis, is recognised as a key aspect of the ATM process. Security is paramount.

In general, military entities need comprehensive, accurate and timely flight/trajectory data on all flights currently within their area of responsibility (AoR). Military operations are, to some extent, dependent on data relating to airspace and aerodromes.

Civil ATM entities need early sharing of military planning information, to improve collaborative decision-making and situational awareness. Access to military surveillance capabilities is, in some local implementations, essential in order to maintain radar coverage and to enable infrastructure optimisation. Those synergies are established on the basis of specific requirements and covered by local agreements, typically between military and civil ANSPs.

C.5 Communications

Significant civil-military challenges emerge from the migration towards ground communication networks based on distributed Internet Protocol (IP) technologies to enable network-centric SWIM architectures and a higher degree of integration of air traffic control (ATC), airline operational control and airport systems.

Based on recognised information exchange needs, the interconnection of military networks already using IP to civil structures may be required, not only to ensure the availability of high-performance/high bandwidth IP networking but also to replace legacy protocols (X.25, IPv4, etc.) by IPv6, connect to NewPENS backbone network and sustain enhanced messaging and data sharing services, notably in full compliance with SWIM services and standards. Security measures and an interfacing approach based on an adequate Information Exchange Gateway (IEG) are a must.

The implementation of voice over IP (VoIP) for inter-centre voice coordination, the use of flight message transfer protocol for inter-centre coordination and transfer and the wider deployment of ICAO FF-ICE (Flight & Flow Integrated Cooperative Environment) and flight data interoperability are domains that will offer substantial civil-military interoperability opportunities.

In the air-ground segment, the interoperability challenges arise from:

- use of air-ground voice, based on VHF 8.33 kHz channel spacing, to support critical communications, keeping a level of provision of UHF for non-8.33 State aircraft;
- introduction of air-ground data link technologies (ATN/VDL-2 followed by future communication infrastructure - FCI) for controller-pilot data link communications and, subsequently, for data link services supporting real-time sharing of (i)4D trajectory management and the availability of ATM information in the cockpit.

Related interoperability recommendations encompass:

- continue to equip State aircraft with VHF 8.33 kHz radios in line with SES regulations while retaining UHF provision for the handling of non-equipped flights;
- equip new transport-type State aircraft with ATN/VDL-2 in line with SES regulations;
- influence FCI research and standardisation to ensure that any military requirements are considered (e.g. SATCOM interoperability, security and spectrum compatibility in the L band);
- consider cybersecurity aspects to protect against communications-related threats;
- monitor and influence research, standardisation and deployment developments to promote civil-military technology convergence, multilink environment, flexible architectures based on software-defined radio technologies, COM solutions for remote piloted aerial systems (RPAS) and drones, performance-based communications approaches and virtual/remote provision of COM services.

C.6 Navigation

Instead of conventional navigation, future navigation services will be based mainly on the ICAO concept of performance-based navigation (PBN) to improve safety and bring capacity and efficiency benefits through the optimisation of air traffic service routes and instrument approach procedures.

The introduction of PBN represents the main evolutionary step in the NAV domain introducing satellite-based navigation (and associated multi-constellation, multi-frequency augmentation systems) as a primary means of navigation. Nevertheless, the navigation infrastructure will retain a terrestrial PBN-support network to cater for situations where GNSS is not available.

As airspace structures and approach procedures based on PBN applications are published, it will become a real challenge to mitigate the military avionics mismatch for PBN and a minimum operational network (MON) (e.g. determined number of VOR and ILS) and transitional arrangements will be required.

A fundamental objective will be to permanently facilitate military operations conducted in PBN environment, guaranteeing military unrestricted and timely access airspace and aerodromes.

Related civil-military interoperability recommendations include:

- retain a sufficient level of conventional means of navigation as an option for handling non PBN-equipped State aircraft;
- study dual use solutions for State aircraft compliance with PBN to maximise the re-utilization of military airborne capabilities (e.g. military inertials, GPS/PPS / GNSS restricted signals, TACAN, differential GPS, enhanced visual systems, etc.);
- influence alternative-positioning, navigation and timing (A-PNT) solutions with TACAN considered as an equivalent means of navigation to DME;
- consider the performance of ARAIM as a means of navigation for en-route, terminal and approach procedures down to Category I in the long-term perspective for some State aircraft operations;
- Seek compatibility between military PALS and civil GBAS standards and equip State aircraft with solutions for approach and landing compatible with SBAS CAT I or GBAS Cat I, depending on the operational scenario.

C.7 Surveillance

The aeronautical surveillance chain must provide updated aircraft identification, position and other information in order to enable safe, secure and efficient air traffic services. The surveillance system should support appropriate separation in a defined volume of airspace.

The (civil) surveillance infrastructure is evolving to rely in an “optimal mix” including SSR Mode S, Wide Area Multilateration (WAM), and Automatic Dependent Surveillance–Broadcast (ADS-B). In the civil context, such infrastructure elements support both terminal and en-route surveillance.

It means that the legacy monopulse SSR (Mode 3/A) will gradually be rationalised. In parallel, a layer of independent and non-cooperative surveillance (primary radar) will remain available, for all flight phases, to track non-transponding targets. State aircraft operators face SES regulatory obligations (SPI IR), when operating as GAT/IFR, to equip all aircraft with Mode S ELS transponders and transport type aircraft with Mode S EHS and ADS-B OUT.

Civil-military surveillance interoperability recommendations comprise:

- retention of independent non-cooperative surveillance (Primary Radar) to track non-cooperative targets and sustain security and safety requirements;
- equip all State aircraft with Mode S ELS Level 2 transponders and transport-type State aircraft with Mode S EHS and ADS-B OUT in line with SES SPI regulation;
- coordinate with EUROCONTROL/NM the allocation and use of IC codes;
- implement appropriate mitigating actions to avoid or minimise security risks, including reversion from Mode S to Mode 3/A in case sensitive flights;

- implement coordination mechanisms and procedures that facilitate compliance with surveillance performance objectives, including related monitoring and contribution to the reduction of 1030/1090 MHz RF pollution;
- consider voluntary equipage for transport-type State aircraft with safety systems, weather and hazard detection (ACAS, Wake Vortex, EGPWS/TAWS, etc.);
- where operationally and technically viable, maximise surveillance data sharing,
- implement frameworks to support or facilitate the compliance of military sensors for civil use.

C.8 Avionics Integration

Military aircraft are platforms optimized for military mission execution that have, in many types/variants, limited (cockpit) space for (additional) avionics equipage. For this reason, the integration of civil ATM/CNS on-board equipment is often problematic and retrofits are limited in option.

Alternative engineering approaches to attain the desired levels of civil-military interoperability may include a certain level of reutilisation of available capabilities, performance-level solutions and multi-mode avionics. For the missing ATM/CNS capabilities, a forward fit / dual use approach may be beneficial to face increasing avionics complexity and form-fit functional allocation principles.

Certification challenges (a national competency for military) must be addressed as early as possible including the assessment of all compliance verification options ranging from direct retrofit with civil solution, to adaptation/modification supported by standard certification or using alternative processes based on performance where beneficial and feasible.

The document Civil-Military CNS Interoperability Roadmap (Edition 3.0 dated 07 October 2020) (https://www.eurocontrol.int/publication/civil-military-cns-interoperabilityroadmap) details some of the possible dual use synergies to be considered for military aircraft compliance with civil requirements.

C.9 Planning and Procurement

National Military Authorities should organise, plan and take deployment decisions on the basis of military requirements that are understood as the maximum priority. Nevertheless, it is important to remain aware and consider provisions from published ICAO concepts, plans and roadmaps as well as European Commission implementing rules and national ATM/CNS regulations. In any case, the EU regulatory framework does not cover military operations and training.

For technical and/or operational reasons, compliance with specific equipage requirements is not always possible or warranted. In particular, it is recognised that combat military aircraft are essentially weapon systems to be specifically equipped. Exemptions for State aircraft should be based on such compelling technical and imperative military reasons.

C.10 Civil-Military Spectrum Coordination

The success of military missions depends on adequate access to RF spectrum resources, in particular to ensure the mobility and interoperability of forces. Military utilization of spectrum bands must be safeguarded and the mitigation of harmful impact to the civil infrastructure ensured through a comprehensive civil-military coordination effort.

Military authorities have always been committed to using the frequency spectrum in accordance with the provisions set out by the International Telecommunications Union (ITU), including its Convention and the Radio Regulations. Nevertheless, it is of utmost importance to push forward adequate military positions to ITU World Radiocommunication Conferences (WRC) consolidated with the global civil aviation positions. The integration of civil-military aspects into aeronautical spectrum strategies is fundamental to facilitating the co-existence of civil and military requirements.

C.11 Security

Military air operations rely heavily on the effective exchange and sharing of digital data among relevant organisations and operators. The military must maintain the ability to safeguard the confidentiality of mission-critical information. The necessary information has to be shared by the competent authorities across the Air Traffic Management network. A resilient and robust data-sharing network, including relevant cyber protection and cyber resilience will be essential.

In normal circumstances, ATM information is sensitive but unclassified and security solutions for data exchanges with military sites/systems can be less stringent. Nevertheless, security and interoperability measures applicable to the interconnection between designated military systems and other external systems with different protection levels must be applied on the basis of sound security assessments.

In summary, the military are particularly sensitive to the need to maintain appropriate security levels. ATM/CNS evolution must incorporate security measures synergized with the military, taking account of their specific security requirements.

For the interconnection of ground communication networks, it is imperative to define an information exchange gateway (IEG) to facilitate secure communications between different security and management domains.

Concerning air-ground data links, the Future Communications Infrastructure (FCI), compliant with the ICAO Aeronautical Telecommunications Network (ATN) concept, must comprise security mechanisms for IP communications and messaging, including features such as authentication/digital signatures/hashing, encryption (e.g. public key infrastructure – PKI) and use of security certificates.

The use of satellite technologies raises significant security concerns, in particular due to the risk of intentional jamming which may render GNSS services unavailable. GNSS performance monitoring is of particular importance to mitigate GNSS service outages. Although GNSS robustness will be enhanced by the introduction of new frequencies and constellations, together with the improvement of current augmentation systems (A-RAIM), vulnerability to interference (non-intentional but mainly intentional) will not be completely eliminated.

Security threats will also impact the surveillance infrastructure, in particular ADS-B. Spoofing and similar techniques represent a significant risk for ADS-B, together with the easy disclosure of SUR data tracking and identifying flights in open internet platforms.

C.12 Unmanned Aircraft

As a general principle, the CNS requirements to be considered for civil Unmanned Aerial Systems (UAS) will also be applicable to military UAS integration. However, military UAS accommodation supports the approach towards integration. The military UAS are certified by a national Military Aviation Authority in terms of type certification and airworthiness against national and/or international military certification specifications, supported when deemed relevant by civil certification specifications and standards.

The CNS infrastructure for U-space must be suitable for low-altitude operations, with additional systems possibly required. Such systems will be based either on space segments or on a large number of ground stations. Due to the high cost of such deployment, a dedicated infrastructure is quite unlikely. A realistic scenario would base the U-space CNS infrastructure on what exists today: a mix of GNSS, signal of opportunity and commercial communications.

For IFR and VFR operations, UAS integration requirements apply so that such insertion is seamless, including compliance with the CNS requirements determined, such as two-way communication with ATC, the technical means to ensure separation from manned aircraft and enablers to cope with lost C2 Link as well as emergency or controlled termination of flight.

UAS integration will entail the availability of a ground- and space-based service and airborne CNS equipment that mirrors the CNS requirements applicable to manned flights.

Appendix D CNS Security

D.1 Introduction

In today’s ATM/CNS environment, one of the biggest challenges is handling the huge flow of information between the CNS systems, applications and users (ANSPs, AO, and Airlines etc.) and keeping this information protected. The CNS infrastructure itself faces many major challenges, such as the vast volume of information to be secured, the diversity in format of the data and the multiplicity of sources they derive from. All these factors contribute to increasing the vulnerability of CNS systems.

The subject of cybersecurity in ATM is a very complex one and is linked to European critical infrastructure and/or national critical infrastructure protection, national security, defence and law enforcement, safety-critical systems and services, multiple actors, technology and interoperability challenges, and also to the need for real-time management. CNS is part of ATM, and cybersecurity has an impact on both ATM and CNS security.

The scope of this appendix is to provide a high-level overview of the main threat scenarios and vulnerabilities which can affect the continuity of CNS operations and, as a consequence, have an impact on ATM services. Examples of potential impacts include a reduction in capacity, an increase in delays, an infringement of safety, and credible corruption of data. This guidance document can support ANSPs in complying with the legal requirements for CNS systems.

Evolutionary trends and implementation of CNS technologies and techniques such as Internet Protocol Security (IPSec), the Voice over Internet protocol (VoIP), the VHF Data Link (VDL), controller-pilot data link communication (CPDLC), satellite communication (SATCOM), global navigation satellite systems (GNSS), performance-based navigation (PBN), and automatic dependent surveillance-broadcast (ADS-B) have increased the security concerns around the supplier, implementer and users.

D.2 Convergence between CNS security and cybersecurity

CNS security and cybersecurity are not stand-alone attributes of a system (Figure 1 – global overview of CNS systems), and because of their interdependencies, it is difficult to draw a line and separate them. Future CNS technologies will be mostly digital and automated, and in turn, ground communications will be done via networks (such as NewPENS). In addition, systems such as system-wide information management (SWIM) will rely on A/G or G/G communication technology such as datalink, for example: LDACS for air/ground connectivity. There are thus clear interdependencies between security and cybersecurity. In fact, SWIM is the concept which will allow the exploitation of expected benefits introduced by new CNS technologies. It could be concluded that CNS security and cybersecurity merge in the same way as INFOSEC[29] and COMSEC[30].

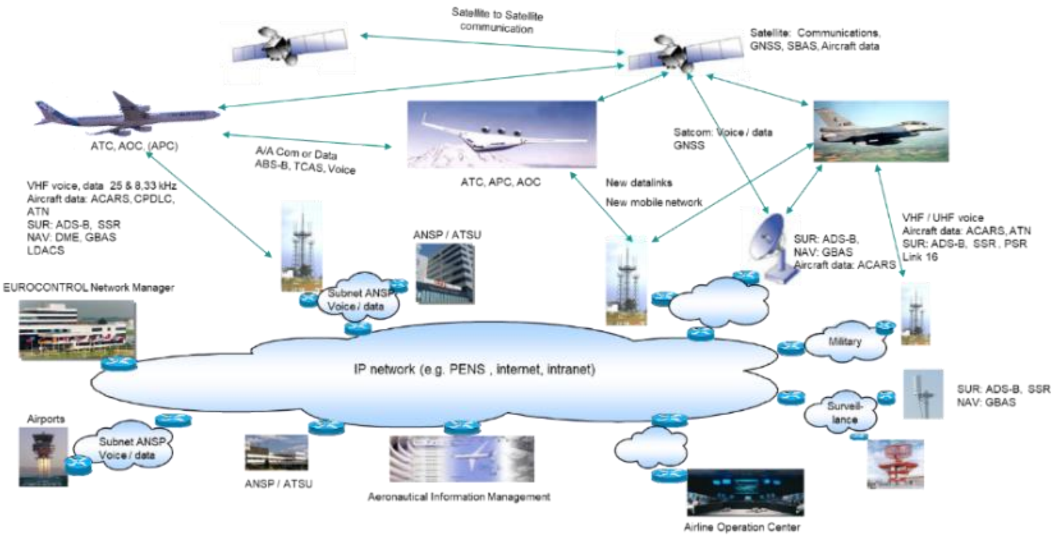

Figure 8: Overview of CNS integration

Security requires a holistic[31] view and an integrated (system of systems) approach. If an attacker tries to tamper with ATM/CNS data, the question is not about whether it is done at the system (CNS) or network level, but about the impact and consequences it might have.

The (holistic) security systems should be capable of identifying:

- the risk (security-driven by intelligence, risk-based, risk-managed and outcome-oriented);

---

[29] Information security (INFOSEC) - The application of security measures to protect information processed, stored or transmitted in communication, information and other electronic systems against loss of confidentiality, integrity or availability, whether accidental or intentional, and to prevent loss of integrity or availability of the systems themselves. INFOSEC measures include those of computer, transmission, emission and cryptographic security. Such measures also include detection, documentation and countering of threats to information and to the systems.

[30] Communications security (COMSEC) - The application of security measures to telecommunications in order to deny unauthorised persons information of value which might be derived from the possession and study of such telecommunications or to ensure the authenticity of such telecommunications. Note: Such measures include crypto, transmission and emission security and also include procedural, physical, personnel, document and computer security.

[31] Holistic security is an approach which seeks to integrate all the elements designed to safeguard an organisation, considering them as a complex and interconnected system. The ultimate purpose of holistic security is continuous protection across all attack surfaces: the totality of all physical, software, network and human exposure.

- risk level (security risk assessment, security risk management), based on the identified critical information and indicators and the impact of a system being compromised;
- where the attack would most likely take place (vulnerability assessment); and
- implementation of the necessary security controls (at system level and at component level).
- ability to anticipate attacks and to understand the threat landscape that includes the techniques used by adversaries to conduct cyber-attack against aviation (e.g.; the MITRE ATT&CK aviation heat map produced by EATM-CERT).

The likelihood of an attack is a function of:

- the intention to act, which includes a motivation to do so;
- operational capabilities to act against the target which includes the means and the opportunity (or possibility to use the means against the target); and
- the attractiveness of the target, which is a function of:
    - impunity (exemption from punishment or freedom from the consequences of an illegal act): possible traceability or full anonymity (impunity considerations might be trivial, for example in the case of suicide attacks);
    - the expected impact or results: casualties, media coverage, profit, challenge;
    - ease of realisation: expert/specialist knowledge, planning requirements, general knowledge, know-how/learning about facilities(e.g. open sources).

The attractiveness of the target is important for matching possible vulnerabilities with attacker profiles. For instance, it is possible to interfere with the GNSS signal to jam or spoof the equipment on the ground or on board the aircraft. In general terms, if an attack was targeted at CNS systems and to compromise data availability or integrity, it might be achieved more easily by means of a cyberattack rather than an electromagnetic attack. This is because adversaries/hackers[32] can be very effective at minimal cost (for example operating from home or also because jammers are cheap and easy to find and you can place them close to the target), because cyber-attacks are efficient and there is no need to be in the physical vicinity of the target, thereby reducing the risk to them. An electronic attack, on the other hand, requires more skills, more sophisticated technics (e.g. spoofing) and a certain degree of exposure in order to perpetrate it. Consequently, for a given intention/motivation, cyberspace would offer better capability (means and opportunities) than an electromagnetic medium for targeting CNS systems, applications and infrastructure.

D.3 ATM Regulatory Framework

This chapter gives an overview of the current legislation, at global, European and national level, laying down the requirements on ATM/CNS security. The diagram below gives an overview of the global, European and national legislation in force and their relations. More information on the security legislation and CNS requirement implementations based on the Global and European set of

---

[32] A cyber adversary is someone or a group that intends to perform malicious actions against other cyber resources. Adversaries: Have more resources and capabilities, and will be able to discover new vulnerabilities.

regulations, can be found in the EUROCONTROL document "CNS Security Implementation Requirements" Annex I Edition 1.0.

Global framework

- **ICAO Annex 17**

Annex 17 is the most important aviation-security-related legislative instrument developed by ICAO for Member States for the implementation of the national civil aviation security system. Each Contracting State requires Air Traffic Service Providers (ATSP) operating in that State to establish and implement appropriate security provisions to meet the requirements of the national civil aviation security programme of that State.

- **ICAO ATM Security Manual Doc 9985 and Aviation Security (AVSEC) Manual Doc 8973 (restricted).**

These documents provide guidelines on the implementation of Annex 17 requirements. Doc 9985 provides guidance to ATSPs on the provision of ATM security services in support of national security and law enforcement requirements, and guidance on the protection of the ATM system infrastructure from threats and vulnerabilities. According to the ICAO AVSEC Manual, the protection of critical information and communication technology systems, including their hardware, software and data, should be included in threat assessment processes established by the appropriate authority. This may be achieved by including critical aviation information and communication technology systems in assessments of likely methods of attack.

- **ICAO Annex 10**

ICAO Annex 10 addresses aeronautical communications and includes five volumes:

- Volume I, "Radio Navigation Aids"
- Volume II, "Communication Procedures"
- Volume III, "Communication Systems"
- Volume IV, "Surveillance Radar and Collision Avoidance Systems"
- Volume V, "Aeronautical Radio Frequency Spectrum Utilization",

This annex contains standards and recommended practices (SARP's) and methods of operation, procedures and codes for worldwide application. Several requirements are recommended for security (integrity and availability) for different parts of CNS.

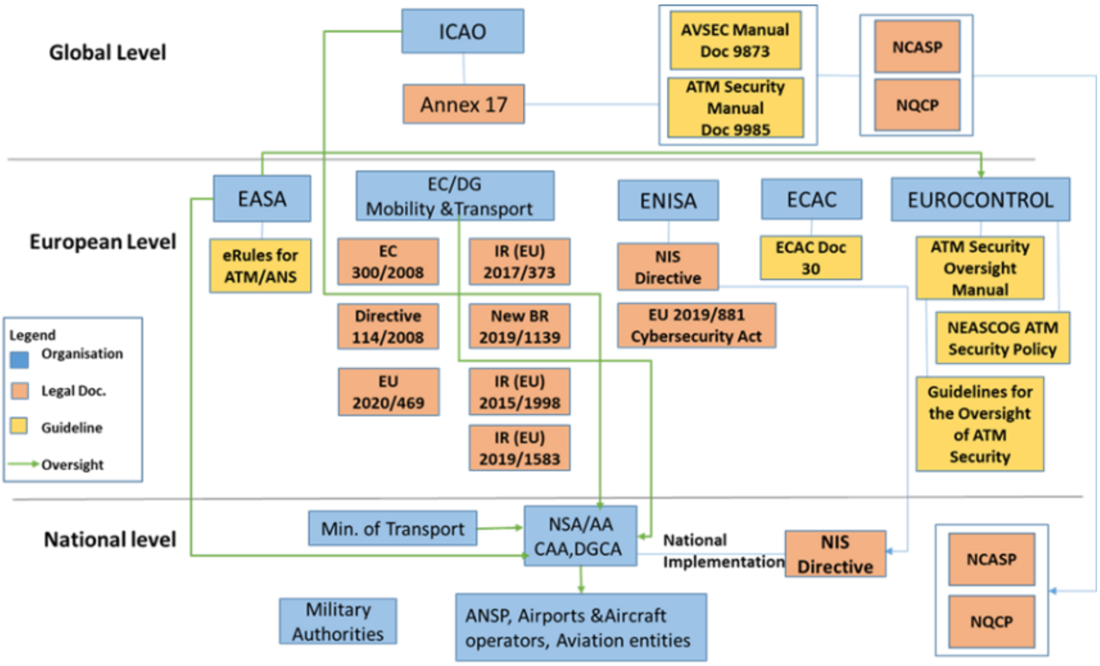

Figure 9: ATM Security Regulatory and Guidance Framework

European framework

- **IR (EU) 2017/373 common requirements for ATM/ANS**

Commission Implementing Regulation (EU) 2017/373, which lays down common requirements for the provision of air navigation services, stipulates that Air Navigation Service Providers (ANSPs) must establish a security management system (including risk assessment, risk mitigation, monitoring, improvement, detection of breaches, and alerting of personnel) to ensure the security of their facilities and personnel and operational data they receive or produce, in order to prevent unlawful interference with the provision of air navigation services.

- **Regulation (EU) 2018/1139 (establishing EASA)**

This Regulation lays down common rules in the field of civil aviation and gives EASA a coordinating role in cybersecurity in aviation. Security requirements for CNS are specified as follows:

  - **Communication** services shall achieve and maintain sufficient performance levels with regard to their availability, integrity, continuity and timeliness. They shall be expeditious and protected from corruption and interference.
  - **Navigation** services shall achieve and maintain a sufficient level of performance with regard to guidance, positioning and, when provided, timing information. The performance criteria include accuracy, integrity, legitimacy of the source, availability, and continuity of the service.
  - **Surveillance** services shall determine the respective position of aircraft in the air and of other aircraft and ground vehicles on the aerodrome surface, with sufficient performance with regard to their accuracy, integrity, legitimacy of the source, continuity and probability of detection."

- **Commission Implementing Regulation (EU) 2019/1583**

This Regulation amends Implementing Regulation (EU) 2015/1998, laying down detailed measures for the implementation of the common basic standards on aviation security, as regards cybersecurity measures. The purpose of this amendment is to help Member States ensure full compliance with the most recent amendment 16 of Annex 17, which introduced new standards relating to national organisations and appropriate authorities and Standard 4.9.1 related to preventive cybersecurity measures.

- **Regulation (EU) 2019/881 (Cybersecurity act)**

This act establishes a cybersecurity certification framework to ensure a common cybersecurity certification approach in the European internal market, and ultimately improve cybersecurity in a broad range of digital products, processes, and services.

The act made ENISA a permanent EU agency, extended its mandate, and expanded its role in assisting and cooperating with national and European cybersecurity actors in the event of large-scale cyber incidents.

D.4 CNS Security

Historically, ATM-related CNS system development didn’t focus on security because the threat level was perceived to be low. Because of several security incidents and attacks, new technologies are now considering (cyber) security requirements to a larger extent, starting from the design phase.

The future ATM system will evolve in several ways, via the application of new operational concepts and subsequent technological enablers, continued wider use of commercial off-the-shelf (COTS) products, the incorporation of open standards, the increase in data sharing, the rationalisation of the infrastructure, and remote-control systems. This transition will clearly not be without risk. ATM is moving into new, unfamiliar territory. The bespoke systems of the past, communicating on closed networks and using technology only available to, or accessible by, community specialists, benefited from “security through obscurity”.

Future developments should have a different approach. Safety and security must both be considered in the design/definition processes as being interdependent. The threat assessment process includes the identification of threats and vulnerabilities, the estimation of the likelihood of a successful attack, and the evaluation of the resulting operational impact. The analysis of potential mitigating controls then leads to the development of requirements which feed the design process. Security must be addressed for the all stages of the lifecycle, including concept development, design, prototyping, development, deployment, operation and decommissioning. The further development of security and cybersecurity standards is key to this process.

Proactive security management at national and international levels is leading to a comprehensive holistic approach to ATM security, which includes looking into the overall spectrum of threats and identifying affordable implementation strategies for risk mitigation and risk reduction to acceptable risk levels. Collaborative sharing of threat information reduces risk for all players and domains of the security (physical and cyber). This risk management process is a continuous exercise, allowing the ATM/CNS system to quickly adapt to evolving emerging security threats.

Three pillars for security, which are also applied to CNS security, are:

- **Confidentiality** –Ensures that sensitive information are accessed only by an authorized person and kept away from those not authorized to possess them. It is implemented using security mechanisms such as usernames, passwords, access control lists, and encryption. Only authorised legitimate recipients get access to the appropriate CNS information, on a “need-to-know‟ or “need-to-share‟ basis.
- **Integrity** – This is the assurance that information is trustworthy and accurate, including non-repudiation and authenticity of CNS data, systems and infrastructure for the legitimate user. The information can be edited by authorized persons only and remains in its original state when at rest. Integrity is implemented using security mechanism such as data encryption and hashing.
- **Availability** – This is a guarantee of reliable access to CNS data, information, systems (infrastructure) by authorised people at the required time. It is implemented using methods such as hardware maintenance, software patching and network optimization. Processes such as redundancy, failover, RAID and high-availability clusters are used to mitigate serious consequences when hardware issues do occur. Dedicated hardware devices can be used to guard against downtime and unreachable data due to malicious actions such as distributed denial-of-service (DDoS) attacks.

The basic examples of threats against these three pillars are:

- **Unauthorised disclosure/access (confidentiality):** More and more information related to ATM/CNS is being made public. However, some flights remain sensitive, and related data should remain restricted. By way of example, we have military flights (training flights for the interception of other aircraft) which follow a special procedure which should not be seen by the public.
- **Data tampering/spoofing (integrity):** Taking control of data from the system (e.g. importing false CNS data, deceit, unauthorised modification (meaconing), or destruction).
- **Denial of service (availability):** Disruption of access to, or use of one or more, critical components of the ATM/CNS infrastructure (data and voice – ground/ground and air/ground).

D.5 Threats and Vulnerabilities posed to CNS

Threat agents to CNS systems

Threat information can come from a wide variety of sources, for example (information sharing and analysis centres (ISACs), computer emergency response teams (CERTs)), and many of these will be external to the organisation which is trying to mitigate the associated risks. External sources include open-source reports, commercial paid-for threat intelligence services, national and international authorities, and industry collaborations with and between operators, manufacturers, regulators and reporting/alerting centres.

Another source of threats is also the ENISA threats landscape[33], which is published every year. This landscape provides an overview of threats, together with current and emerging trends. It is based on publicly available data and provides an independent view on observed threats, threat agents and

---

[33] https://www.enisa.europa.eu/news/enisa-news/enisa-threat-landscape-2020

threat trends. For 2020 based on this report, cyber-attacks are becoming more sophisticated, targeted, widespread and undetected.

All the existing threats to CNS will remain and new threats will take advantage of the vulnerabilities being introduced as the system evolves. These attacks may not consider CNS as the prime target but may still cause damage. Unlike in the past, where CNS was a direct target attackers may target the support system (IP network) of CNS in order to undermine the CNS system. This is because many CNS applications and a large number of ATM functions will be dependent on the IP network (CPDLC, VoIP, ATM messaging, flight plan coordination, etc.), and attacking this has an impact not only on CNS systems but also on ATM itself.

Examples include:

- disruption of remote control and monitoring of system status for CNS systems, causing lack of, or a reduction in, confidence in communication, surveillance or navigation systems;
- using remote control and monitoring systems to shut down CNS systems;
- using CNS to access the network and launch cyberattacks on other systems (e.g. the military, AOCs, the emergency services);
- coordinated malware attack as systems move to common suppliers and COTS;
- hacking ATM systems by intrusion via the back doors of the mobile networks (mobile commercial networks at airports, dedicated A/G mobile networks, passenger communications, etc.).
- abusing insiders to get access to systems

Vulnerabilities posed to CNS systems

Vulnerabilities will emerge as CNS systems become more interconnected and dependent on one other (integrated CNS), with increased dependence on navigation position by surveillance systems, or surveillance plots and tracks transmitted and shared via communications networks (e.g. NewPENS).

The lack of some of the following controls could affect the (cyber) resilience of the CNS system:

- diversity of suppliers and implementation solutions, making it more complex in the event of an attack to affect the service provided at once
- custom or bespoke systems, making it difficult for an attack on multiple system at the same time;
- systems located at different sites, limiting the geographical impact of an attack;
- local implementation of functions (e.g. local surveillance data processing and distribution (SDPD)/flight data processing and distribution (FDPS) at ANSPs, meaning that an attack on one SDPD/FDPS has limited geographical impact;
- different technologies/techniques which complement one other in providing CNS services such as datalink (VDL/LDACS/SATCOM) and VHF air-ground voice for air-ground communication or cooperative dependent and non-cooperative independent surveillance;
- back-up/redundant systems as a common practice, possibly with the implementation of dissimilar technologies;
- lack or very basic means to identify & authenticate users and thus control the access to systems;
- distributed management functions (e.g. localised response, coordinated within a single organisation).

The future CNS systems may also be vulnerable as a result of collateral damage when CNS is not the intended target of an attack but is impacted as a side-effect. Examples include the following:

- As a result of a physical attack on infrastructure shared with other domains (such as shared communication links outsourced to a telecommunications provider).
- Malware or a DDOS attack on a shared communication infrastructure
- Jamming of signals (e.g. GPS), intentionally used by criminals located close to an airport to camouflage their location, or unintentional jamming by a delivery driver or wrong connected cables.

D.6 Risk matrix

Security risk is a combination of the impact of a successful attack and the likelihood that the impact will be achieved. Below we propose the Risk matrix table to be used for Risk assessment (Table 3). This matrix was developed in SESAR and is used in the SESAR Security Risk Assessment Methodology (SecRAM 2.0). The methodology itself, was developed based on international standards during the first SESAR programme were EUROCONTROL led this task. The method was refined during SESAR2020. It provides a systematic, holistic approach to security risk management from an early stage in the development life-cycle, ensuring that assets, threats, and vulnerabilities are identified, associated risks are evaluated, and that mitigating security controls can be identified for design-in to the system. The methodology is generic, adaptable, and applicable to the broad variety of emerging aviation assets, and can deliver the evidence required for compliance purposes (e.g. Reg. (EU) 2017/373).

	Impact				
Likelihood	**1**	**2**	**3**	**4**	**5**
5	Low	High	High	High	High
4	Low	Medium	High	High	High
3	Low	Low	Medium	High	High
2	Low	Low	Low	Medium	High
1	Low	Low	Low	Medium	Medium

Table 3 Risk matrix model used in SESAR

D.7 Security controls

There are several controls which are ATM-specific which are designed to make the CNS system robust and/or manage the consequences of CNS outage or disruption. These controls have been used in the past to ensure that ATM remains safe even in the event of a CNS system failure. These practices include:

- ATM procedures;
- multiple coverage (SSR, WAM, ADS-B);
- different techniques and technologies operating with security mechanism at RF level (such as frequency hopping);

- the human element (training, awareness, security culture);
- automated systems;
- navigation and surveillance performance monitoring and reporting tools;
- safety management systems;
- security management systems.

The existing design principles in place within ATM already make the CNS infrastructure robust (typically as a result of safety assessment, but they can be taken advantage of from a security viewpoint). For example, if surveillance were lost or corrupted, there are already a large number of controls (procedures, SSR, ADS-B, WAM) in place to ensure that ATM keeps working safely.

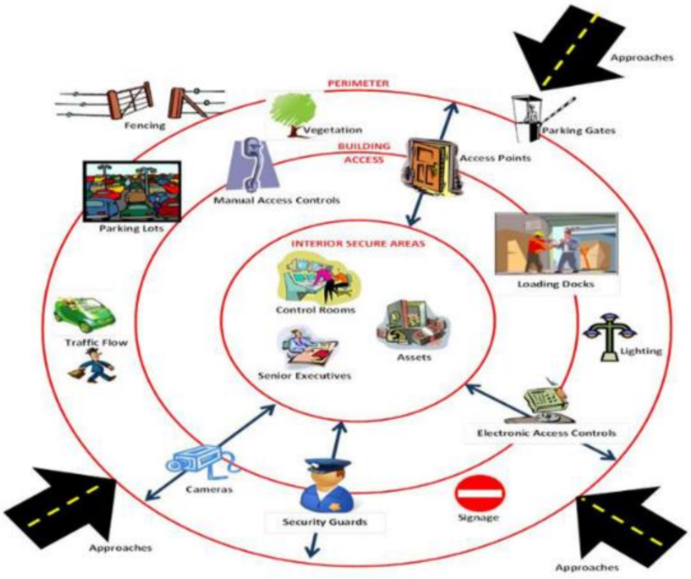

Figure 10: Overview on physical / cyber security systems and layers of security[34]

The general CNS/ATM controls and design principles include:

- dual technologies and techniques providing a basic security resilience because they can be reverted to in the event of an attack (e.g. Intention of Dual Frequency MultiConstellation for GNSS for example);
- duplicate/back-up systems (Minimum Operating Network);
- the monitoring of signals in space (e.g. communication or navigation or surveillance- e.g. Receiver Autonomous Integrity Monitoring for NAV[35])

---

[34] Source: https://www.bayometric.com/best-practices-physical-security-management/

[35] A technique whereby a civil GNSS receiver / processor determines the integrity of the GNSS navigation signals without reference to senders or non-DoD integrity systems other than the receiver itself. This determination is achieved by consistency check among redundant pseudorange measurements.

- the obligation to implement an Security Management System (SeMS), including the need for a security risk assessment (SRA) which is updated on a regular basis (Commission Implementing Regulation (EU) 373/2017, which entered in force on 2 January 2020).
- standard operating procedures (SOPs, for example from ICAO) in the event of CNS failure.

A minimum set of security controls based on ISO 2700x series security control is also recommended:

- Security policy
- Organisation of information security
- Human resource security
- Asset management
- Access control (identification & authentication management)
- Physical and environmental security
- Operational security
- Communication security
- System acquisition, development and maintenance
- Information security incident management
- Information security aspects of business continuity management
- Compliance

The legacy controls will either reduce the likelihood of the attack being successful or limit the impact of the attack. It is important to remember that legacy system sometimes have lack of security principles in their design phase (lifecycle and age of the equipment) and that the update are too difficult or too expensive for the implementation in the existing systems.

D.8 Security recommendations

The traditional focus of CNS security has been the protection against physical attacks and radio frequency (RF) spectrum interference. It is recommended that a set of controls based on best practices (for example the ISO27000 series) be implemented. There are also a set of security management good practices, including but not limited to:

- implementing an ATM/CNS security policy;
- sharing security information related to potential attacks (intelligence-led), actual attacks, their impact, and how they were resolved;
- establishing a security cell for CNS (at CERT[36] level);
- tightening controls on cyber threats and RF interference;
- sharing the civil/military infrastructure;
- a stress test infrastructure (including penetration test).

In addition, there are security recommendations for the CNS components.

---

[36] A Computer Emergency Response Team (CERT) is an expert group, which handles computer security incidents. Alternative names for such groups include Computer Emergency Readiness Team and Computer Security Incident Response Team.

Communication

- Implement identification/authentication to verify and validate authorised users and trusted data origin sources.
- Implement non-repudiation in order to provide an audit trail of the information or service provided over the communication system.
- Continue the implementation of best practices compliant with the SWIM technical infrastructure specification[37].
- Continue developing procedures to mitigate and counter the spoofing of VHF communications.
- Continue to introduce enhanced protected modes of broadcast and point-to-point air-to-ground communication services.
- Introduce ground network monitoring functions to recognise normal behaviour, detect and report abnormal behaviour, and introduce upper-lower traffic boundary limits.
- Monitor the aviation communication spectrum to detect and localise potential interferers with unwanted connections.

Surveillance

- Strengthen all surveillance components (sensors, transponders and the SDPD) against cyberattacks.
- Continue protection of inter-system surveillance data exchange.
- Continue deployment of techniques to strengthen ground stations (particularly ADS-B receivers) in order to detect and resolve spoofing and jamming attacks e.g. implement identification/authentication to provide the proof of identity of the signal origin sources.
- Where needed, maintain an independent non-cooperative surveillance system (e.g. primary radar) in order to act as a back-up in the event of overload, interference and jamming of 1030/1090 MHz. This infrastructure could be a shared resource between the civil and military domains.
- Develop a procedure to detect and manage the consequence of spoofing of position reports as a result of attacking either the SDPD or the ADS-B reports.
- Enhance the SDPD in order to provide monitoring and reporting of major errors in surveillance data.
- Implement identification and authentication to verify and validate trusted data origin sources.
- Develop and enhance the monitoring function of the 1030-1090 MHz to detect and alert in real-time anomalous activities.
- Develop means to ensure privacy of civil flights

Navigation

- Strengthen the conventional navigation aids and ground augmentation infrastructure supporting GBAS against physical and cyberattacks, including any interfaces connecting to such facilities for operational control and maintenance.

---

[37] EUROCONTROL-SPEC-170: Specification for SWIM Technical Infrastructure (TI) Yellow Profile

- Continue to provide and optimise ground-based Navigational aids in order to allow cross-checking of position and switching to alternate navigation.
- Introduce procedure to detect and manage wide-area navigation failures (specifically due to jamming, for example by monitoring ADS-B).
- Continue to develop techniques to strengthen the (airborne) components against spoofing and jamming attacks.
    - Note: The core satellite constellations (GPS, GLONASS currently, Galileo and BeiDou in the coming years for aviation use) and also SBAS (EGNOS in Europe) are multi-modal systems serving multiple user segments, of which aviation is one. They have their own security requirements and management procedures and are outside the scope of the current document.
- Develop means to detect interference on-board of the aircraft and downlink the detected interference to the ground.

Appendix E Airbus considerations on CNS evolution roadmap and strategy

CNS functions are vital for aircraft operations. CNS functions are notably achieved with the support of radio systems installed on board the aircraft and which interoperate with external systems located on the ground, in space, or on other aircrafts.

CNS functions are sensitive and this implies that any update or modifications of the CNS supporting equipment take a lot of times and require many efforts to be analysed, implemented, certified and finally deployed. Also, the introduction of changes or of new solutions need to be timely coordinated with the pace of adaptations required to be synchronously made on the external systems and networks. This leads to a situation where a large majority of CNS functions evolves slowly, so remains based on aging technologies for a long time, and where some parts of equipment may be faced to issues of obsolescence. Another implication is that CNS functions performance remains quite limited compared to what state of the art spectrum-related technology could offer, and may not be appropriate any more to accommodate future operations and to deal with "New entrants" (UAVs Space planes..) .

To ease CNS functions evolutions, a clear strategy needs to be planned with all stakeholders, taking care about all the factor of influences, and notably those which may, if neglected, jeopardize all the roadmap achievement and limit the scope of CNS evolution to minor update, insufficient to meet the requirements for future operations.

This appendix includes some initial considerations from an Air framer on CNS functions evolution, on operational and technical aircraft evolution and also some considerations on spectrum approach.

E.1 General considerations on CNS functions evolution

CNS performances-based approach is a key opportunity to optimise CNS systems and to take benefits from the latest technologies. It should also contribute to meet more general objectives such as decreasing environmental footprint of aviation, getting more capacity, facilitating/supporting new operational scenario and possibly enhancing safety, security and regularity of flights while reducing cost

General considerations on Aircraft integration

From an aircraft designer point of view, in addition to facilitate meeting general objectives, investigating on CNS evolution is also an opportunity to look for a more optimised integration of the systems on board the airplane, maybe to reduce weight, volume occupation, wiring, complexity, costs, to enhance reliability and maintainability and also to investigate for possible new services or functionalities to better serves the airlines.

However, the path may be long to find a consensus on a common CNS evolution roadmap and strategy. To ensure adherence, a step-by-step approach (Near, Mid and Long term) will certainly be key. CNS functions are vital and CNS evolution will impact systems which are essential to the safety and regularity of flights. Any changes will consequently require rigorous prior impact assessments including definition of performance and associated requirement. Standardisation process will be essential in that perspective in order to clearly define the minimum essential requirements to which the new system has to comply and also to foster a common understanding on the objective and to promote a harmonised approach. In addition, any CNS evolution might have impact on new aircraft as well as on existing fleet and multiple analysis will certainly have to be carried out covering both situations.

Of course, any modification in an aircraft is always a delicate operation which implies many activities and requires long time to be made and certified. Changing a technical part, either an update of existing system or the integration of a complete a new system, is never straightforward. It is always preceded by in-depth analysis of all the possible impacts of the modification.

Impacts of a new system are multiple for an Aircraft integrator; the three main immediate categories of impacts are:

- Technical impact, related to feasibility and acceptability of the modification (e.g. radio compatibility issue, EMC, Safety, Electricity, mechanical impact, cabling issue,…), non-regression investigations (demonstrate the benefits of the new system in case of replacement), impact related to the introduction of a new value chain for a totally new system (e.g. new interfaces to be developed, obsolescence of former system to be managed, data security to be totally reviewed,…). Verification and Validation of the new integrated system including certification operations for which the process and tests to be performed have to be defined.

- Commercial impact, related to the business case

- Industrial impact, related to the risks on the supply chain: the provisioning of the new equipment (e.g. new supplier to be contracted, former contract and former engagement to be aborted such as engagement on volume purchasing, maintenance engagement, availability and stocks…)

General considerations in performance-based CNS approach

Performance-based approach is based on operational requirements without imposing any specific technology to meet the expectations. One of the immediate benefits is to leave the choice of the technology to the integrator who then could take into account, in addition to the recognised performances of a system, other considerations such as the dispatch, cost, easiness of integration/ deployment or other parameters. Also, this might enable timely introduction of new agreed state of the art technologies able to meet the required performance in a more efficient way.

However, such a technology agnostic approach may also lead to increased compatibility and interoperability issues between systems. Multiplying systems which are not compatible or interoperable will jeopardise a possible economy of scale approach and would not ensure an efficient use of the spectrum.

In addition, in terms of aircraft integration, multiplicity of systems that are not uniformly deployed from one country to another may also cause extra cost, delays and extra burden:

- Multiplicity of the products to be developed and maintained, coupled with reduced costs amortization bases for every product

- Multiplicity of competences have to be maintained (e.g. impact on installation, maintenance);

- Modification of the functional requirements may lead to retrofit of all systems which will be equipment designer-dependant.

Cost impacts will be significant and one of the main issues will be to identify who will support the associated costs?

E.2 Operational and technical considerations

The main drivers which contributes to operational Aircraft evolution are safety enhancements, environmental aviation footprint, satisfying customer demands, higher level of automation and cost reduction of infrastructure. Many studies concur toward these objectives and may result in requirements for improved performance of CNS functions. Amongst the main investigations the following axes of development may be emphasised:

- **Trajectory optimization**: Optimising air traffic management reaction is one approach which has been experimented through 4D trajectory approach. The real-time transmission of four-dimensional trajectory data greatly improve aircraft’s trajectory prediction. By reducing the inaccuracy of current air traffic management (ATM) prediction models by approximately 30-40%, the Trajectory Based Operations in 4 Dimensions (4D-TBO) is helping to pave the way to a more sustainable management of tomorrow’s air traffic. In the perspective of achieving similar objectives, other studies are ongoing to study the benefit of formation flight which inspired by biomimicry, formation flight will reduce fuel consumption using technique of a follower aircraft retrieving energy lost by a leader by flying in the smooth updraft of air the wake creates.

- **More automation** could serve for a better piloting conditions and contribute to perform autonomous functions. These include cockpit procedure automation, pilot health monitoring systems such as eye tracking and the use of sensors, head worn displays, ground collision avoidance, new navigation sensors, voice recognition systems for commands and for processing instructions from air traffic controllers and Airline Operation Centres, multimodal integration for flight crew interface, tactile interfaces, image based landing….

- **More autonomy** to improve flight operations and overall aircraft performance, pilots will remain at the heart of operations. Autonomous technologies are paramount to supporting pilots, enabling them to focus less on aircraft operation and more on strategic decision-making and mission management. As example, autonomous take-off and landing operation solely using on-board technology to maximise efficiency without the support of any infrastructure on the ground could bring many benefits in terms of optimising the operation, saving infrastructure cost and freeing pilots for other tasks to be performed during these phases.

Developing these new functionalities may require that additional avionics technologies will be developed such as to offer future weather radar technology for collision risk detection, a voice to text module to capture ATC voice messages, LIDAR technology for air data measurement, and image sensors and processing technologies for runway detection and autonomous landing guidance.

In addition, autonomous flight technology will include artificial intelligence, cognitive computing science, machine learning and other relevant technologies that will help the pilot concentrates during adverse conditions on essential tasks without being distracted by other factors which could be directly handled by the system.

Some new cockpit and flight operation technologies that are currently studied will allow taking into account more complex flight operations that are noticeably optimising fuel consumption and minimizing traffic congestion, while simplifying the management from the pilot's point of view.

To develop all the new technologies to equip future commercial aircraft, the aviation industry requires the assistance of new digital and simulation tools which need to be developed in parallel.

E.3 Spectrum considerations

Spectrum is essential for aircraft operation and it is recognised as such. With regard to spectrum regulation, aviation is recognised as a specific user and safety of life as well as regularity of flight application do benefit from a protected status in the international spectrum regulation framework.

This protected status, in the ITU regulation, makes that some specific frequency bands are specifically allocated to aeronautical radio services and that Administrations are invited to take all necessary actions to protect these frequency bands against radio interferences.

The protection is ensured a priori in taking care of aeronautical application in compatibility studies which are carried out when a request to use spectrum is received from other spectrum users, and a posteriori through continuous spectrum monitoring and interferences managing.

Spectrum is a limited resource and, at least below 6 GHz, there is no free spectrum available for any application. More and more applications have to share the spectrum based on specific interference mitigation techniques to gain the right of using some frequencies. Taking into account the continuous demand for spectrum for new applications, the spectrum is increasingly congested with the risk of more interferences to occur in the band as well as from adjacent frequency bands.

There is increasing pressure to share the existing global aeronautical frequency allocations with non-aviation frequency spectrum users. Spectrum dedicated to aviation application is therefore more and more at risk. Many criticisms are pointing out that aeronautical spectrum management is not efficient and also the lack of transparency of the aeronautical community (e.g. performances of system are not clear and might include some different margins) which prevent the use of some piece of spectrum around aero frequencies by other applications.

Today new spectrum opportunities don’t exist and therefore, benefiting from more resources may require a different approach which may be seen as alternative or complementary. As possible steps forward, the following proposal could be seen as solutions to benefit from more spectrum opportunities:

- Review and optimising the use of dedicated aeronautical current spectrum (e.g. new spectrum arrangement);
- Usage of more efficient technologies (e.g. more robust against interference and more efficient usage of spectrum);
- Improve transparency of system performance to foster spectrum sharing when possible for non-safety application;
- Use of commercial services operated outside the dedicated aeronautical spectrum, if it can be demonstrated that associated risks can be appropriately mitigated (e.g. Hyper Connected ATM approach). .

- A combination of the above mentioned proposals.

E.4 Conclusion of Air framer considerations on CNS system evolution

Aircrafts are world widely delivered and as such, worldwide harmonised measures are highly beneficial for an Air framer. In addition, aeronautical domain is strongly regulated and Aircraft shall comply with stringent requirements defined at international level which grant a high level of confidence on equipment which are installed in an aircraft. The consequence of this situation is that the least deviation either due to a technology evolution or a modification of a system may imply long and complex operation of compliancy checking (e.g. non regression testing) to ensure that modification has no adverse impact on aircraft operation.

It is of the utmost importance for an Air framer to be comfortable with safety analysis. Guaranteeing safety of flight and satisfaction of the Airline are the first priorities for Airbus.

In addition, it is worth noting that as an aeronautical industry, it is also important to identify the correct tradeoff between reliability, cost, installation, safety analysis and ramp up of any systems which are installed in Aircrafts.

This context is driving the different considerations developed in this section.

Considerations on Performance-based approach

Performance based approach is largely supported leaving choice of the more appropriate technology to fulfil the defined requirement and offering flexibility on how the requirement could be met. In the context of integrated CNS approach, the Performance-based principle is essential. Promoting such kind of technology neutrality principle, leave the system designer to identify the more appropriate technology to bring the best response to the required objectives. In that context, the choice of the more appropriate technology could be subject to the development of demonstrators which help industry evaluating the appropriateness of the solution taking care about real life conditions.

Such quite open approach is also leaving room for some adverse impacts such as systems multiplicity to perform similar functions which could create quite challenging situations for an Air framer to be supported in several aspects.

As a general manner, multiplying systems could

- result in multiplying the competences to ensure the follow up and the maintenance of the system,
- imply more important stock to manage,
- challenge the opportunity to benefit from economy of scale,
- multiply the aircraft configuration to be managed and maintained.

Considering systems operating under the control of a ground network infrastructure, such as systems used for Communication, the burden is much more important since Aircrafts could fly over different countries and it cannot be envisaged to install different systems to cope with the situation where the technology could vary from one country to another. The interoperability between systems is at least a key requirement to be ensured and which, in some extend, drives the choice of the technology. In that perspective, a full performance-based approach cannot be assumed without at least minimum guidance on the technology.

No particular future system are strongly promoted within Airbus. However, some analysis are performed to assess systems and technologies which are currently under discussion in the different standardisation fora and how a possible migration or evolution toward these system could impact on board equipment. The main results of on going analysis are the following:

- **LDACS** : this future communication systems is promoted to serve navigation and communication functions. But depending on region of the world, Airbus is observing different technology approaches. Even if LDACS could be seen as a promising system, an harmonised approach in terms of technology should be promoted as a worldwide Aeronautical approach. Even if LDACS is under discussion since now more than a decade, it is important to note that no deployment are known. At least, it is recognised that LDACS could be suitable way to use more efficiently the aero “ground L-band”. A clear transition path has to be agreed between countries prior initiating any migration.
- **AEROMACS** : today, only few deployment are observed. Similarly to LDACS, there is a need to ensure the interoperability between the networks. It is indicated that AEROMACS could be supported by WiMax technology which is a quite old technology which has never meet the expected success especially in Europe. Today it appears quite improbable to see those networks to be deployed as it is envisioned. In addition, it is important to note that AEROMACS is supposed to be operated in a frequency band which is also identified for UAS CNPC LOS and BVLOS for which standardisation are ongoing which may challenge the deployment of such AEROMACS networks.
- **DFMC :** DFMC is a promising technology which may bring some benefits to Aircraft operations. However, the introduction of DFMC (Dual Frequency Multi-Constellations) SBAS will have a significant impact on avionics systems inducing significant costs of modifications and certification and it must provide additional capabilities to our customers that would compensate for associated investments. DFMC is supposed to be a substitute to the standard GNSS receiver which is largely connected to more than 20 different functions in any Aircrafts. As a consequence of this situation, such evolution cannot be seen as a simple evolution of the existing system and a lot of non–regression assessment needs to be performed to ensure that no adverse impact will occur on aircraft operations. This evolution is not only a replacement of a receiver but a replacement of a full system including the antenna which also require new aero certification process. In addition to that, it is worth noting that standardisation issue should be finalised to better understand the different scenario (e.g. priority of constellation, what happen in case of no response, what happen in case of interferences for 1constellation/2 constellations,…). Finally, talking about the DFMC, it is important to note that such system open the room for national decision to promote one constellation over another keeping in mind that GNSS systems belong to specific country and their operation are, generally, under the remit of national defence organization. To conclude, DFMC is a new system with many possible impact on Aircraft operation which need to be carefully assessed for every aircraft family and this will take time to be deployed on the all fleets (more than half a decade is required).

Considerations on Integrated CNS approach

The Integrated CNS concept relies on the principle to consider C, N and S domains as one domain in the objective to improve the overall CNS efficiency. Based on CNS Performance-Based framework, the

basic principle consist in identifying a system which is able to meet the different safety requirement to be able to provide the appropriate C, N and/or S functions.
As a general approach, this could assumed as a seducing approach in limiting network infrastructure, merging different systems and of course, as aircraft applications, such optimising approach will contribute in saving weight, place and possibly also energy which are key drivers for system to be installed in an aircraft.
Even as a first step different advantages are quite obvious, from an Air framer standpoint, it is important to emphasise that such an approach as multiple impacts on the industrial process which require to be more deeply investigated such as

- Too much integration could lead to technology complexity which, first, could distort industrial competition in system provider and second, could require too much competence for one system;
- In terms of operation, all functions in one box could result in too much integrated functionalities and therefore, a system failure could lead to the simultaneous unavailability of too much functions which could challenge the overall aircraft operation;
- In terms of design, it is important to note that Aircraft function system design has to comply with design assurance quality level and merging different functions in one box could result in marrying different design assurance quality in one system whereas it may not be appropriate.
- Merging different functions from different domains create a link between those domains which are currently fully separated and as such, any considerations for future evolution will become more complex to achieve as far as multiple impacts in several domains could be expected. Any new approach in one of the three domains may disrupt the other domains in place.

Benefits of the harmonisation and standardisation

Standardisation and harmonisation are key factors for the aviation industry. Aviation is international and even if ground supporting networks are deployed on national territory, the Aircraft is operated all over the world. In that context, aircraft operation supported by standardised networks and harmonised in all countries is preferable to national or even regional network solutions.
Advantages standardised and harmonised solution facilitate cost reduction due to economy of scale, facilitate interoperability between systems, ensure a full transparency of achievable performances and foster better management of the different systems due to multiple experiences.

Some consideration on how to alleviate future challenges related to spectrum congestion

In the last decades, spectrum environment has been in constant evolution and has changed quite quickly. The increase interest for wireless technology, the development of mobile network and progresses in technology make that the smallest part of spectrum is of interest of multiple application and that the spectrum is more and more densely used and some parts of it are congested for different applications.

In that situation, the aeronautical spectrum equilibrium is more and more challenged by different threats which could jeopardize the good operation of radio applications operated in aeronautical frequency bands. The following examples are concrete illustrations on the impact of RF spectrum evolution on Aeronautical application:

- The introduction of 5G in the C-band;

- Introduction of Mobile network in adjacent band to aero L-Band Satcom in Europe and also in the Aero L-Band Satcom in USA,
- The interferences which are observed on GNSS

An entirely new RF environment is created which has the potential to generate multiple issues for incumbent and multiple challenges for new systems both within and in adjacent frequency band. This situation requires some adaptation in designing radio system and also some adaptation on the way the aero radiocommunication could be achieved and how to modernize CNS system.

On the system design, the above mentioned examples demonstrated the clear need to revise all aero standards to make a status on the robustness of aero system against interferences coming from new radio systems. Airbus support and is strongly engaged on this activity which is currently ongoing. The next step will be to update all the aero standards to make aero system more resilient to new spectrum environment. The aero community cannot relies anymore only on the usage of dedicated spectrum to ensure interference free communication and need to also ensure that the systems are robust enough to cope with new usages and new technologies which are more and more spread over the full range of frequency.

- **Need to be more resilient to face to more dense spectrum environment as part of our duty to ensure an efficient use of the spectrum**

Ensuring an efficient use of the aeronautical spectrum could also contribute to release some spectrum resources and to facilitate developing and deploying new radio systems.
Whereas it could be assumed that the increased deployment of new networks and application in the spectrum is challenging the good operation of existing radio application, this new spectrum environment could also be seen as an opportunity to develop new approaches and new strategy in aero communication to take advantage of this new system and networks.
Indeed, new networks could also be seen as an available radiocommunication opportunity to achieve some aeronautical communications. It is worth noting that such infrastructures could rely on multiple independent infrastructures of different nature (e.g. ground network, satellites…) which provide worldwide coverage and facilitating multilink communications to gain more confidence in the communication achievement.
Thinking about how the aero community could benefit opportunistically from this already deployed infrastructure could also be seen as a complement or an alternative to a completely newly dedicated radio network compare to the existing one. Some promising investigations are carried out in the context of SESAR project on Hyperconnected ATM which could be a solution in the future to offer a new breath for aeronautical radiocommunication which may contribute to alleviate congestion observed in aeronautical spectrum and also offer more communication capacity.

- **Some alternative approach to aeronautical dedicated radiocommunication network could also be able to offer some solution to alleviate spectrum congestion in Aeronautical band and to offer more communication capacity such as Hyperconnected ATM approach as developed in the context of SESAR project.**

Considerations on new needs for UAS

The UAS market is quite large and depending on the nature of the considered UAS (small drones, flying taxis, RPAS, professional drones…), the needs and the requirements in terms of communication are

different. Even if traditional ATM is a source of inspiration for UTM, ATM system are not dimensioned to cope with the diversity and the specificities of UAS. Weight and size of aeronefs are important when considering Traffic management operation. Re-use of existing communication networks may only be seen as an opportunists approach but not as an ultimate goal. Noting that identification of needs and the most appropriate technology for UAS is under consideration with many experiments and trials all over the world, it is important to note that at this stage, there is no expectation for a single wide technology which could be able to cope with all constraints.
Finally, it is important to note that even if traffic management mechanism should differ compare to traditional approach taking into account the different needs, some mechanism overlaps may not be avoided.

Considerations on security and cybersecurity

Security is a Key Performance Area (KPA) for Performance-based CNS. While, in principle, the identified KPIs (Accuracy, Continuity, Availability, Integrity) can be considered to address security as well (assuming that confidentiality is not of relevance for CNS), some additional considerations to the ones included on the Annex D of this document should also be taken into account :

- When considering security, the KPIs should be defined in terms of a threat model (describing anticipated security threats). For example, availability and continuity cannot be maintained in the presence of arbitrary threats. So, the security requirements should state for which threats (if any) the availability and continuity requirements remain applicable. Same for integrity: No system can tolerate arbitrary sophisticated threats. The security integrity requirements need to clearly state, for which threats integrity needs to be maintained.
- The aspect of self-stabilization (i.e. to return to a nominal mode after an interference ends) needs also to be considered and, when talking about security, associated KPIs should be put in place to confirm the return to a normal operation. Otherwise, without the indication on a return to a normal mode, a system could be stuck in a failure mode.
- To ensure that a Security threat is managed in a complete manner, a harmonised approach for security monitoring could be of high value.

Appendix F Acronyms and Terminology

Term	Definition
AIM	Aeronautical Information Management
A/G	Air/Ground
ABAS	Aircraft Based Augmentation System
ACARS	Aircraft Communications Addressing and Reporting System
ACAS	Airborne Collision Avoidance System
ACC	Area Control Center
ACID	AirCraft Identification
ACNS	Airborne Communications, Navigation and Surveillance
ACSS	Aviation Communication and Surveillance Systems
ADC	Air Data Computer
ADD	Architecture Description Document
ADF	Automatic Direction Finder
ADIRS	Air Data Inertial Reference Unit
ADS-B	Automatic Dependent Surveillance-Broadcast
ADS-C	Automatic Dependent Surveillance-Contract
AeroMACS	Aeronautical Mobile Airport Communications System
AFTN	Aeronautical Fixed Telecommunication Network
AIC	Aeronautical Information Circular
AIDC	ATS Interfacility Data Communication (ICC)
AIP	Aeronautical Information Publication
AIRB	AIRBorne situational awareness

Term	Definition
AIRM	Aeronautical Information Referece Model
AIS	Aeronautical Information Service
AMC	Acceptable Means of Compliance
AMHS	Aeronautical Message Handling System
ANS	Air Navigation Services
ANSP	Air Navigation Service Provider
AO	Aircraft Operators
AOA	Airport Operations Area
AOC	Airline Operational Communications
AOP	Airport Operation Plan
APC	Aeronautical Passenger Communications
APCH	APproaCH
A-PNT	Alternative-Position, Navigation and Timing
APT	AirPorT
APV	Approach Procedure with Vertical guidance
ARES	Airspace REServation
ARINC	Aeronautical Radio, INCorporated
A-RNP	Advanced-Required Navigation Performance
ARTAS	ATM Surveillance Tracker and Server
AS	Aerospace Standard
ASA	Aircraft Surveillance Applications
ASAS	Airborne Separation Assurance Systems

Term	Definition
ASM	AirSpace Management
A-SMGCS	Advanced-Surface Movement Guidance and Control Systems
ASTERIX	All purpose STructured Eurocontrol surveillance Information eXchange
ATC	Air Traffic Control
ATCO	Air Traffic Control Officer
ATF©M	Air Traffic Flow (and Capacity) Management
ATM	Air Traffic Management
ATN	Aeronautical Telecommunication Network
ATS	Air Traffic Services
ATSA	Air Traffic Situational Awareness
ATSAW	Air Traffic Situational Awareness
ATSU	Air Traffic Service Unit
AMHS	Aeronautical Message Handling System
AUP	Airspace Use Plans
BaroVNAV	Barometric Vertical NAVigation
B-RNAV	Basic aRea NAVigation
CAA	Civil Aviation Authority
CAT	Category
CDFA	Continuous Descent Final Approach
CDM	Collaborative Decision Making
CDMA	Code Division Multiple Access
CERT	Computer Emergency Response Team

Term	Definition
CFR	Code of Federal Regulations
CIDIN	Common ICAO Data Interchange Network
CMF	Communications Management Function
CONOPS	Concept of Operations
COTR	COordination and TRansfer
COTS	Commercial Off-The-Shelf
CPDLC	Controller-Pilot Data Link Communications
CS	Certification Specifications
CSP	Communication Service Provider
DAMA	Demand-Assigned Multiple Access
DAP	Downlink Aircraft Parameters
DATIS	Digital Automatic Terminal Information Service
DCL	Departure Clearance
DDoS	Distributed Denial-Of-Service
DF	Downlink Format
DFMC	Dual Frequency Multi Constellation
DGPS	Differential GPS
DLS	Data Link Services
DME	Distance Measuring Equipment
DMPR	DME Passive Ranging
DOD	Detailed Operational Description
DVB-T	Digital Video Broadcasting-Terrestrial

Term	Definition
EAD	European AIS Database
EASA	European Aviation Safety Agency
EATMN	European Air Traffic Management Network
E-ATMS	European Air Traffic Management System
EC	European Commission
ECAC	European Civil Aviation Conference
EGNOS	European Geostationary Navigation Overlay Service
EHS	EnHanced Surveillance
ELS	ELementary Surveillance
EN	Enabler
ENR	En-Route
EPU	Estimated Position Uncertainty
ES	Extended Squitter
ESTO	European Technical Standard Order
EU	European Union
EUROCAE	European Organisation for Civil Aviation Equipment
FAA	Federal Aviation Administration
FAB	Functional Airspace Block
FANS	Future Air Navigation System
FCI	Future Communications Infrastructure
FCOM	Flight Crew Operations Manual
FDE/ICD	Flight Data Exchange / Interface Control Document

Term	Definition
FDPS	Flight Data Processing System
FIR	Flight Information Region
FIS	Flight Information Service
FIS-B	Flight Information System-Broadcast
FMC	Flight Management Computer
FMS	Flight Management System
FMTP	Flight Message Transfer Protocol
FO	Flight Object
FOC	Flight Operations Centre
FRUIT	False Replies Unsynchronized with the Interrogation Transmissions
FSS	Fixed Satellite Service
FUA	Flexible Use of Airspace
FTI	FAA Telecommunications Infrastructure
G/G	Ground/Ground
GA	General Aviation
GANIS	Global Air Navigation Industry Symposium
GANP	Global Air Navigation Plan from ICAO
GAST	GBAS Approach Service Type
GAT	General Aviation Traffic
GBAS	Ground Based Augmentation System
GCA	Ground Controlled Approach
GFT	Global Flight Tracking

Term	Definition
GLONASS	GLObal NAvigation Satellite System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HDOP	Horizontal Dilution of Precision
HF	High Frequency
HFR	High-level Flight Rules
i4D	initial 4D
IA	Indicators and Alerts
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ICC	Inter Center Communication
ICD	Interface Control Document
ICNS	Integrated CNS
IFF	Identification Friend or Foe
IFP	Instrument Flight Procedures
IFR	Instrument Flight Rules
II	Interrogator Identifier
ILS	Instrument Landing System
IM	Interval Management
INS	Inertial Navigation System
INTEROP	Interoperability Requirements
IOC	Initial Operational Capability

Term	Definition
ISAC	Information Sharing and Analysis Centre
IP	Internet Protocol
IPS	Internet Protocol Suite
IPSec	Internet Protocol Security
IR	Implementing Regulation
iRBT	initial Reference Business Trajectory
iRMT	initial Reference Mission Trajectory
IRS	Inertial Reference System
iSBT	initial Shared Business Trajectory
iSMT	initial Shared Mission Trajectory
ISO	International Standards Organization
ISRM	Information Service Reference Model
ITP	In Trail Procedure
ITU	International Telecommunication Union
ITU-T	ITU Telecommunication Standardization Sector
JPALS	Joint Precision Approach and Landing System
KPA	Key Performance Area
LAN	Local Area Network
LARA	Local And sub-Regional Airspace Management support system
L-DACS	L-band Digital Aeronautical Communications System
LF	Low Frequency
LFR	Low-level Flight Rules

Term	Definition
LNAV	Lateral NAVigation
LORAN	Long Range Navigation
LPV	Localiser Performance with Vertical guidance
LTE	Long Term Evolution
LVO	Low Visibility Operation
LVP	Low visibility procedures
MC/MF	Multi-constellation/Multi-Frequency
MEMS	Micro-ElectroMechanical Systems
MHS	Message Handling System
MLAT	Multilateration
MLS	Microwave Landing System
MM	Military Messaging
MMHS	Military Message Handling System
MMR	Multi-Mode Receiver
MMS	Military Mission System
MOPS	Minimum Operational performance Specification
MPS	Minimum Performance Standard
MSPSR	Multi-Static Primary Surveillance Radar
MTCD	Medium Term Conflict Detection
MTOW	Maximum Take Off Weight
NAF	NATO Architecture Framework
NATO	North Atlantic Treaty Organization

Term	Definition
NAV	NAVigation
NAVAID	NAVigation AIDs
NDB	Non-Directional Beacon
NGSS	Next Generation Satellite System
NM	Network Manager
NO	Network Operations
NOP	Network Operations Plan
NOTAM	Notice To AirMen
NPA	Non Precision Approach
NRA	Non-Radar Airspace
NSA	National Supervisory Authority
NSV	NAF System View
NTP	Network Time Protocol
OCL	Oceanic Clearance
OFA	Operational Focus Area
OFDM	Operational Flight Data Monitoring
OI	Operational Improvement
OPMA	On Board Performance Monitoring and Alerting
OSED	Operational Service and Environment Definition
OSI	Open Systems Interconnection
PA	Precision Approach
PALS	Precision Approach and Landing System

Term	Definition
PAR	Precision Approach Radar
PBC	Performance-Based Communications
PBN	Performance-Based Navigation
PBS	Performance-Based Surveillance
PCL	Passive Coherent Location
PCP-IR	Pilot Common Projects Implementing Rule
PENS	Pan-European Network Service
PKI	Public Key Infrastructure
PNT&D	Positioning, Navigation, Timing, and Data
POA	Plain Old ACARS
PPS	Precise Positioning Service
PRF	Pulse Repetition Frequency
P-RNAV	Precision aRea NAVigation
PRS	Public Regulated Service
PSR	Primary Surveillance Radar
QoS	Quality of Service
RA	Resolution Advisory
RAD	RADar airspace
RADALT	Radar Altimeter
RAID	Risks, Assumptions, Issues, and Dependencies
RAIM	Receiver Autonomous Integrity Monitoring
RAP	Recognised Air Picture

Term	Definition
RF	Radius to Fix
RMT	RuleMaking Task
RNAV	aRea NAVigation
RNP	Required Navigation Performance
RPA	Remotely Piloted Aircraft
RPAS	Remotely Piloted Aircraft Systems
RSP	Radar Signal Processor
RTA	Required Time of Arrival
RTCA	Radio Technical Commission for Aeronautics
SARPS	Standard and Recommended Practices
SATCOM	Satellite Communications
SBAS	Satellite Based Augmentation System
SBB	Swift BroadBand
SDDS	Surveillance Data Distribution System
SDPDS	Surveillance Data Processing and Distribution System
SDR	Software-Defined Radio
SES	Single European Sky
SESAR	Single European Sky ATM Research Programme
SESAR Programme	The programme which defines the Research and Development activities and Projects for the SJU.
SF	Single Frequency
SI	Surveillance Identifier
SID	Standard Instrument Departure

Term	Definition
SJU	SESAR Joint Undertaking
SJU Work Programme	The programme which addresses all activities of the SESAR Joint Undertaking Agency
SMR	Surface Movement Radar
SMT	Simple Message Text
SMTP	Simple Mail Transfer Protocol
SOA	Service Oriented Architecture
SoS	System of Systems
SPI	Surveillance Performance and Interoperability requirements
SPR	Safety, Performance Requirements
SRA	Security Risk Assessment
SSR	Secondary Surveillance Radar
STAM	Short Term ATFCM Measures
STANAG	STANdarization Agreement
STAR	Standard Terminal Arrival Procedure
STATFOR	STATistics and FORecasts
STCA	Short Term Conflict Alert
STDMA	Self-organising Time Division Multiple Access
SURF	situational awareness on the SURFace
SV	Satellite Vehicle
SWIM	System Wide Information Management
TACAN	TACtical Air Navigation system
TAD	Technical Architecture Description

Term	Definition
TAS	True Air Speed
TCAS	Traffic alert and Collision Avoidance System
TCP	Transmission Control Protocol
TDMA	Time Division Multiple Access
TDOA	Time Difference Of Arrival
TIS-B	Traffic Information Services-Broadcast
TMA	Terminal Manoeuvring Area
TS	Technical Specification
TSO	Technical Standard Order
TTA	Target Time Arrival
TTO	Target Time Over
Tx	Transmitter
UAM	Urban Air Mobility
UAS	Unmanned Aircraft Systems
UAT	Universal Access Transceiver
UAV	Unmanned Aerial Vehicle
UDP	User Datagram Protocol
UTC	Coordinated Universal Time
UUP	Updated airspace Use Plans
VDL	VHF Data Link
VDLM2	VDL Mode 2
VFR	Visual Flight Rules

Term	Definition
VNAV	Vertical NAVigation
VoIP	Voice over IP
VOR	VHF Omnidirectional Radio Range
VORTAC	VOR+TACAN
VPN	Virtual Private Network
VSA	Visual Separation on Approach
VSATS	Very Small Aperture Terminal
WAIC	Wireless Avionics Intra-Communications
WAM	Wide Area Multilateration
WAN	Wide Area Network
WOC	Wing Operations Centre