INDUSTRIAL RESEARCH

PJ.14-W2-76: Integrated CNS and Spectrum "CNS Performance-based"

Deliverable ID:	D2.2.300
Dissemination Level:	PU
Project Acronym:	PJ14-W2 I-CNSS
Grant:	874478
Call:	H2020-SESAR-2019-1
Topic:	SESAR-IR-VLD-WAVE2-12-2019
Consortium Coordinator:	LEONARDO
Edition date:	22nd November 2022
Edition:	00.04.08
Template Edition:	02.00.05

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Authoring & Approval

Authors of the document

Beneficiary	Date
EUROCONTROL	10/06/2022
ESSP	10/06/2022
NATS	10/06/2022
ENAIRE	10/06/2022
AIRBUS	10/06/2022

Reviewers internal to the project

Beneficiary	Date
AIRBUS	20/06/2022
DSNA	20/06/2022
ENAIRE	20/06/2022
ESSP	20/06/2022
INDRA	20/06/2022
NATS	20/06/2022
DFS	20/06/2022
LEONARDO	20/06/2022

Reviewers external to the project

Beneficiary	Date

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

Beneficiary	Date
EUROCONTROL	01/08/2022
ESSP	01/08/2022
NATS	01/08/2022
ENAIRE	01/08/2022
INDRA	01/08/2022

Rejected By - Representatives of beneficiaries involved in the project

Beneficiary	Date

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Document History

Edition	Date	Status	Beneficiary	Justification
00.04.01	01/02/2022	Draft	EUROCONTROL	First draft of document content proposal with next improvements: Voice Communication Performance Requirements; Introduction to 'CNS Infrastructure Monitoring'; Voice over IP and Satellite Communication
00.04.02	04/03/2022	Draft	EUROCONTROL	Second draft of document content proposal with next improvements: Introduction to Performance-based CNS concepts description; Section 4 about Performance-based CNS in SESAR context updated and PJ14 CNS solutions overview added
00.04.03	29/04/2022	Draft	EUROCONTROL	Third draft of document content proposal with next improvements: Appendix A – Civil-Military Implications from Performance-based CNS; updated Appendix B - Performance-based CNS framework support to FRA; Appendix C - GNSS Timing Performance Parameters for CNS
00.04.04	20/06/2022	Draft	EUROCONTROL	Forth draft of document content proposal with next improvements: Appendix D – Spectrum aspects in Performance-based CNS; Appendix E – Consideration about CNS airborne capabilities; Section 5 – Summary
00.04.05	01/07/2022	Final Draft	EUROCONTROL	Fifth draft of document content proposal after internal review by Sol76 members
00.04.06	31/08/2022	Final Draft	EUROCONTROL	Final draft with updates following review from PJ14 SLs, IATA and DFS (via JCSP)
00.04.07	04/11/2022	Final Draft	EUROCONTROL	Updated following S3JU deliverable assessment: Section 1.2 update; Section 3.4 CNS Security added; Performance-based CNS in SESAR context

				chapter moved from Appendix F to Section 4.
00.04.08	22/11/2022	Final Draft	EUROCONTROL	Updated following S3JU deliverable assessment: updated Figure with overview of SESAR 2020 Wave 2 R&D activities

PJ14-W2 I-CNSS

INTEGRATED COMMUNICATION, NAVIGATION AND SURVEILLANCE SYSTEM

CNS Performance-based 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

Performance-based Communication, Navigation and Surveillance (CNS) is considered by SESAR as one of key aspects of CNS evolution. General idea of performance-based CNS was presented in PJ14-01-01 deliverables D2.1.010 (CNS evolution roadmap and strategy, Edition 00.03.01 of August 30, 2019) and D2.1.020 (Performance based integrated CNS, Edition 00.02.01 of September 9, 2019). The present document is a continuation of work done in Wave 1 of SESAR 2020 and focuses on Performance-based CNS and provides results of detailed analysis as well as insights and strategic view on possible ways of integration of performance-based Communication, Navigation and Surveillance on development of this specific subject.

Executive summary

A performance-based CNS approach will enable a possibility to evolve from system/technology-based operations, where systems/technologies are prescribed, towards the delivery of performance-based services, which specify what is to be achieved within a specific environment based on the operational requirements and considering CNS as a whole and integrated system. For end-users, the technological solutions will be packaged or merged in a way that guarantees safety, security, and performance requirements (e.g., availability, integrity), as mandated by relevant authorities. This leaves to the service providers the choice of systems/technologies that can achieve the specified performance, taking into account their service delivery models and local specificities. This also enables airspace users to rationalise airborne systems by customising the required airborne equipage to their aircraft, taking into account their operation models. At the end, it is anticipated that this service-based and performance-based approach will favour potential technological/functional synergies across Communication (COM), Navigation (NAV) and Surveillance (SUR), taking advantage of common system and common infrastructure capabilities for the ground, airborne and space segments.

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1 Performance-based CNS concept

1.1 Definition

The Performance-based Communication, Navigation and Surveillance (CNS) concept means a transition from system/technology-based operations, where systems/technologies are prescribed, towards technical performance indicators definition for CNS systems (e.g., Availability, Integrity, and Continuity) to be achieved for specific operational needs and types of airspace.

It is important to mention that Performance-based CNS implementation requires compliance to performance values, thus it does not dictate which technologies need to be developed, and it rather stimulates the acceleration of an innovative approach for the new CNS systems development. As an example, ICAO has already declared a transition from detailed technical specifications to performance-based standards in 2004. The 35th Session of the Assembly stated in the Resolution A35-14 (Appendix A) [1]:

> *3. SARPs and PANS shall be drafted in clear, simple and concise language. For complex aeronautical systems, SARPs shall consist of broad, mature and stable provisions specifying system-level, functional and performance requirements that provide for the requisite safety levels and interoperability. For such systems, any technical specifications necessary to achieve these requirements shall be appendices to Annexes. Any related detailed technical specifications shall be placed in separate documents and be referenced in Annexes by means of notes.*

In the same Session another Resolution A35-15 (Appendix B) urges its implementation:

> *4. Urges the Council to take the steps necessary to ensure that the future global ATM system is performance-based and that the performance objectives and targets for the future system are developed in a timely manner;*

One of ICAO Documents that gives the Performance-based Approach definition is Doc 9883: Manual on Global Performance of the Air Navigation System [2]which provides a general methodology on how it can be implemented in the Air Navigation System (ANS) where CNS is a part of ANS according to Regulation (EU) 2017/373 [3].

> *The Performance-based Approach (PBA) is a decision-making method based on three principles: strong focus on desired/required results; informed decision-making driven by those desired/required results; and reliance on facts and data for decision-making.*

This approach allows to categorize performance subjects in air traffic management (ATM) into 11 so-called Key Performance Areas (KPA) which are defined in ICAO Doc 9854 [4]:

- **Access and equity**. ANS should provide an operating environment that ensures that all airspace users have the right of access to ATM resources needed to meet their specific operational requirements; and ensures that the shared use of the airspace for different airspace users can be achieved safely. The global air navigation system should ensure equity for all airspace users that have access to a given airspace or service.

- **Capacity**[1]. ANS should exploit the inherent capacity to meet airspace user demand at peak times and locations while minimizing restrictions on traffic flow. To respond to future growth, capacity must increase, along with corresponding increases in efficiency, flexibility, and predictability while ensuring that there are no adverse impacts to safety giving due consideration to the environment.
- **Cost effectiveness**[1] **('Cost efficiency' – European ATM Master Plan)**. ANS should be cost effective, while balancing the varied interests of the ATM community. The cost of service to airspace users should always be considered when evaluating any proposal to improve ATM service quality or performance.
- **Efficiency**[1] **('Operational efficiency' – European ATM Master Plan)**. Efficiency addresses the operational effectiveness of gate-to-gate flight operations from a single-flight perspective. Airspace users want to depart and arrive at the times they select and fly the trajectory they determine to be optimum in all phases of flight.
- **Environment**[1]. ANS should contribute to the protection of the environment by considering noise, gaseous emissions, and other environmental issues in the implementation and operation of the global air navigation system.
- **Flexibility**. Flexibility addresses the ability of all airspace users to modify flight trajectories dynamically and adjust departure and arrival times thereby permitting them to exploit operational opportunities as they occur.
- **Global interoperability**. ANS should be based on global standards and uniform principles to ensure the technical and operational interoperability of air navigation systems and facilitate homogeneous and non-discriminatory global and regional traffic flows.
- **Participation by the ATM community**. The ATM community should continuously be involved in the planning, implementation, and operation of the system to ensure that the evolution of the global air navigation system meets the expectations of the community.
- **Predictability**[1] **('Increased predictability' – is a part of Operational efficiency in European ATM Master Plan)**. Predictability refers to the ability of the airspace users and air navigation service providers (ANSP) to provide consistent and dependable levels of performance. Predictability is essential to airspace users as they develop and operate their schedules.
- **Safety**[1]. Safety is the highest priority in aviation, and ATM plays an important part in ensuring overall aviation safety. Uniform safety standards and risk and safety management practices should be applied systematically to the ANS.
- **Security**[1]. Security refers to the protection against threats, which stem from intentional or unintentional acts affecting aircraft, facilities and systems.

The KPAs presented above have performance objectives that are usually expressed in qualitative terms and include a desired or required trend for a performance indicator while not expressing the performance objective in numeric terms. For this purpose Key Performance Indicators (KPI) are defined which show current/past performance, expected future performance (estimated as part of forecasting and performance modelling) expressed quantitatively. These indicators are often not directly measured and correspondently supporting metrics are applied. For the systems and technology level,

[1] The following KPA is also considered in European ATM Master Plan 2020 [38].

that are ATM enablers, the performance-based approach defines technical performance indicators. Currently CNS systems within performance-based framework have KPIs [5] such as:

- **Accuracy** is defined as the difference between a computed and a true position.
- **Availability** of a service is the portion of time during which the system is simultaneously delivering the required accuracy and integrity.
- **Continuity** is the capability of the system to perform its function without unscheduled interruptions during the intended operation, expressed as a probability.
- **Integrity** is a measure of the trust that can be placed in the correctness of the information supplied by the total system.

The description of KPIs applicable to Communication (COM), Navigation (NAV) and Surveillance (SUR) will be presented in Chapter 2.

The supporting metrics specific to CNS systems/technologies will be presented in Chapter 3 together with a description of tools that can be used for their estimation.

1.2 Vision

Because systems/technologies are not prescribed, Performance-based approach will motivate to replace the legacy systems that are not easy to maintain with expanded replacement options. It aims at high-performance and secure systems that can integrate different functionalities/capabilities in a common system block by ensuring at the same time the low probability of single point of failure occurrence. This means that the performance-based approach will foster potential technological synergies across COM, NAV and SUR, taking advantage of common system and common infrastructure capabilities for the ground, airborne and space segments. The development of a Performance-based CNS framework could also support flexibility for ANSPs to define their own CNS service delivery model. 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 CNS Advisory Group Report [6] identified a list of recommendations, in particular Recommendation 3 considers the application of a Performance-based approach towards the development and deployment of the future CNS infrastructure. In this case a detailed and balanced implementation planning needs to be applied in order to provide CNS services for all interoperable technologies selected by airspace users and avoiding redundant technologies that may lead to technological complexities and higher overall cost. To that aim the CNS Advisory Group proposes the development of a CNS evolution plan[2] "which should identify solutions for each CNS service based on several criteria such as technical performance, cost-efficiency, spectrum-efficiency, coverage, environmental impact and worldwide interoperability to limit the costs and complexity for airspace users operating outside Europe." The objective is to apply "a performance-based approach in a way that is simple and cost-effective". In order to ensure a proper governance an establishment of CNS Programme Manager was proposed in Recommendation 11 of CNS Advisory Group Report.

[2] The CNS evolution plan should assess which CNS services require redundancy and technology diversification to meet technical performance requirements (e.g., availability and continuity of service) [6].

Another key element of a performance-based approach is operational and technical interoperability. It is presented in Recommendation 7 of CNS Advisory Group which urges to conduct a large-scale demonstration before deploying a new CNS technology in close to realistic conditions in order to validate interoperability requirements and to confirm that the levels of technical performance can support the expected concepts of operations. Such demonstrations should assure that all types of certified avionics would work with all types of ground and space systems.

However, an interoperability should be ensured through a common set of standards which should be performance-based rather than technology-based. In the coming years, EASA will play a key role in the CNS regulatory field as all CNS technical interoperability regulations will be fully under the EASA Basic Regulation framework. In parallel to the legal framework, a global interoperability is addressed through international standards e.g., ICAO SARPS for CNS systems in Annex 10 and joint EUROCAE-RTCA standards development activities.

In practice, to secure global interoperability in support of the ICAO Global Air Navigation Plan (GANP) and its Aviation System Block Upgrade (ASBU) a Memorandum of Cooperation between EU and U.S. was signed in 2011. The U.S. and EU have established roadmaps for the development and implementation planning of aircraft capabilities for CNS and SWIM. These roadmaps balance short-, medium- and long-term requirements in order to understand the interoperability risks related both to current deployment plans and to the options for developing and implementing solutions in the medium and longer term.

Therefore, the main advantages of implementing the Performance-based CNS concept are as follows:

- Enables annual operating cost and investment budget;
- Performance requirements will fit the airspace users and operational environment needs while ensuring the contingency and security of service provision;
- Improvement of spectrum efficiency usage;
- Drive the innovation in terms of performance, virtualization and security aspects;
- Improve the adoption of innovative and diverse technological platforms to support service delivery;
- Enable implementation of synergies across COM, NAV and SUR.

2 Individual Performance-based CNS Concepts

The Performance-based framework is characterised as following:

- **Performance-based Communication (PBC)**: COM is and will continue to be fundamental to ATM. PBC is about further refining the specifications for Required Communications Performance (RCP) types associated with the communication capability supporting an air traffic management (ATM) function. In combination with SUR, the ICAO PBCS Manual (PBCS) [7] concept provides a framework for managing performance of the COM and SUR aspects of ATM with a purpose of ensuring that emerging technologies for COM and SUR that are designed to support ATM operations are implemented and operated safely.
- **Performance-based Navigation (PBN)**: The PBN concepts of RNAV and RNP have expanded area navigation techniques, to a more extensive definition of required performance. These performance requirements are defined in terms of accuracy, integrity and continuity, along with how such performance is to be achieved in terms of aircraft functionalities and flight crew requirements. PBN is comprised of three components: the navigation application; the navigation specification; and the navigation infrastructure [8]. A navigation application is defined by the implementation of a navigation specification and its supporting navigation infrastructure, applied to routes, procedures, and/or a defined airspace volume, in accordance with the intended airspace concept.
- **Performance-based Surveillance (PBS)**: The PBS concept specifies Surveillance System Performance requirements per operational application in a technology agnostic way. PBS defines minimum performance requirements per application covering aspects such as data items, update rates, accuracy, integrity etc. At the European level, PBS for the 3NM and 5NM separation applications, is specified in the EUROCONTROL Specification for ATM Surveillance System Performance (ESASSP) [9]. Evolution and expansion of PBS, in terms of applications, is ongoing both at European and ICAO level.

The next Sections of this document aim at paving the way toward the PB CNS integration by describing the performance-based COM (Section 2.1), NAV (Section 2.2) and SUR (2.3) concepts.

2.1 Performance-based Communication

To meet airspace capacity and operational efficiency requirements, aeronautical communication is playing a key role in Air Traffic Management by means of Voice and Data Communication. Both types of Communication covering Air-Ground (A-G) and Ground-Ground (G-G) segments are presented in the section below. As an example, a data link can support integration of Air Traffic Management functional capabilities on the aircraft and at ATS units, including direct controller-pilot communication enabling user-preferred and dynamic rerouting, as well as intervention capabilities in reduced separation environments. The Required Communication Performance (RCP) concept provides a means to ensure the acceptable performance of communications within a complete ATM system.

Voice communications have some advantages over data communications, such as: high availability, low latencies, and use for non-routine, time critical, or emergency situations. In practical terms, Voice

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Communication is preferred in regions with lower density of Air Traffic in comparison to regions with higher one that could benefit from transition to Data Communication. In this case when Data Communication is used, Voice may be used as an alternative form of communication depending on the dynamics of the situation.

Data Communication provides a number of advantages over Voice Communication, such as:

- Direct controller-pilot communication
- Reduced VHF radio frequency congestion
- Automatic exchange of flight information between aircraft and ATS unit.

2.1.1 Voice Communication Performance Parameters

Air-Ground Voice Communications

The aeronautical VHF band (118-137 MHz) is the main radio communications band for line-of-sight air-ground voice communications used at all ATC Centres and Airports, for en-route, approach and landing phases of flight.

The increasing demand and congestion of VHF frequencies in European high-density traffic areas have motivated the introduction of 8.33 kHz channel spacing. For the moment a direct controller-pilot VHF voice communication is considered as a primary mean of communication and VHF datalinks are supporting operation by transmitting non-time critical or routine instructions.

It is also important to indicate that the VHF voice communication between controller and pilot is composed of two segments Ground-Ground (G-G) and Air-Ground (A-G), where the last one is broadcasting a voice over a carrier signal by means of Double Side Band – Amplitude Modulation (DSB-AM) and it implies an almost 'real-time' communication. In comparison to G-G segment, which is a link between Controller Working Positions (CWP) networked by Voice Communication System (VCS) and VHF Transmitters (Tx) and/or Receivers (Rx).

With regard to G-G segment of VHF voice communication EUROCAE Working Group 67 (WG-67) defined criteria, requirements and guidelines for providing ATM VoIP services based upon operational needs and constraints in EUROCAE document ED-136.

Therefore, the following performance requirements of Radio System[3] were defined:

1. Speech Signalling Integrity
2. End-to-End signalling integrity
3. 100ms max Transmitter Activation Delay
4. 100ms max Aircraft Call Indication Delay
5. 250ms max Cross-coupled PTT (Push-To-Talk) inhibition period
6. 130ms max Ground Transmission Voice delay

[3] The Radio System includes all the ground and aircraft components

7. 10ms max Voice delay differential for Climax operation
8. 130ms max Ground reception voice delay
9. Transmit signal speech clipping <64ms
10. Receive signal speech clipping <64ms

Ground-Ground Voice Communications

The telephone call types needed to meet the operational ground communications requirements of ATM are known as ‘primary user ground telephone facilities’, and are used for routine and urgent communications between ATS units. The main signalling protocols used on the ground: ATS-R2, ATS-N5, ATS-QSIG are currently being replaced by VoIP in ATM protocol (ED-136, ED-137 & ED-138).

Performance requirements for the operation of primary ground telephone facilities between ATS units for ATC purposes can be found in ICAO Doc 9804 – ‘Manual on ATS Ground-Ground Voice Switching and Signalling’ for legacy technologies and in EUROCAE ED-136 standards for implementation of ATM VoIP on the ground.

The following call establishment performance requirements for primary user ground telephone facilities were defined:

- Direct Access: 2 second or less for 99% of call attempts.
- Instantaneous Access: 1 second or less for 99% of call attempts.
- Indirect access 15 second or less for 99% of call attempts.

Note.- It is known that in case of ATS-R2 and ATS-No.5 analogue signalling protocols, this establishment time is not achievable.

2.1.2 Data Communication Performance Parameters

The currently applicable Aeronautical Communication safety and performance standards are ED-120 [10] (for continental airspace) and ED-122 [11] (for oceanic and remote airspace). However, future (ATS B2) performance requirements (generally more demanding and more comprehensive) are described in ED-228A [12]. Please note, that this chapter is using as a reference EUROCAE standard ED-228A, which is not fully aligned with ICAO Doc 9869 PBCS Manual (2nd edition) [7] RCP/RSP specifications. To that aim the EUROCAE Working Group (WG) 78 has been reactivated and at the moment of writing this document WG78 is working on the new version of the standard ED-228B. For all the values of RCP/RSP specifications that will be fixed in ED-228B footnotes are assigned. It specifies the following performance parameters:

- Transaction Time
- Continuity
- Availability
- Integrity

Transaction time

Transaction Time refers to a complete Communication exchange, in general involving more than one message. **Figure 1** (taken from ED-228A) illustrates a so-called *Exchange Transaction*, which includes:

- Message preparation (composition)

- Message transmission
- Reaction
- Response message transmission
- Reaction to the response message (recognition)

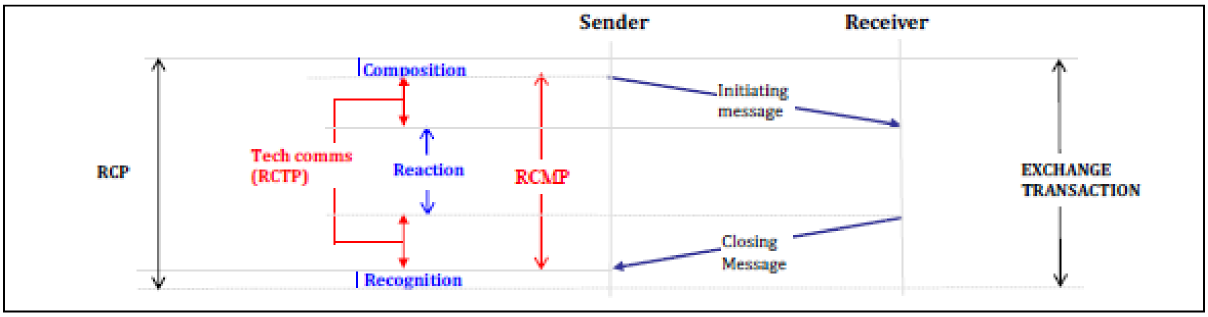

Figure 1: Exchange Transaction

Acronyms:

RCP - Required Communication Performance
RCTP - Required Communication Technical Performance
RCMP- Required Communication Monitored Performance

The end-to-end operational performance requirement for a communication transaction in general is characterized by RCP Transaction Time and thus represents an operational requirement. The technical requirement on the data link infrastructure must be derived from that. This is shown in **Figure 1** as RCTP.

ED-228A specifies three RCP types:

- RCP 130 (130 sec. Transaction Time) typically applicable to APT, TMA and ENR-1[4] airspace
- RCP 240 (240 sec. Transaction Time) typically applicable to ENR-2[5] airspace
- RCP 400 (400 sec. Transaction Time) typically applicable to ENR-2 airspace,

The RCP Transaction Time value is significant from two viewpoints:

- 99.9% of operational communication transactions must complete in this time [12].

[4] ENR-1 airspace is a volume of controlled airspace that encloses the flight paths above and between airports where air traffic service in TMA is provided. Jet routes and airways are typically used to traverse the En-route airspace structure. The typical separation minima in this airspace are 3NM, 5NM, appropriate vertical and/or visual separation as required

[5] ENR-2 airspace is a volume of controlled airspace that is characterized by the use of procedural control and the lack of ATS surveillance service. The airspace is typically characterized by the use of flex tracks and customized trajectories but may also use fixed jet routes and airways. The typical separation minima in this airspace are 60NM to 100NM lateral, 80NM to 100NM longitudinal, 1000ft (RVSM) as required.

- It represents the Expiration Time (ET), i.e., the time after which the initiator times out.

It is important to note that, although each RCP *type* is designated by the corresponding Transaction Time, the type specification addresses also Continuity, Availability and Integrity parameters (ED-228A requirements for these parameters will be presented in Sections 2.1.3.1, 2.1.3.2, 2.1.3.3 correspondingly).

Continuity

Continuity is understood as the probability that a transaction completes within the expiration time. The Continuity requirement relates to timely delivery of the full message and is intended to address the risk of a message being delayed in transit (as opposed to a message being corrupted).

Availability

Availability is defined as the *required probability that an operational communication transaction can be initiated*. It is thus a measure of the probability that the communication systems (end-to-end) that are required to provide an air-ground path are operational. It corresponds to conventional measures of Availability in terms of Mean Time between Failure (MTBF) and Mean Time to repair (MTTR)[6].

To demonstrate compliance with Reliability, Availability and Maintainability (RAM) requirements, normally some form of RAM analysis is provided. This is a theoretical calculation, based on the architecture, the design of the system and certain key measured parameters of the equipment. Normally, this analysis takes the form of a calculation of equipment Availability.

ED-228A defines Availability as a RCP parameter that specifies the required probability that an operational communication transaction can be initiated. It is the ratio between the time the system is actually available for service (MTBF) and the time the system is planned for service (MTTR). Thus, **Availability = MTBF / (MTTR + MTBF).**

The RCP availability is evaluated over the aircraft, Air Traffic Services Unit (ATSU) and communication service provider (CSP).

Integrity

ED-228A defines Integrity as the required probability that an operational communication transaction is completed with no undetected errors. ED-228A further clarifies that “Whilst RCP integrity is defined in terms of the “goodness” of the communication capability, it is specified in terms of the likelihood of occurrence of malfunction on a per flight hour basis, e.g., 10^{-5}, consistent with RNAV/RNP specifications.” Hence, an Integrity value of 10^{-5} would imply that 99.999% of transactions complete

[6] The definition of availability (ED-228A) does not take into account the fading conditions that may affect the CSP channel performances, in particular multipath effects for radio links and atmospheric fading for SATCOM links. Using the same rationale, the notion of continuity should take into account fading and interfading characterization, as done in MOPS

without undetected errors. For a digital communication system, this places a requirement on the error detection and correction function.

2.1.3 Data Communication Performance Requirements

This section presents the performance requirements applicable to **air-ground digital communication systems**.

Table 1 presents a summary of the requirements (ATS-B2) applicable to Transaction Time, Continuity, Availability and Integrity applicable to Controller-Pilot Data Link Communications (CPDLC) according to ED-228A/DO-350A.

RCP Specification	Transaction Time Expiry Time (sec)[7]	Transaction Time 95% (sec)[8]	Continuity	Availability	Integrity
RCP 130	130	67	0.999	0.989[9]	Malfunction = 10-5 per flight hour
RCP 240	240	210	0.999	0.989[10]	Malfunction = 10-5 per flight hour
RCP 400	400	350	0.999	0.989[11]	Malfunction = 10-5 per flight hour

Table 1 Communication performance specifications

Note that the Transaction Time values specified here are the full operational values across multiple message exchanges and are provided for reference. The values applicable to the technical infrastructure are discussed in the following sub-sections.

The following presents the key performance transaction time requirements on the air-ground communication systems. The focus is on the RCTP at the 95% level[12]. Table 2 presents the technical performance requirements applicable to the three RCP types, with a breakdown across the components. This breakdown is referred to as *allocation* and ED-228A [12] allocates the time budget to the following components:

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[7] Transaction Time Expiry Time is understood as time-out, it indicates an error condition for an individual message

[8] Transaction Time 95% is a statistical requirement on the system and does not apply to one individual message.

[9] This value is 0.999 according to ICAO Doc 9869 PBCS Manual.

[10] This value is 0.999 according to ICAO Doc 9869 PBCS Manual.

[11] This value is 0.999 according to ICAO Doc 9869 PBCS Manual.

[12] i.e., the time within which 95% of message transfers must complete.

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- Air Traffic Services Provider (ATSP) includes Air Traffic Control Centres (ATCCs)
- Air Traffic Services Unit (ATSU) refers to ATCCs
- Communication Service Provider (CSP) covers the ground networks and air-ground links
- Aircraft covers the on-board elements

The ED-228A specifies both the end-to-end requirements and the allocated requirements. Sometimes only, some requirements are allocated to the ATSP (ATSU+CSP) and not to the ATSU and CSP. In such a (rare) case, only a recommended value is allocated to the ATSU and to the CSP. They have to find an agreement to apportion the requirement allocated to the ATSP.

For example, whilst for the Operational Performance Assessment (OPA) the ATSP includes ATSU and CSP as subsets, for RCP 130 time allocations (RCP 130 is intended to be used for some ATM operations such as ATC communication or 4D TBO in ENR-1, TMA and APT airspaces), a statistical model[13] is used to combine the components of the delay and, on the basis that the respective delays are uncorrelated, ED-228A allows the sum of the components to be greater than the end-to-end delay (this can be seen in Table 2 for RCP 130/A1, where the sum of ATSU and CSP is 16 secs., while the overall ATSP delay is 14 secs.).

	RCP 130/A1 TT95% (sec)	RCP 240/A1 TT95% (sec)	RCP 400/A1 TT95% (sec)	RCP 400/A2 TT95% (sec)
RCTP	20	120	260	20
$RCTP_{ATSP}$	14	n/a	n/a	14
$RCTP_{ATSU}$	6	10	10	6
$RCTP_{CSP}$	10	100	240	10
$RCTP_{Aircraft}$	10	10	10	10

Table 2 Required Communication Technical Performance Requirements

As can be seen in Table 2, ED-228A presents just one allocation for each of RCP 130 and RCP 240 (RCP 130/A1 and RCP 240/A1 respectively). For RCP 400, however, two allocations are provided in the standard. The operational scenarios corresponding to the RCP types are as follows:

RCP 130/A1 applies to APT, TMA and ENR-1[14] (such as Continental) airspace, covering Air Traffic Control (ATC) communication services such as CPDLC, Taxi Clearance and 4D TBO.

[13] ED-228A assumes a log-normal distribution.

[14] ENR-1 airspace is a volume of controlled airspace that encloses the flight paths above and between airports where air traffic service in TMA is provided. Jet routes and airways are typically used to traverse the En-route airspace structure. The typical separation minima in this airspace are 3NM, 5NM, appropriate vertical and/or visual separation as required

RCP240/A1 applies to ATC communication support for services such as Separation Assurance 2, ITP, IM-PTM, DRNP (Dynamic Required Navigation Performance) in ENR-2[15] (i.e., Oceanic and Remote) airspace.

RCP 400/A1 refers to most air-ground communications in ENR-2 airspace (i.e., Oceanic and Remote), including CPDLC, ACM, AMC, IER and OCL.

RCP 400/A2 applies to APT airspace and is tailored to Departure Clearance (DCL). It allocates a much greater interval for flight crew response (compared to RCP 400/A1), as a result of which a considerably shorter amount of time from the 400 sec. total is left for the technical infrastructure, in particular the CSP. Table 2 shows that RCP 400/A2 values are the same as of RCP 130/A1 and this applies mainly to Pre-Departure Clearance, where the overall transaction time can be very long, but a significant time needs to be allocated to operations.

2.1.3.1 Continuity requirements

According to ED-228A [12], breaches to the Continuity requirement are expected to come mainly from congestion in the communication system. In light of the nature of congestion, it is concluded that Continuity requirements are not to be broken out and allocated to the various components. ED-228A states that Continuity may remain fixed over all components when using the statistical distribution and arithmetic summation – the allocation is made purely by the time allocated to each component.

Thus, the Continuity requirement for each component is that the specified percentage (either 99.9% or 95% as appropriate) of messages shall transit that component in the allocated time[16].

	RCP 130/A1 $TT_{95\%}$	RCP 240/A1 $TT_{95\%}$	RCP 400/A1 $TT_{95\%}$	RCP 400/A2 $TT_{95\%}$
Continuity $_{\text{ATSU, CSP, and Aircraft}}$	0.95	0.95	0.95	0.95

Table 3 Continuity Requirements

2.1.3.2 Availability requirements

Availability here is the probability that an operational communication transaction can be initiated: this is evaluated over the A/C, ATSU and CSP (ED-228A). The Availability requirements are shown in Table 4.

In addition to the statistical requirement on Availability, there is also a rigid limit on the permitted maximum unplanned outage duration for a single system (cf. the last row in Table 4, values expressed in minutes).

[15] ENR-2 airspace is a volume of controlled airspace that is characterized by the use of procedural control and the lack of ATS surveillance service. The airspace is typically characterized by the use of flex tracks and customized trajectories but may also use fixed jet routes and airways. The typical separation minima in this airspace are

[16] Table 3 must thus be read in conjunction with Table 2. For example, the RCP 130/A1 Continuity requirement on the Aircraft is that 95% of message shall transit the Aircraft domain within 10 seconds

	RCP 130/A1	RCP 240/A1	RCP 400/A1	RCP 400/A2
A_{ATSU}	0.9995	n/a	n/a	0.9995
A_{CSP}	0.9995	0.999 (safety) 0.9999 (efficiency)	0.999	0.9995
$A_{Aircraft}$	0.99[17]	0.99[17]	0.99[17]	0.99[17]
Unplanned outage duration limit$_{ATSU\ \&\ CSP}$ (min)	6	10 (CSP only)	20	6

Table 4 Availability Requirements

It can be seen that the Availability requirement on the ground systems is considerably higher than that on the aircraft[18], reflecting the operational impact of loss of the respective capabilities. The RCP 130 and RCP 400/A2 requirements correspond to a total outage of 4.4 hours per year and can be expected to represent major design drivers for the ground systems.

ED-228A specifies further limits on the annual number of unplanned outages and on the total outage time per year.

2.1.3.3 Integrity requirements

Table 5 shows the Integrity requirements. The requirement of “1E-5 per flight hour” means that the likelihood of a malfunction is no greater than in 1 in 100,000 per flight hour[19].

	RCP 130/A1	RCP 240/A1	RCP 400/A1	RCP 400/A2
I_{ATSU}	1E-5 per flight hour	1E-5 per flight hour	1E-5 per flight hour	1E-5 per flight hour
I_{CSP}	Not specified	Not specified	Not specified	Not specified
$I_{Aircraft}$	1E-5 per flight hour	1E-5 per flight hour	1E-5 per flight hour	1E-5 per flight hour

Table 5 Integrity Requirements

[17] This value will be set to 0.999 in ED-228B to align with ICAO Doc 9869 PBCS Manual.

[18] The aircraft requirement is 1-0.01, while the CSP requirement in certain cases is 1-0.0005, representing a factor 20 in the allowed unavailability.

[19] This is taken to mean that, in 100,000 flight hours, on average no more than 1 malfunction shall occur.

2.2 Performance-based Navigation

Airborne performance requirements are expressed in navigation specifications in terms of accuracy, integrity, continuity and functionality needed for the proposed operation in the context of a particular airspace concept. Within the airspace concept, the availability of GNSS Signal-In-Space (SIS) or that of some other applicable navigation infrastructure has to be considered in order to enable the navigation application[20] (Explanation of Terms in ICAO PBN Manual [8]).

The PBN concept represents a shift from sensor-based to performance-based navigation. Performance requirements are identified in navigation RNP and RNAV specifications described in ICAO PBN Manual [8], which also identify the choice of navigation sensors and equipment that may be used to meet the performance requirements [8]. These navigation specifications are defined at a sufficient level of detail to facilitate global harmonization by providing specific implementation guidance for States and operators.

PBN offers a number of advantages over the sensor-specific method of developing airspace and obstacle clearance criteria, i.e.:

- reduces the need to maintain sensor-specific routes and procedures, and their associated costs;
- reduces the number of specific sensors and thus, respective re-investment and maintenance cost;
- avoids the need for developing sensor-specific operations with each new evolution of navigation systems, which would be cost-prohibitive;
- allows for more efficient use of airspace (route placement, fuel efficiency and noise abatement);
- clarifies how RNAV and RNP systems are used; and
- facilitates the operational approval process for operators by providing a limited set of navigation specifications intended for global use.

There are three components of PBN so that *each **PBN application*** is supported by the requirements set out in the appropriate ***navigation specification*** and the ***NavAid infrastructure*** (both ground- and space-based) allowing the system to operate (**Figure 2**). A navigation specification is a set of aircraft and aircrew requirements needed to support a navigation application within a defined airspace concept. The navigation specification defines the performance required by the PBN system as well as any functional requirements such as the ability to conduct curved path procedures or to fly parallel offset from a parent route. The PBN system performance requirements are defined for a single aircraft and for the total system which includes the NavAid infrastructure, the airborne equipment, and the ability of the aircraft to fly the desired trajectory. The NavAid infrastructure performance requirements derive from these total system requirements (Attachment D of ICAO Annex 10) [13]. The NavAid infrastructure is the underlying system that provides a positioning service to support the PBN application. In the case of GNSS, the potential of degraded configurations affecting multiple aircraft is to be considered [13].

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[20] https://www.skybrary.aero/index.php/Performance_Based_Navigation_(PBN)

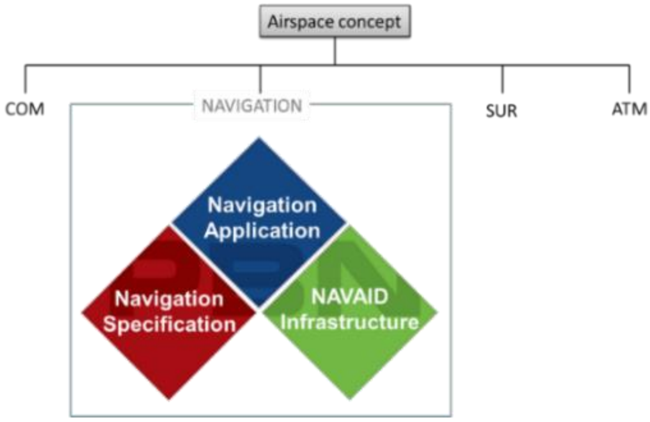

Figure 2: PBN Supporting the airspace concept

Two generations of PBN applications exist that are fundamentally similar:

- Area Navigation (RNAV) where the aircraft computes an absolute position
- Required Navigation Performance (RNP) where the aircraft computes an absolute position combined with an alerting system that monitors the estimated error.

Area Navigation (RNAV)

On-board navigation computers, also called area navigation system or flight management systems, have been progressively implemented in the cockpit since the 80s. This system retrieves information from all of the on-board available sensors (ground navigation aids, space-based sensors or airborne based sensors) and **computes an absolute position** independent of the location of the ground stations. This capability removed the limitations on procedure design and waypoints can be located anywhere.

RNAV applications are identified by a number representing the lateral track accuracy (95% of the flying time) expressed in nautical miles required for the application. It has to be noted that the accuracy is not the only difference between RNAV applications: for each application, a set of functionalities are also required that may differ between the different RNAV applications. However, the modern RNAV system usually support a common set of functions:

- A flight planning function that includes the management of DIRECT TO.
- The management and automatic sequencing of the most common ARINC 424 legs
- The capability to define and fly a RNAV holding pattern
- The display of commonly used navigation data (Next waypoint, distance and time to go….)
- The capability to load, use and manage a navigation database although RNAV 5 does not have a requirement for one.

RNAV applications can be supported by the following positioning sources:

- GNSS
- DME/DME
- DME/DME/Inertial
- Inertial
- VOR/DME (only for RNAV 5)

Required Navigation Performance (RNP)

Required Navigation Performance applications are based on **the computation of an absolute position combined with an On-board Performance Monitoring and Alerting (OBPMA) system that monitors the aircraft's performance as regards its ability to determine positioning error and/or to follow the desired path**. If the lateral and/or longitudinal error is estimated to be larger than the required accuracy, or the probability of exceeding 2 times the accuracy is estimated to be excessive [8], an alert is provided to the flight crew. This alerting is also applied to the estimated vertical error during the final approach segment. Just like RNAV, RNP applications are also identified by a number representing the required navigation accuracy, but this required accuracy is not the only difference: each RNP application requires different functionality.

However, RNP equipment usually support the same common set of functions that are supported by modern RNAV equipment (see above) with the following options:

- Radius to Fix (RF) is a particular leg that allows the procedure designer to define a curved path between two waypoints. RF legs are used in terminal areas.
- Fixed Radius Transition (FRT) is a particular transition between two legs that ensure the aircraft will transit following a pre-determined and curved ground path. FRT can be used in En-route.
- Parallel offset allows the pilot to fly along the procedure with a left or right offset. Parallel offset is only used in en-route and usually in oceanic or remote areas: aircrafts fly with a right offset which mitigates the risk of mid-air collision.

Currently, the On-board Performance Monitoring and Alerting (OBPMA) requirement can only be met by GNSS; hence, only GNSS can support RNP applications.

2.2.1 Description of PBN applications

Oceanic and remote En-Route PBN applications

The RNAV oceanic application is the RNAV 10 which requires a navigation accuracy of 10 NM (95% of the flying time). This application can either be based on GNSS or inertial positioning and requires the aircraft equipage of two fully independent navigation systems.

There are 3 RNP applications that cover the oceanic and remote areas: RNP 4, RNP 2 and Advanced RNP; the latter two specifications require high continuity to operate in this airspace. These applications require the aircraft to be equipped with a modern navigation system that supports the common set of functions defined above. In addition:

- RNP 2 has identified the capability to fly FRT and parallel offset as an option
- RNP 4 and Advanced-RNP have identified the capability to fly FRT as an option but requires the parallel offset function.

Continental En-Route PBN applications

There are two generations of RNAV applications:

- RNAV 5 (historically called Basic-RNAV)
- and RNAV 2/1 (historically Precision-RNAV).

Initially, RNAV 5 was only requesting some very basic functionality whereas RNAV 2/1 was a more recent application requiring a more modern 1990s technology providing better navigation capability.

There are two RNP applications that cover fixed wing and rotorcraft operations in the continental En-Route airspace: Advanced RNP and RNP 2; RNP 1 is not exclusive to terminal operations so could also be considered. These applications require the aircraft to be equipped with a modern navigation system that support the common set of functions defined above.
In addition:

- RNP 2 has identified the capability to fly FRT and parallel offset as an option
- Advanced RNP has identified the capability to fly FRT as an option but requires the parallel offset function.

Terminal PBN applications

The RNAV applications that could be used for the terminal area are RNAV 1 and RNAV 2; however, RNAV 2 is considered more as an En-route application in Europe. Both applications come under one navigation specification (RNAV 2/1) and therefore both have the same functionalities.

There are 2 RNP applications that cover fixed wing and rotorcraft operations in the terminal area: the Advanced RNP and RNP 1. These applications require the aircraft to be equipped with a modern navigation system. In addition:

- RNP 1 has identified the capability to fly RF legs as an option
- RNP 1 has identified the advisory VNAV function as an option
- Advanced- RNP required the capability to fly RF legs.

Both RNAV and RNP applications can support operations down to the Final Approach Fix at which stage a different operation will need to be undertaken.

Approach PBN applications

The approach area is split between the initial, intermediate and missed approach segment on one hand and the final approach segment on the other hand. The definition of the initial, intermediate and missed approach segments are very similar to arrival and departure procedure: although some altitude constraint may be defined, there is no vertical path defined. On the opposite, the final approach segment can be defined by both a lateral and a vertical path.

Concerning the initial, intermediate and missed approach segment, the navigation performance required is the same as that required for arrival and departure procedures; if a tighter navigation performance is required in these approach segments, then a ‘special’ Authorisation Required (AR) procedure must be put in place. There are two approach applications: RNP APCH and RNP (AR) APCH. Advanced RNP has been considered as an approach application, but the PBN Study Group (PBNSG) intends to stop the A-RNP navigation specification at the Final Approach Fix. All PBN approach applications are RNP.

Concerning the final approach, applications are classified depending on the applicable minimum descent altitude/height (MDA/H) or decision altitude/height (DA/H):

- Type A groups the approach with DA/H or MDA/H higher than or equal to 250ft. There are two group A families:
    - 2D approaches where path guidance only is provided. They are the current non-precision approaches. The approaches can either be flown using a conventional

procedure based on ground navigation aid (VOR/DME, NDB, LOC) or using a RNP application RNP APCH based on the GPS/ABAS position.

- 3D approaches where both lateral and vertical paths are defined. These approaches are called Approach with Vertical guidance (APV). Two RNP specifications can be used:
  - RNP APCH which will use the GPS/ABAS for the lateral and barometric altimetry for the vertical positioning or GPS /SBAS for both the lateral and vertical positioning.
  - RNP AR APCH which is primarily based on GPS/ABAS for the lateral positioning and barometric altimetry for the vertical positioning. RNP AR APCH is a particular RNP operation which requires the aircraft, operator and flight crew to be specifically equipped and trained for this operation. RNP AR procedures are usually designed in demanding terrain environment.

- Type B groups the approaches with DA/H lower than 250ft. Type B approaches are 3D approaches and can be called precision approaches. They can be based on:
  - Conventional application based on ILS or MLS down to Category I, II or III minima.
  - RNP APCH application based on GPS/SBAS down to Category I minima, also called SBAS CAT I.
  - GPS augmented with GBAS down to Category I, II or III minima. Although GBAS applications are not defined in the PBN Manual, it relies on the computation of an absolute position combined with an alerting system that monitors the estimated error and thus could be included in the future into the RNP applications.

The **Figure 3** summarizes the approach classification.

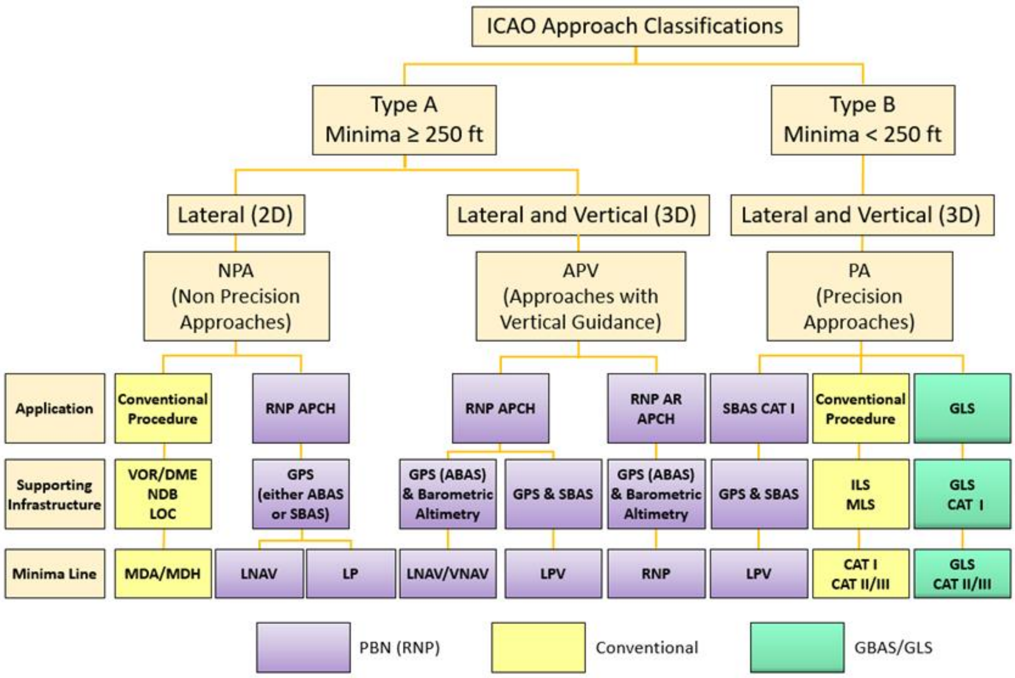

Figure 3: ICAO approach classification

PBN application for helicopters

A specific RNP application has been developed for the rotorcraft operations: RNP 0.3. This application requires the aircraft to be equipped with a modern navigation system primarily utilising SBAS augmented positioning. In addition, it identifies the advisory VNAV and the use of RF legs as optional. This application allows the use of 0.3NM navigation accuracy for rotorcraft in the majority of the phase of flight except oceanic and the final approach segment.

2.2.2 Navigation Performance Parameters

The following parameters are used to define navigation performance requirements:

- **Accuracy** (horizontal and vertical) means in the context of PBN operations the degree of conformance between the estimated, measured or desired position and/or the velocity of a platform at a given time, and its true position or velocity.
- **Continuity** (horizontal and vertical) of function means in the context of PBN operations the capability of the system, to perform its intended function without unscheduled interruptions.
- **Integrity** (horizontal and vertical) means in the context of PBN operations the quality which relates to the trust which can be placed in the correctness of the information supplied by the system.
- **Availability** of GNSS signal-in-space (SIS) or some other NAVAID infrastructure is considered within the airspace concept in order to enable the navigation application [8]. **Availability** is characterized by the portion of time the system is to be used for navigation during which reliable navigation information is presented to the crew, autopilot, or other system managing the flight of the aircraft, and should consider the desired level of service (Attachment D of ICAO Annex 10) [13].

Note.- while accuracy, continuity and integrity are defined in the navigation specifications as aircraft requirements, the availability is defined for the navigation infrastructure.

Table 6 presents an example of the technical performance requirements applicable to a navigation system, the GNSS, for a specific flight operation, the approach operation with vertical guidance (APV-I).

Horizontal accuracy 95%	**Vertical accuracy** 95%	**Integrity**	**Horizontal alert limit**	**Vertical alert limit**	**Time to alert**	**Continuity**	**Availability**
16.0 m	20.0 m	$1 - 2\times 10^{-7}$ in any approach	40 m	50 m	10 s	$1 - 8 \times 10^{-6}$ per 15 s	0.99 to 0.99999

Table 6 GNSS signal-in-space performance requirements for APV-I

The content below explains in detail each parameter and provides respective navigation performance requirements.

Note.- navigation performance requirements are defined in different documents such as ICAO Doc 9613 PBN Manual [8] and ICAO Annex 10 Aeronautical Telecommunications Volume I Radio Navigation Aids [13]. Across these documents, the performance requirements are not always expressed in a consistent way, different aspects are being considered and for some specifications, some requirements are not detailed. Instead of listing the requirements as written in the different document, this section provides a view on what may be a harmonised version of the navigation performance requirements that could be supported by modern navigation systems. As a consequence, the reader may find some difference between the requirements defined in this section with some of the document listed in the previous section.

2.2.2.1 Horizontal Accuracy

The horizontal accuracy or Total System Error (TSE) should be calculated as the combination of the Path Definition Error (PDE), which is usually negligible, the Flight Technical Error (FTE) and the Navigation System Error (NSE) (see **Figure 4**). Assuming that these 3 errors are Gaussian and independent, the 95% containment value of the TSE should be calculated as the RMS of the 95% containment values of the PDE, FTE and NSE:

$$\mathrm{TSE} = \sqrt[2]{\mathrm{PDE}^2 + \mathrm{FTE}^2 + \mathrm{NSE}^2}$$

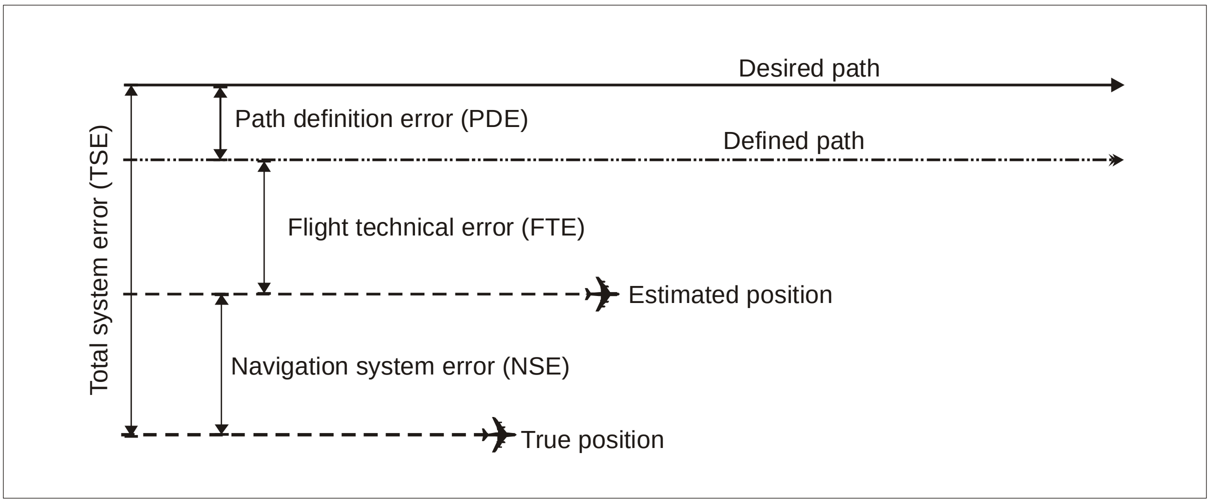

Figure 4: Definition of TSE, PDE, FTE and NSE

The cross-track and along-track lateral TSE of the aircraft area navigation system should be within +/- one time the value (in NM) in Table 7 below for at least 95% of the flight time depending on the phase of flight and the PBN application.

PBN Navigation specification	Flight phase							
	En-route oceanic remote	En-route continental	Arrival	Approach				Departure
				Initial	Intermed	Final	Missed	
RNP 4	±4 NM							
RNP 2	±2 NM	±2 NM						
RNP 1			±1 NM	±1 NM	±1 NM		±1 NM	±1 NM
Advanced RNP	±2 NM	±2 or ±1 NM	±1 NM	±1 NM	±1 NM[21]	±0.3 NM[22]	±1 NM	±1 NM[21]
RNP APCH				±1 NM	±1 NM	±0.3 NM	±1 NM	
RNP AR				±1-0.1 NM	±1-0.1 NM	±0.3-0.1 NM	±1-0.1 NM	±1-0.3 NM
RNP 0.3		±0.3 NM	±0.3 NM	±0.3 NM	±0.3 NM		±0.3 NM	±0.3 NM

Table 7 Lateral TSE 95 % containment values in NM

Table 8 below indicates allowable "FTE credit" for various RNP operations when using autopilot, flight director, or manual flight control; manual flight is managed by the pilot maintaining within ½ full scale deflection provided the Course Deviation Indicator (CDI) is correctly scaled for that phase of flight.

Lateral TSE 95% containment	FTE credit in NM	FTE Basis
±0.3 NM	0.125 0.25	Autopilot, Flight Director or Manual Operation
±1 NM	0.5	Autopilot, Flight Director or Manual Operation
±2 NM	1.0	Autopilot, Flight Director or Manual Operation
±4 NM	1.0	Autopilot, Flight Director or Manual Operation

Table 8 Lateral FTE credit

[21] Will be reduced to ±0.3 NM in the 5th Edition of ICAO Doc 9613 PBN Manual

[22] Final Approach Segment will be deleted from A-RNP specification in the 5th Edition of ICAO Doc 9613 PBN Manual

The allocation for these FTE values are quite conservative and based on studies from the 70s. They may be refined in the future, considering the significant improvement performed in the cockpit and its ability to follow a defined path.

2.2.2.2 Vertical Accuracy

When supporting VNAV, the 99.7 % containment value of the Vertical Total System Error TSE_Z should be calculated as the combination of the Altimetry System Error (ASE), the Vertical Path Steering Error (PSE_Z), the Vertical Path Definition Error PDE_Z and the Horizontal Coupling Error (HCE) (see **Figure 5**). Assuming that these 4 errors are Gaussian and independent, the 99.7% containment value of the TSE_Z should be calculated as the RMS of the 99.7% containment values of the ASE, PSE_Z, PDE_Z and HCE:

$$TSE_Z = \sqrt{ASE^2 + {PSE_Z}^2 + {PDE_Z}^2 + HCE^2}$$

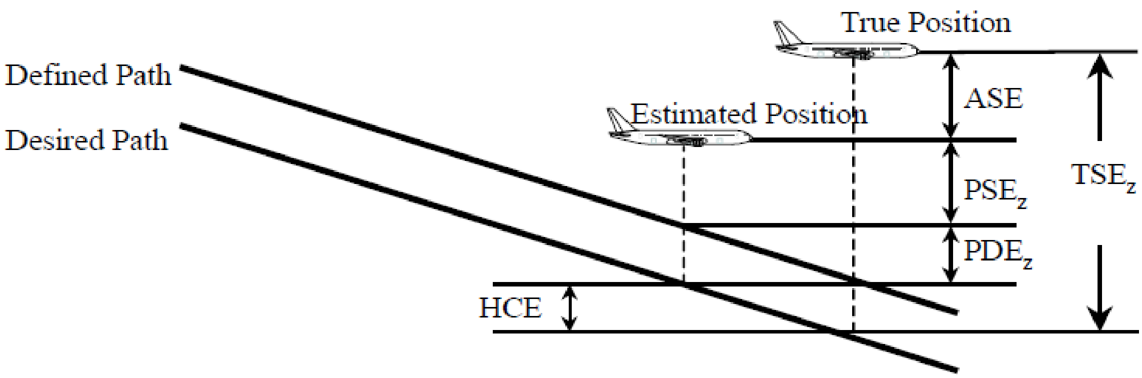

Figure 5: Vertical Errors

- **Altimetry System Error (ASE)**: considering the aircraft in approach configuration, the ASE containment value (in ft.) at 99.7 % should be less than or equal to: $-8.8 \cdot 10^{-8} \cdot H^2 + 6.5 \cdot H + 50$, with H being the true aircraft altitude in feet.

- **Vertical Path Steering Error (PSE_Z)**: it is the vertical path steering performance which varies depending on how operations are conducted (manual, flight director or autopilot). Use of a flight director or autopilot may be required to support PSE_Z requirement in certain conditions.

- **Vertical Path Definition Error (PDE_Z)**: VNAV Path Definition Error is the error associated to the vertical path computation. It includes path definition error (PDE) and approximation made by the VNAV equipment for the vertical path construction if any.

- **Horizontal Coupling Error (HCE)**: the Horizontal Coupling Error (vertical error component of along-track positioning error) is a function of the horizontal NSE and is directly reflected in the along track tolerance offset used in BARO/VNAV procedure design criteria. The HCE should only be taken into account in the final approach segment and may be assumed to be equal to 24 ft on a vertical path of 3°.

When supporting VNAV except for stabilised constant descent path under RNP AR operations, the 99.7 % containment value of the Vertical Total System Error TSE_Z taking into account all the error in the aircraft processing chain of the vertical guidance should be lower than or equal to the values specified in Table 9 below:

Altitude bands	Level Flight Segments & Climb/Descent Intercept of Clearance Altitudes	Flight Along Specified Vertical Descent Profile
At or below 5000 ft MSL	150 ft	160 ft
Above 5000 ft to 29000 ft MSL	200 ft	210 ft
Above 29000 ft to 41000 ft MSL	200 ft	260 ft

Table 9 Maximum Vertical Total System Error

When performing stabilised constant descent path under RNP AR operations, the area navigation system should ensure a 99.7% containment of the vertical position error which is equal to or less than the Vertical Error Budget attributed to the aircraft, as defined by (in feet):

$$\mathrm{VEB} = \sqrt{(-8.8 \cdot 10^{-8} \cdot \mathrm{H}^2 + 6.5 \cdot \mathrm{H} + 50)^2 + 75^2 + (60 * \tan\theta)^2 + (6076.115 * 1.225 * \mathrm{RNP} * \tan\theta)^2}$$

where H is the aircraft altitude (in ft.) and θ the vertical navigation path angle.

Note.-

- The term $-8.8 \cdot 10^{-8} \cdot \mathrm{H}^2 + 6.5 \cdot \mathrm{H} + 50$ is the contribution from the Altimetry System Error
- The term 75 ft is the contribution from the Vertical Path Steering Error
- The term $60 * \tan\theta$ is the contribution from the Vertical Path Definition Error or also called Waypoint Precision Error
- The term $6076.115 * 1.225 * \mathrm{RNP} * \tan\theta$ is the contribution from the Horizontal Coupling Error or also called the Actual Navigation Performance Error.

2.2.2.3 Continuity: horizontal and vertical guidance

The continuity of the provision of the aircraft horizontal guidance (cross track or distance) by the area navigation system should be designed to an allowable qualitative probability of “Remote” except for the RNP AR application with either RNP < 0.3 NM or a Missed Approach with RNP < 1 NM.

For the RNP AR application with either RNP < 0.3 NM or a Missed Approach with RNP < 1 NM, the continuity of the provision of the aircraft horizontal guidance by the area navigation system should be designed to an allowable qualitative probability of “Extremely Remote” for the lateral cross-track and “Remote” for the distance.

When vertical guidance is provided during final approach, the continuity of the provision of the aircraft vertical guidance by the area navigation system should be designed to an allowable qualitative probability of:

- “Extremely Remote” for RNP AR operations
- “Remote” for others operations.

2.2.2.4 Integrity (horizontal and vertical)

The integrity requirement includes an alert limit, specific of each flight operation, against which the requirement can be assessed. The alert limit represents the largest position error allowable for a safe operation. The position error cannot exceed this alert limit without annunciation within a time to alert, also specific of each flight operation.

The integrity of the aircraft **horizontal** position data and of the aircraft **horizontal** guidance for the lateral cross-track and the distance provided by the aircraft area navigation system should be designed commensurate with the Table 10.

Operation	Position	Guidance	
		Cross-track	Distance
RNP APCH down to LNAV	Major	Major	Minor
RNP APCH down to LP	Major	Hazardous	Major
RNP APCH down to LNAV/VNAV	Major	Major	Major
RNP APCH down to LPV	Major	Hazardous	Major
RNP AR with RNP≥0.3NM and missed approach with RNP≥1NM	Major	Major	Major
RNP AR with RNP<0.3NM or missed approach with RNP<1NM	Hazardous	Hazardous	Major
Other operations	Major	Major	Minor

Table 10 Horizontal integrity

The integrity of the aircraft **vertical** position data for the **vertical** position and for the combined horizontal and vertical position, and of the aircraft vertical guidance for the vertical guidance and the combined horizontal and vertical guidance provided by the aircraft area navigation system should be designed commensurate with the following Table 11.

Operation	Position		Guidance	
	Vertical position	Horizontal & Vertical position	Vertical guidance	Horizontal & Vertical guidance
RNP APCH down to LNAV/VNAV	Major	Hazardous	Major	Hazardous
RNP APCH down to LPV	Hazardous	Hazardous	Hazardous	Hazardous
RNP AR with RNP≥0.3NM and missed approach with RNP≥1NM	Major	Hazardous	Major	Hazardous
RNP AR with RNP<0.3NM or missed approach with RNP<1NM	Hazardous	Hazardous	Hazardous	Hazardous

Table 11 Vertical integrity

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2.2.3 Performance based aerodrome operating minima

As explained earlier, traditionally aerodrome operating minima has been predicated upon the navigational guidance, non-visual and visual facilities provided for the runway and on the instrument approach procedures related to those facilities (NPA, APV or PA). These minima and the requirements for aerodrome facilities are designed to support operations with those aircraft carrying only the minimum equipment required for the particular operation. Modern aircraft are increasingly equipped with additional systems like Head-Up Display (HUD), Enhanced Vision System (EVS), auto-land, etc. These aircraft can safely operate to lower Runway Visual Range (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)”.

Operations with operational credit are foreseen as part of the performance based operating minima:

- **Category I** operation with operational credit leading to a decision height less than 200ft and/or runway visual range of less than 550m. The equipage of HUD, SVS, CVS or an autoland capability combined with the radio-altimeter may be required. One example of this operation is the Lower Than Standard CAT I (LTS CAT I) or SA-CAT I (Special Authorisation CAT I).

Operations comprising operational credit for an enhanced visual segment based on EVS. For this operation, two decision heights will be used: the pilot will be allowed to descent below the first decision height if runway elements are visible with the enhanced vision system, and below the second decision height if runway element are visible with the natural vision.

- **Category II** operation with reduced infrastructure: the additional aircraft capabilities provided by HUD, EVS, SVS, CVS or autoland can compensate for a reduced infrastructure such as no touchdown zone lights and/or no centreline light. One example is the Other Than Standard CAT II (OTS CAT II) approaches.

Operational credit for take-off: credit for low visibility take-off operations depends on the runway equipage in term of visual aids. ILS guided take-off with HUD or the use of EVS can also provide credit for lower visibility take-off.

2.3 Performance-based Surveillance

The overall objective of the surveillance infrastructure is to enable a safe, efficient and cost-effective air navigation service (ANS). The objective of Performance-based Surveillance (PBS) is to determine, in a technology-agnostic way, the minimum Surveillance System performance requirements per Air Traffic Services (ATS) application.

A Surveillance application is not implemented based on isolated PBS requirements. Execution of a surveillance application often has several prerequisites, including requirements on air-ground SUR interoperability, COM and NAV capabilities and performance (e.g., including PBC and/or PBN).

This section considers two currently published PBS related documents. The EUROCONTROL Specification for ATM Surveillance System Performance (ESASSP) [9] and the ICAO Performance-based Communications and Surveillance Manual (PBCS) [7].

2.3.1 Description of PBS applications

In the currently published PBS documents, the ESASSP (ed. 1.2) [9]:

- covers the 3 and 5NM separation applications in support of the Air Traffic Control service,
- is Means of Compliance for SPI IR (Surveillance performance and interoperability Implementing Regulation) [14],
- and is widely used in European Civil Aviation Conference member states (ECAC area) to demonstrate surveillance performance.

On its last edition, performance is expected to be the same for cooperative and non-cooperative surveillance systems providing the same separation service, only excluding in the case of the non-cooperative systems those criteria applied to data items not provided (e.g., pressure-altitude and aircraft identification).

The ICAO PBCS Manual (Doc 9869) [10] covers with the Required Surveillance Performance (RSP) concept only the surveillance data transfer requirements via the ADS-C protocol, in support of procedural separation in Oceanic applications, such as the RlongSM, RLatSM, 30-30NM, etc. Therefore, it is marked as RSP_{com}, which includes the data provision process, but does not take into account the actual performance of the surveillance systems.

2.3.2 Availability Requirements

2.3.2.1 Surveillance separation applications

The ESASSP availability requirements are shown in the Table 12. Availability is defined, together with the continuity, as the two necessary elements to assess the frequency and duration of service failures (reliability).

The table below is linked with the information included in Section 2.3.7, Table 21 and Table 22, where the requirements are explicitly provided.

	3 NM separation	5 NM separation
Horizontal position	3N_C_R1 to 3N_C_R2	5N_C_R1 to 5N_C_R2
Pressure altitude	3N_C_R1 to 3N_C_R7	5N_C_R1 to 5N_C_R7
SPI/Emergency indicator	Note 4	Note 4
Aircraft identity	3N_C_R1 to 3N_C_R14	5N_C_R1 to 5N_C_R14
Rate of climb/descent	Note 5	Note 5
Track velocity	Note 5	Note 5
System	Note 8	Note 8

Table 12 ESASSP Availability Requirements

Note 4.- Data items are checked procedurally by Air Traffic Control Officer (ATCO) (SPI is generated on request by ATCO to the pilot ("squawk IDENT"), if it does not appear the ATCO will check with the pilot – in case of emergency indicator the ATCO will call the pilot for further information).

Note 5.- Requirements are to be defined locally when these data items are provided and used.

Note 8.- System requirement is to be defined locally.

2.3.2.2 Procedural separation in Oceanic applications

The availability requirements are shown in the Table 13. Availability here is the proportion of time that the air-ground link is operational. In addition to the statistical requirement on availability, there is also a rigid limit on the permitted maximum duration of any single system outage (cf. the last row in the Table 13 values expressed in minutes).

	RSP_{Com} 180/A1	RSP_{Com} 400/A1
A_{ATSU}	n/a	n/a
A_{CSP}	0.999 (safety) 0.9999 (efficiency)	0.999
$A_{Aircraft}$	0.99[23]	0.99[23]
Unplanned service outage $duration_{ATSU\ \&\ CSP}$ (min)	10 (CSP only)	20

Table 13 RSP_{Com} Availability Requirements

Again, it can be seen that the availability requirement on the ground systems is considerably higher than that on the aircraft, reflecting the operational impact of loss of the respective capabilities. The communication RSP 160 requirement corresponds to total outage of 4.4 hours per year and can be expected to represent major improvement design drivers for the ground systems.

ED-228A specifies further limits of the unplanned outages annual number and on the total outage time per year.

2.3.3 Continuity Requirements

2.3.3.1 Surveillance separation applications

The ESASSP continuity requirements are shown in the Table 14. Availability is defined, together with the Continuity, as the two necessary elements to assess the frequency and duration of service failures (reliability).

The Table below is linked with the information included in Section 2.3.7, Table 21 and Table 22, where the requirements are explicitly provided.

[23] This value will be set to 0.999 in ED-228B to align with ICAO Doc 9869 PBCS Manual.

	3 NM separation	5 NM separation
Horizontal position	3N_C_R3	5N_C_R3
Pressure altitude	3N_C_R3	5N_C_R3
SPI/Emergency indicator	Note 4	Note 4
Rate of climb/descent	Note 6	Note 6
Track velocity	Note 6	Note 6
System	3N_C_R21	5N_C_R21

Table 14 ESASSP Continuity Requirements

Note 4.- Data items are checked procedurally by ATCO (SPI is generated on request by ATCO to the pilot ("squawk IDENT"), if it does not appear the ATCO will check with the pilot – in case of emergency indicator the ATCO will call the pilot for further information).

Note 6.- Because of the way these data items are calculated (by a tracker), once started they will continue to be provided, so continuity is 100% by design if the availability requirement is fulfilled.

2.3.3.2 Procedural separation in Oceanic applications

As with RCP, continuity is specified in relation to the required transaction time. Table 15 presents the percentage of messages that transit the component in the allocated time (Delivery Time - DT).

	RSP$_{Com}$ 180/A1 DT$_{95\%}$	RSP$_{Com}$ 400/A1 DT$_{95\%}$
Continuity $_{\text{ATSU, CSP, and Aircraft}}$	0.95	0.95

Table 15 RSP$_{Com}$ Continuity Requirements

2.3.4 Integrity Requirements

2.3.4.1 Surveillance separation applications

The ESASSP integrity requirements are shown in the Table 16. Integrity refers to the influence of errors and inaccuracies on the Quality of Service. Integrity is further refined in three different performance characteristics: core errors, correlated errors and spurious.

The Table below is linked with the information included in Section 2.3.7, Table 21 and Table 22, where the requirements are explicitly provided.

	Error type	3 NM separation	5 NM separation
Horizontal position	Core	3N_C_R4	5N_C_R4
	Correlated	3N_C_R5 and 3N_C_R20	5N_C_R5 and 5N_C_R20
	Spurious	3N_C_R19	5N_C_R19
Pressure altitude	Core	3N_C_R11 to 3N_C_R17	5N_C_R11 to 5N_C_R17
	Correlated	Note 2	Note 2
	Spurious	3N_C_R10	5N_C_R10

	Error type	3 NM separation	5 NM separation
SPI/Emergency indicator	Core	Note 4	Note 4
	Correlated	Note 4	Note 4
	Spurious	Note 4	Note 4
Aircraft identity	Core	3N_C_R14	5N_C_R14
	Correlated	-	-
	Spurious	3N_C_R15	5N_C_R15
Rate of climb/descent	Core	3N_C_R16	5N_C_R16
	Correlated	Note 7	Note 7
	Spurious	Note 7	Note 7
Track velocity	Core	3N_C_R17 to 3N_C_R18	5N_C_R17 to 5N_C_R18
	Correlated	Note 7	Note 7
	Spurious	Note 7	Note 7

Table 16 ESASSP Integrity Requirements

Note 2.- Pressure altitude correlated error due to ground surveillance system is assumed to be addressed by R10. Pressure altitude correlated error due to the airborne system cannot be assessed by a ground surveillance system. It has to be assessed by specific systems like the Height Monitoring Unit's (HMU) deployed in the frame of RVSM monitoring.

Note 4.- Data items are checked procedurally by ATCO (SPI is requested by ATCO, if it does not appear the ATCO will check with the pilot – in case of emergency indicator the ATCO will call the pilot for further information).

Note 7.- No specific requirement when supporting 3 or 5 NM horizontal separation, requirement likely to be needed when supporting safety nets.

2.3.4.2 Procedural separation in Oceanic applications

The Table 17 shows the Integrity requirements. The requirement of "1E-5 per flight hour" means that the likelihood of a malfunction is no greater than in 1 in 100,000 per flight hour[24].

	RSP_{Com} 180/A1	RSP_{Com} 400/A1
I_{ATSU}	1E-5 per flight hour	1E-5 per flight hour
I_{CSP}	Not specified	Not specified
$I_{Aircraft}$	1E-5 per flight hour	1E-5 per flight hour

Table 17 RSP_{Com} Integrity Requirements

[24] This is taken to mean that, in 100,000 flight hours, on average no more than 1 malfunction shall occur.

2.3.5 Time Requirements

2.3.5.1 Surveillance separation applications

The ESASSP time requirements are shown in the Table 18. Time refers to the processing delay for the data items that are forwarded from the aircraft to the surveillance system user on the ground.

The Table below is mapped with the information included in Section 2.3.7, Table 21 and Table 22, where the requirements are explicitly provided.

	3 NM separation	5 NM separation
Horizontal position	3N_C_R4 Note 1	5N_C_R4 Note 1
Pressure altitude	3N_C_R8 and 3N_C_R9	5N_C_R8 and 5N_C_R9
SPI/Emergency indicator	3N_C_R12	5N_C_R12
Aircraft identity	3N_C_R13	5N_C_R13
Rate of climb/descent	3N_C_R16 Note 1	5N_C_R16 Note 1
Track velocity	3N_C_R17 Note 1	5N_C_R17 Note 1

Table 18 ESASSP Time Requirements

Note 1.- Impact of information latency is taken into account within error calculation method.

2.3.5.2 Procedural separation in Oceanic applications

The following Section presents the key performance requirements on the air-ground communication systems. The focus is on the Required Surveillance Technical Performance (RSTP) at the 95% level. Table 19 presents the technical performance requirements applicable to the three communication RSP types, with a breakdown across the components. This breakdown is referred to as allocation and ED-228A allocates the time budget to the following components:

- Air Traffic Services Provider (ATSP) includes ATCCs
- Air Traffic Services Unit (ATSU) refers to ATCCs
- Communication Service Provider (CSP) covers the ground networks and air-ground links
- Aircraft covers the on-board elements

	RSP_{Com} 160/A1 $DT_{95\%}$ (sec)	RSP_{Com} 180/A1 $DT_{95\%}$ (sec)	RSP_{Com} 400/A1 $DT_{95\%}$ (sec)
RSTP	90[25]	90	300
$RSTP_{ATSP}$	7	n/a	n/a
$RSTP_{ATSU}$	3	3	15
$RSTP_{CSP}$	5	84	270
$RSTP_{Aircraft}$	86	3	15

Table 19 Required Surveillance Technical Performance Requirements

$DT_{95\%}$ is the Surveillance Nominal Delivery Time and is defined as: The maximum nominal time within which 95% of surveillance data deliveries are required to be successfully delivered.

2.3.6 Coherence Requirements

2.3.6.1 Surveillance separation applications

The ESASSP coherence requirements are shown in the Table 20. Coherence refers to time consistency of the provided aircraft positions.

The table below is linked with the information included in section 2.3.7, Table 21 and Table 22, where the requirements are explicitly provided.

	3 NM separation	5 NM separation
Horizontal position	3N_C_R6	5N_C_R6
Pressure altitude	Note 3	Note 3

Table 20 ESASSP Coherence Requirements

Note 3.- Time consistency of pressure altitude data item is partly addressed through R8 and R9.

2.3.7 Surveillance separation performance requirements

The following Table 21 shows a mapping between the ESASSP requirement identifiers used in sections 2.3.2, 2.3.3, 2.3.4, 2.3.5 and 2.3.6, and the quality of service and expected performance for the 5 NM separation application.

[25] See detailed description in EUROCAE ED-120 - Safety and Performance Requirements Standard for Air Traffic Data Link Services in Continental Airspace

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Requirement Identifier	Quality of Service	Mandatory performance	Recommended performance
5N_C-R1	Measurement interval for probability of update assessments (R2, R7 and R14)	Less than or equal to 8 seconds	Less than or equal to 6 seconds
5N_C-R2	Probability of update of horizontal position	Greater than or equal to 97% for 100% of the flights, any flight below 97% shall be investigated as defined in R22	Greater than or equal to 97% for 100% of the flights, any flight below 97% shall be investigated as defined in R22 and greater than or equal to 99 % global
		Greater than or equal to 97% global, counting only target reports based on a horizontal position measurement with a data age lower than or equal to 10 sec	Greater than or equal to 99 % global
5N_C-R3	Ratio of missed 3D position involved in long gaps (larger than 26.4 s = 3 x 8 s + 10%)	Less than or equal to 0.5 %	
5N_C-R4	Horizontal position RMS error	Less than or equal to 500 m global and less than 550 m for 100% of the flights, any flight above 550 m shall be investigated as defined in R22	Less than or equal to 350 m global and less than 385 m per flight
5N_C-R5	Ratio of target reports involved in series of at least 3 consecutive correlated horizontal position errors larger than 926 m - 0.5 NM		Less than or equal to 0.03 %
5N_C-R6	Relative time of applicability of horizontal position for aircraft in close proximity (less than 18520 m - 10 NM)		Less than or equal to 0.3 second RMS for relative data age
5N_C-R7	Probability of update of pressure altitude with correct value	Greater than or equal to 96 % global	
5N_C-R8	Forwarded pressure altitude average data age	Less than or equal to 4 seconds	
5N_C-R9	Forwarded pressure altitude maximum data age	Any forwarded pressure altitude data item with an age greater than or equal to 16 s shall be considered as not available when assessing R3, R7, R8 and R10	

Requirement Identifier	Quality of Service	Mandatory performance	Recommended performance
5N_C-R10	Ratio of incorrect forwarded pressure altitude	Less than or equal to 0.1 %	
5N_C-R11	Pressure altitude unsigned error	Less than or equal to 200/300 ft in 99.9% of the cases for stable flights and less than or equal to 300 ft in 98.5% of the cases for climbing / descending flights	
5N_C-R12	Delay of change in emergency indicator/SPI report	Less than or equal to 12 s for 100% of the cases, case above 12 s shall be investigated as defined in R22	
5N_C-R13	Delay of change in aircraft identity	Less than or equal to 24 s for 100% of the cases, case above 24 s shall be investigated as defined in R22	
5N_C-R14	Probability of update of aircraft identity with correct value	Greater than or equal to 98 % global	Greater than or equal to 98 % per flight
5N_C-R15	Ratio of incorrect aircraft identity	Less than or equal to 0.1 %	
5N_C-R16	Rate of climb/descent RMS error		Less than or equal to 250 ft/mn for stable flights and less than or equal to 500 ft/mn for climbing/descending flights
5N_C-R17	Track velocity RMS error		Less than or equal to 4 m/s for straight line and less than or equal to 8 m/s for turn
5N_C-R18	Track velocity angle RMS error		Less than or equal to 10° for straight line and less than or equal to 25° for turn
5N_C-R19	Density of uncorrelated false target reports		Less than 10 false target reports per area of 900 NM^2 and over a duration of 450 applicable measurement intervals
5N_C-R20	Number per hour of falsely confirmed track close to true tracks		Less than or equal to 2 non-coincident falsely confirmed tracks per hour that are closer than 13000 m - 7 NM from true tracks

Requirement Identifier	Quality of Service	Mandatory performance	Recommended performance
5N_C-R21	Continuity (probability of critical failure)		Less than or equal to 2.5 10^{-5} per hour of operation
5N_C-R22	Investigations	Flights/cases for which requirements R2, R4, R12 or R13 are not achieved shall be investigated and an impact assessment conducted, and appropriate risk mitigation/reduction measures introduced if necessary.	

Table 21 Mandatory and recommended performance requirements for 5 NM horizontal separation provided by ATCO using cooperative surveillance

The following Table 22 shows the mapping between the ESASSP requirement identifiers used in sections 2.3.2, 2.3.3, 2.3.4, 2.3.5 and 2.3.6, and the quality of service and expected performance for the 3 NM separation application.

Requirement Identifier	Quality of Service	Mandatory performance	Recommended performance
3N_C-R1	Measurement interval for probability of update assessments (R2, R7 and R14)	Less than or equal to 5 seconds	Less than or equal to 4 seconds
3N_C-R2	Probability of update of horizontal position	Greater than or equal to 97% for 100% of the flights, any flight below 97% shall be investigated as defined in R22	Greater than or equal to 97% for 100% of the flights, any flight below 97% shall be investigated as defined in R22 and greater than or equal to 99 % global
		Greater than or equal to 97% global, counting only target reports based on a horizontal position measurement with a data age lower than or equal to 7 sec	Greater than or equal to 99 % global
3N_C-R3	Ratio of missed 3D position involved in long gaps (larger than 16.5 s = 3 x 5 s + 10%)	Less than or equal to 0.5 %	
3N_C-R4	Horizontal position RMS error	Less than or equal to 300 m global and less than 330 m for 100% of the flights, any flight above 330 m	Less than or equal to 210 m global and less than 230 m per flight

Requirement Identifier	Quality of Service	Mandatory performance	Recommended performance
		shall be investigated as defined in R22	
3N_C-R5	Ratio of target reports involved in series of at least 3 consecutive correlated horizontal position errors larger than 555 m - 0.3 NM		Less than or equal to 0.03 %
3N_C-R6	Relative time of applicability of horizontal position for aircraft in close proximity (less than 11110 m - 6 NM)		Less than or equal to 0.3 second RMS
3N_C-R7	Probability of update of pressure altitude with correct value	Greater than or equal to 96 % global	
3N_C-R8	Forwarded pressure altitude average data age	Less than or equal to 4 seconds	
3N_C-R9	Forwarded pressure altitude maximum data age	Any forwarded pressure altitude data item with an age greater than or equal to 16 s shall be considered as not available when assessing R3, R7, R8 and R10	
3N_C-R10	Ratio of incorrect forwarded pressure altitude	Less than or equal to 0.1 %	
3N_C-R11	Pressure altitude unsigned error	Less than or equal to 200/300 ft in 99.9% of the cases for stable flights and less than or equal to 300 ft in 98.5% of the cases for climbing / descending flights	
3N_C-R12	Delay of change in emergency indicator/SPI report	Less than or equal to 7.5 s for 100% of the cases, case above 7.5 s shall be investigated as defined in R22	
3N_C-R13	Delay of change in aircraft identity	Less than or equal to 15 s for 100% of the cases, case above 15 s shall be investigated as defined in R22	
3N_C-R14	Probability of update of aircraft identity with correct value	Greater than or equal to 98 % global	Greater than or equal to 98 % per flight

Requirement Identifier	Quality of Service	Mandatory performance	Recommended performance
3N_C-R15	Ratio of incorrect aircraft identity	Less than or equal to 0.1 %	
3N_C-R16	Rate of climb/descent RMS error		Less than or equal to 250 ft/mn for stable flights and less than or equal to 500 ft/mn for climbing/descending flights
3N_C-R17	Track velocity RMS error		Less than or equal to 4 m/s for straight line and less than or equal to 8 m/s for turn
3N_C-R18	Track velocity angle RMS error		Less than or equal to 10° for straight line and less than or equal to 25° for turn
3N_C-R19	Density of uncorrelated false target reports		Less than 2 false target reports per area of 100 NM^2 and over a duration of 720 applicable measurement intervals
3N_C-R20	Number per hour of falsely confirmed track close to true tracks		Less than or equal to 1 falsely confirmed track per hour that are closer than 16700 m - 9 NM from true tracks
3N_C-R21	Continuity (probability of critical failure)		Less than or equal to 2.5 10^{-5} per hour of operation
3N_C-R22	Investigations	Flights/cases for which requirements R2, R4, R12 or R13 are not achieved shall be investigated and an impact assessment conducted, and appropriate risk mitigation/reduction measures introduced if necessary.	

Table 22 Mandatory and recommended performance requirements for 3 NM horizontal separation provided by ATCO using cooperative surveillance

2.3.8 Procedural separation in Oceanic performance requirements

The ICAO PBCS Manual [7] includes the RSP_{com} description used for **ADS-C** (**automatic dependent surveillance — contract)**. ADS-C supports ATM operations in airspace, where **procedural separations** are being applied.

The RSP_{com} performance is only associated with the surveillance data delivery time, from the time associated with the aircraft's position provided with the data, to the time when the ATS unit receives the data (referred to as actual (operational) surveillance performance (ASP)). Post-implementation monitoring continues to assess ASP. When applying RSP_{com}, it is assumed that the supporting system components are compatible and interoperable, in accordance with interoperability standards.

The specifications are identified by a designator RSP_{com}160, RSP_{com}180, RSP_{com}400 (where 160, 180 or 400 is transaction time - surveillance data delivery time in seconds). Each designator provides specifications for each surveillance performance parameter (time, continuity, availability, integrity). The Table 23 below presents an overview of the ED-228A's [12] end-to-end requirements applicable to ADS-C.

RSP Type	Transaction Time Overdue Delivery Time (sec)	Delivery Time 95% (sec)	Continuity	Availability	Integrity
RSP_{com} 160	160	90	0.95	0.989[26]	Malfunction = 10-5 per flight hour
RSP_{com} 180	180	90	0.95	0.9899[26] (Efficiency)	Malfunction = 10-5 per flight hour
RSP_{com} 400	400	300	0.95	0.989[26]	Malfunction = 10-5 per flight hour

Table 23 Surveillance performance specifications (ED-228A/DO-350A, applicable to ADS-C)

Regarding allocations, the same principle applies to RSP_{com} as to RCP, viz. ED-228A specifies end-to-end performance requirements and some allocated requirements may be recommended. Allocation is a matter for local implementation as such ED-228A only provides one allocation per RSP_{com} type (RSP xxx/A1), but implementers are free to perform their own allocation.

RSP_{com}160 is appropriate for 4DTBO and ATC Communications: In support of the ATS functions, defined for ENR-1, TMA and APT airspace. The RSP_{com}160 specification is required for the delivery of periodic/event reports, containing prediction data.

The RSP_{com}180 and RSP_{com}400 specifications are derived from ED122/DO-306 [11] and ICAO GOLD [15]. For ENR-2 airspace and use of two of these specifications, the following ATS functions apply:

- Separation Assurance 1 (SA 1);
- Separation Assurance 2 (SA 2).

The main use of ADS-C in ENR-2 airspace is the provision of position reports (periodic and/or waypoint change event), using the PR service and the provision of reports (single, periodic or event) associated with a projected route (re-routing) or a change to the lateral deviation/vertical rate/level range, using the IER service. Therefore, the RSP_{com} 180/400 specifications only apply to ADS-C reports which do not

[26] This value is 0.999 according to ICAO Doc 9869 PBCS Manual.

contain any route prediction data but rather include a number of predicted waypoints ahead of the aircraft. Allocation specifications per each surveillance performance parameter are provided further.

2.4 Application of PB CNS parameters at each flight phase

Flight operations, at each phase, are supported by all 3 types of services: COM, NAV and SUR. However, the three exist as separate domains and tend to evolve separately (**Figure 6**). The idea of CNS integration in general terms is to find possible synergies at each flight phase. At the same time, there is the global trend of shifting from sensor-based to more efficient performance-based service provision. To address both above mentioned drivers, a Performance-based integrated CNS concept is being developed and this concept is considered as one of the main aspects of CNS evolution.

The idea to harmonize, where beneficial, C, N, S concepts in order to ensure a more optimized CNS service provision, has a great potential. However, there is a long way to go towards the harmonization and unification of the individual C, N and S Performance-based concepts.

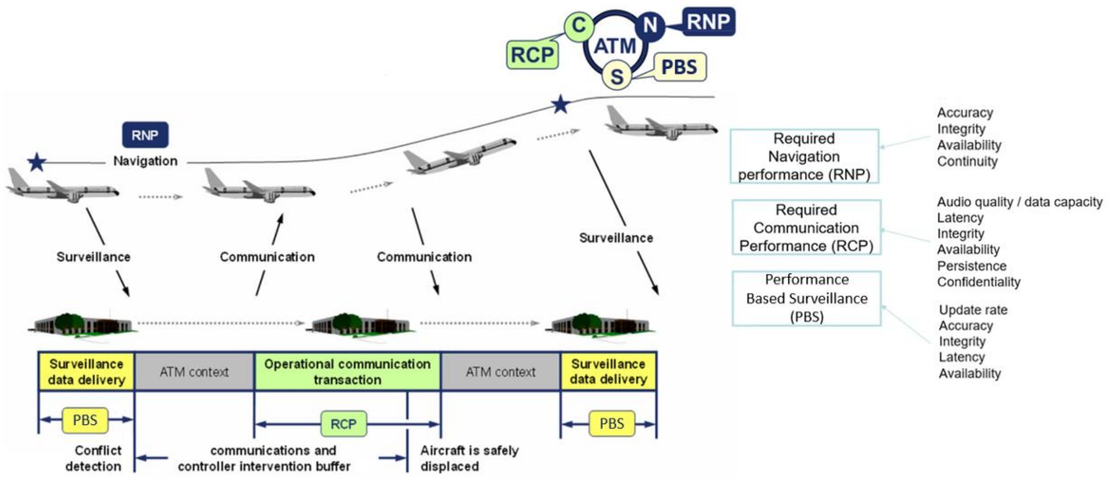


Figure 6: Performance-based Communication, Navigation and Surveillance framework

- **Integrated and Performance-based CNS (iCNS and PBCNS)**: The performance-based CNS concept represents a possible shift from technology-based to a performance-based CNS framework. Performance requirements must be defined based on the operational requirements. Operators would be enabled to evaluate options in respect of available technologies and CNS services that could allow these requirements to be met. The chosen solution would be the most cost effective for the operator based on intended operations and operational environment, rather than a solution being imposed as part of general. Technologies can evolve over time without requiring the operation itself to be revisited, as long as the requisite performance is provided by the system.

The **Figure 7** presents the COM, NAV and SUR performance-based applications and their supporting infrastructure, per flight phase. Concerning the infrastructure, the technologies have not been identified for a specific timeframe, the current and foreseen evolution have been listed. As detailed in the CNS evolution roadmap and strategy [16], the CNS infrastructure is foreseen to evolve towards a two-layers approach:

- A CNS backbone of recent and global technologies, mainly composed of the next generation datalink, ADS-B (terrestrial and space-based), dual frequency and multi-constellation GNSS, combined with advanced airborne capabilities
- Minimum Operatonal Network of the legacy infrastructure, allowing for the rationalisation of legacy systems while ensuring an efficient back-up to CNS backbone infrastructure.
- In the **Figure 7**, the technology foreseen for the CNS backbone and for the MON are differentiated with colour coding.

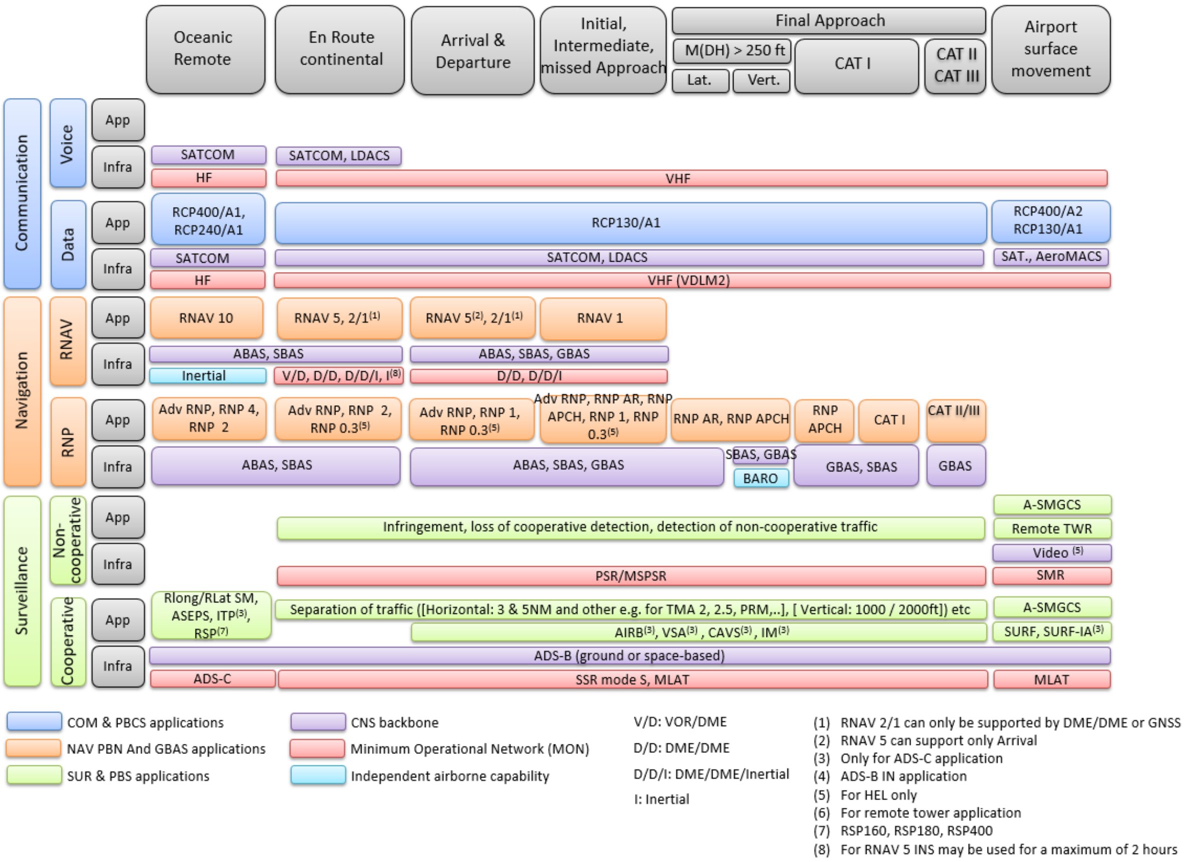


Figure 7: Performance-based applications and their supporting infrastructure

3 CNS Infrastructure Monitoring

The monitoring process of CNS infrastructure plays a key role to ensure CNS services provision. It aims to confirm CNS service provision compliance in terms of Continuity, Availability, Integrity and Accuracy. The monitoring can be also considered as a quality control process that gives provider and user confidence about compliance with performance requirements. It is carried out at the stages of a new system implementation with more detailed analysis and during system operation via a number of channels: data collection and analysis from real-time monitors, post operation data analysis, flight inspection, special event reports, ATC and Flight crew feedback. Adoption of Performance-based CNS approach is considered as a possible way to simplify the monitoring process and evaluation of service compliance.

The Performance-based CNS concepts description and monitoring aspects analysis presented in Chapter 2 that the PBCS concept includes post-implementation monitoring programmes, on a local and regional basis, with global exchange of information, whereas the PBN concept includes real time monitoring and alerting functionality in the aircraft capability.

This chapter will provide a detailed description about how the monitoring is setup in COM (Section 3.1), NAV (Section 3.2) and SUR (Section 3.3) to support Performance-based CNS and different tools available. In addition, the last Section 3.4 is providing an overview of CNS Security, where performance monitoring tools presented in each domain can support an activity.

3.1 COM performance monitoring

3.1.1 Datalink Performance monitoring

The Performance-based Communication (PBC) concept provides a framework to apply Required Communication Performance (RCP) specifications to ensure acceptable levels of communication capabilities and the performance of an operational system.

With respect to Datalink Performance Monitoring, the ICAO PBCS Manual [7] describes only PBCS concept post-implementation monitoring programmes, on a local and regional basis mostly for oceanic and remote airspaces, with global exchange of information, in comparison to the PBN concept [8] that includes real time monitoring and alerting functionality in the aircraft capability. The PBCS concept was described in Section 2.3 by giving an overview of data collection and performance measurement for Aeronautical Communication applications. Those analysis are based on the measurement of actual communication performance (ACP) against required communication monitored performance (RCMP), actual communications technical performance (ACTP) against required communication technical performance (RCTP), and pilot operational response time (PORT) against required communication performance (RCP) PORT.

In Europe, CPDLC performance monitoring parameters and their target values are described in the document “Link 2000+ DLS CRO Performance Monitoring Requirements (PMR)” [17] (Link 2000+). It was developed initially in accordance with the Data Link Services Implementing Rule (DLS IR) adopted by the European Commission and published as Regulation 29/2009 - Data link services for the Single European Sky [18] and amended later on by Commission Implementing Regulation (EU) 2020/208 [19] which obliges ANSPs to "…monitor the quality of communication services and verify their conformance with the level of performance required for the operational environment under their responsibility".

The regulation refers to ED120 [10] as the source of the performance requirements and ED-78A [20] defines the guidelines for the provision and use of services supported by data link. As an outcome, "the purpose of the CNS/ATM system performance monitoring is not specifically to measure every requirement from ED120 but rather to assure that the system is operating smoothly and achieving its overall performance requirements".

The set of proposed monitoring parameters presented in the document Link 2000+ is listed below, whether detailed description of each parameter measurement and target values can be found in Chapter 3 and 4 of the document [17], correspondingly.

- Technical Round Trip Delay.
- Data Link Initiation Capability (DLIC) Initiation Logon Counts.
- DLIC Contact Transaction Delay.
- DLIC Contact Continuity.
- CPDLC Transaction Delay.
- CPDLC Continuity.
- Availability (Use).
- Availability (Provision).

In addition to the documents mentioned above, the Datalink Performance Monitoring Function (DPMF) developed the DPMF Report Catalogue (DRC)[27] [21] describing performance report content taking into account Monitoring Categories. These categories are:

- **Network Operational Status Indicators.** This is a small set of high-level metrics to show the general status of deployment and performance.
- **Overall system performance monitoring.** This is the monitoring of the overall system performance i.e., ensuring the system meets the end-to-end performance requirements.
- **Investigative performance monitoring.** This is to investigate elements of the system that are not performing as well as expected; to help identify the causes behind poor end to end system performance. This requires monitoring the performance of individual elements of the overall system.

The monitoring results are presented in the report depending on its category. From the network perspective, it is published in the **Data link Network Operational Status Report**, where this report provides information about how widely CPDLC over the ATN is used in Europe, including information on the aircraft equipage and usage of data link as well as how well the system is performing operationally. It covers all countries subject to the DLS IR [19] but present the data in an aggregated form.

[27] Although the PMR document contains a more detailed description of the metrics, it does not cover all the metrics defined in the RDC. In addition, some of the definitions are currently under reconsideration.

Currently, there are two software tools that support the performance monitoring.

The first one is called **LINK2000+ Statistics Reporting and Analysis Tool (LISAT)**. LISAT is an analysis tool to be used with operational logs extracted from the operational system and/or received by the contributing ANSPs and CSPs. Its purpose is to:

- Support CPDLC operational monitoring through the generation of routine statistical reports on CPDLC data-link usage and performance, with minimal operator effort;
- Support additional technical analysis on data link usage and performance in support of investigations;
- Provide access to ANSPs and Airlines for routine statistical reports on CPDLC data-link usage and performance-based on data associated with their own operations.

The second tool is called **MOnitOring Network (MOON)**, which is designed to enable in a cost-effective way:

- Monitoring VDL 2 channels load for a capacity planning purpose: MOON automatically generates a set of key statistics including the load of the VDL channels in operation.
- Consulting live VDL 2 traffic: Using a specific interface an operator can consult the technical aspects of the traffic exchanged
- Detecting early and automatically VDL 2 issues: thanks to a powerful and extensible query engine, it is possible to set up a routine detection covering a wide range of possible VDL 2 implementation issues.
- Automatically monitoring issues resolution and reoccurrence: while an issue is reported to be solved by the industry or the airspace users, MOON enables to automatically monitor and notify its operators through E-mail generation in case of re-appearance of the issue.
- Generating detailed statistics: a wide range of statistics can automatically be computed by the MOON system. Charts (e.g., 2D or 3D bars or Pie charts or plain tabular reports) can easily be Copy/pasted for regular reporting.

The MOON monitoring system is made of local receiver stations named “Remote Monitoring Units” (RMU) communicating with a Central Monitoring Server (CMS). MOnitOring Network (MOON) infrastructure is totally independent of Communication Service Providers operating their own equipment for commercial VDL 2 service purposes.

An RMU is made of a VHF digital receiver operating VDL 2 and an industrial computer on which the recordings are stored. The traffic characteristics captured and recorded at each RMU are then provided to the Central Monitoring Server (CMS) through the internet or possibly the Pan-European Network Service (PENS) network. The data transmissions from the RMUs to the CMS can be done automatically (on a regular – configurable – basis) or manually (at user’s request). The CMS role is to gather data traffic from RMUs, to merge them and filter out any potential duplicates (two RMUs could receive the same traffic because of coverage overlap). A large picture of VDL 2 data link communication is then available for analysis and statistics. RMUs are deployed at different locations depending on the target area to be monitored. Due to propagation issues and in order to get as much uplink data as possible, it is always best to locate them close to active and operational VDL 2 Ground Stations at airports.

3.1.2 Radio Frequency Function Monitoring

Commission Implementing Regulation (EU) 2019/123 [22] lays down detailed rules for the implementation of air traffic management (ATM) network functions (NF IR), article 7(1)e requires the Network Manager to provide the central function for the coordination of radio frequencies. This is called the Radio Frequency Function (RFF), detailed in Annex 3 of the regulation.

The Radio Frequency Function manages scarce resources and provides common centralised network support services to ensure the required level of performance, interoperability, compatibility and coordination of activities and contributing to the sustainable development of the air transport system.

The activities of the RFF together with the ongoing implementation of 8.33 kHz below flight level FL195 has enabled to satisfy again all requests for new aeronautical voice frequencies in Europe in 2020. **Figure 8** shows the evolution of the request satisfaction rate for the European most congested areas.

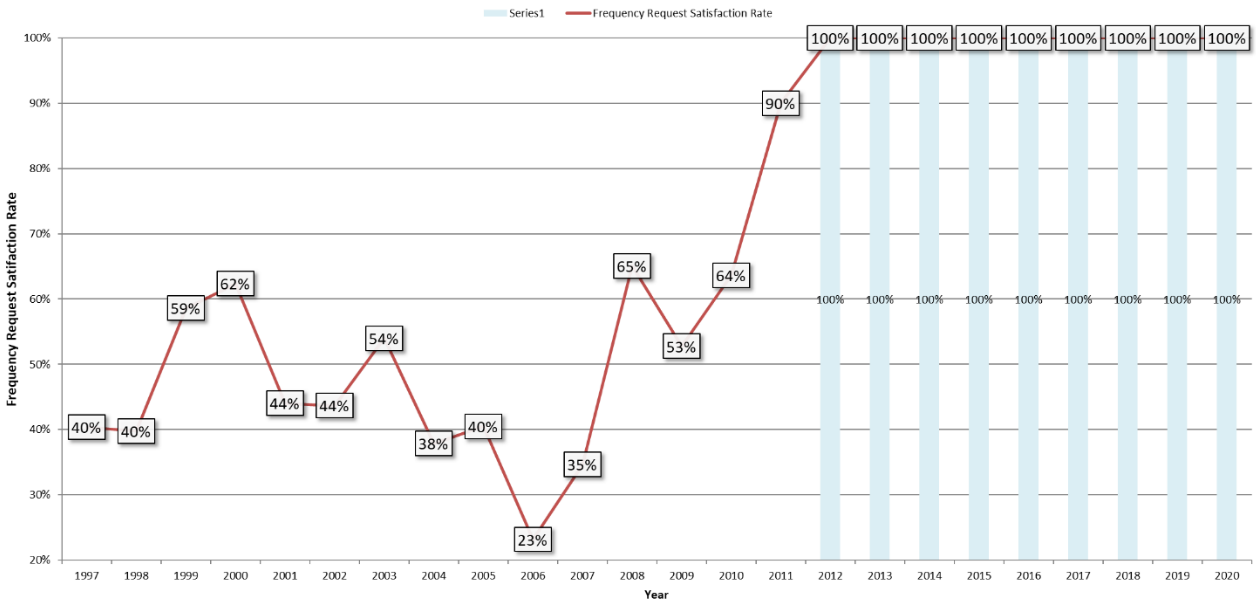


Figure 8: The evolution of the request satisfaction rate for the European area

As mandated by the regulation, an Annual report is produced by NM and provided to the Commission. The 2020 edition is the latest one at the time of writing and shall be consulted for more details.

In any case, in 2020, the Radio Frequency Function has continued to provide support to the National Frequency Managers by coordinating monitoring activities, by contributing to the resolution of reported radio interferences and by performing local studies to satisfy complex frequency requests.

A number of KPIs are used in the RFF report, summarized below. Current values are to be found for registered users only on the EUROCONTROL SharePoint site of RFF[28].

[28] https://ost.eurocontrol.int/sites/RFF/SitePages/Home.aspx

Number of Radio Interferences

Description	This KPI measures the quality of the European process to mitigate the impact of reported interferences.
Value	The number of reported radio frequency interferences that have not been closed within 6 months of the report.
Current Value	See Interference on EUROCONTROL SharePoint site of RFF.

Number of Unsatisfied Requests

Description	This KPI measures the quality of the European process to satisfy frequency requests.
Value	The number of frequency requests that have not been satisfied within 6 months of the request.
Current Value	

Average Time to Satisfy a Request

Description	This KPI reports the average time required to satisfy a frequency request (plus the minimum and maximum number of days required).
Value	This KPI measures the average of the time difference between the time a BP request is filed and the time when a new frequency assignment is available to satisfy the request.
Current Value	**48 days (min 30, max 64)**

Number of Unsatisfactory Shift Proposals

Description	This KPI measures the quality of the BP process.
Value	The number of shift proposals that are not processed correctly (i.e., in accordance with the agreed RAFT procedures) during the previous 12 months.
Current Value	**0 Unsatisfactory Shift Proposals**

3.1.3 NewPENS

NewPENS is an European international IP network in operation since 2008, supporting NM, EAD and ANSP communication needs, with a vision for extension to other stakeholders in the future (airports, industry, Airspace Users and etc.). At the time of writing, there are 43 signatories to the contract, the latest one in red in the table (ENNA) (**Figure 9**).

	NewPENS Users	Country		NewPENS Users	Country		NewPENS Users	Country
1	EUROCONTROL (NM - MUAC)		19	ENNA	Algeria (to be connected)	37	Ports of Jersey	Jersey
2	ALBCONTROL	Albania	20	FinTraffic ANS	Finland	38	RNLAF	The Netherlands
3	ANA	Luxemburg	21	IAA Ireland	Ireland	39	SKEYES	Belgium
4	ANS CR	Czech Republic	22	IAA Israel	Israel	40	SKYGUIDE	Switzerland
5	AUSTROCONTROL	Austria	23	ISAVIA	Iceland	41	SLOVENIACONTROL	Slovenia
6	AVINOR	Norway	24	LFV	Sweden	42	SMATSA	Serbia and Montenegro
7	AZANS	Azerbaijan	25	LPS SR	Slovakia	43	ROMATSA	Romania
8	BULATSA	Bulgaria	26	LGS	Latvia			
9	CROCONTROL	Croatia	27	LVNL	The Netherlands			
10	DCAC	Cyprus	28	M-NAV	Republic of North Macedonia			
11	DFS	Germany	29	MATS	Malta			
12	DHMI	Turkey	30	NATS	United Kingdom			
13	DSNA	France	31	NAV Canada	Canada			
14	EANS	Estonia	32	NAV Portugal	Portugal			
15	ENAIRE	Spain	33	NAVIAIR	Denmark			
16	HCAA	Greece	34	OACA	Tunisia			
17	HUNGAROCONTROL	Hungary	35	ORO NAVIGACIJA	Lithuania			
18	ENAV	Italy	36	PANSA	Poland			

Figure 9: The list of NewPENS users

The contractor in charge of deploying and maintaining this network on behalf of the signatories is British Telecom at the time of writing.

Performance monitoring as part of the contract includes a Service Level Agreement based on the reporting of a number of KPIs.

3.1.4 Voice over IP

VoIP in ATM performance requirements are defined in EUROCAE ED-136 (2009) [23] and ED-138 (2009) [24] documents. EUROCAE WG-67 is currently working on revisions of ED-136 (ED-136/1A (OSED) and ED-136/2A (SPR)) and ED-138 (ED-138A), planned for publication by end 2023. ED-136/2A will contain updated application performance requirements, while ED-138A will contain updated network performance requirements.

VOTER is a test suite software that developed by and on behalf of EUROCONTROL which provides conformance testing to EUROCAE Document ED-137 ‘Interoperability Standards for VoIP ATM components’ (“ED-137”) as well as conformance testing to ED-136 requirements by executing timing performance measurements between VoIP ATM components.

Commercial off the shelf tools to monitor standard VoIP SIP entities (RFC3261) are available on the market. A number of ATM industry manufacturers have also developed specific tools tailored to the use of VoIP in ATM.

The NM Operational Excellence Programme includes Work Stream 13.5 covering IP Services and Voice over IP. It is to be seen whether VoIP performance monitoring will be part of it in medium/long term.

3.1.5 Satellite Communications

Although available for many years in oceanic environment in support of FANS over ACARS (CPDLC/ADS-C), satellite communications are now close to being operational as part of the ICAO ATN under the ESA/Inmarsat IRIS programme.

An initial proposal for ATN SATCOM performance monitoring was thus presented at the Data Link Performance Monitoring Group #4 in April 2019. The document is available on the relevant EUROCONTROL OneSkyTeams but no further work has however taken place in DPMG.

The end-to-end datalink performance is monitored by ANSPs independently of the link being used (SATCOM, VDL2) by analysing the ground end system logs, reports from communications service providers etc.

Performance monitoring within SATCOM boundaries is based on system-specific provisions and tools. An overview of available information at the time of writing is given below for ACARS and ATN for both major constellations, Inmarsat and Iridium.

3.1.5.1 ACARS

A significant amount of documentation is available on ACARS/FANS 1/A Satcom over Inmarsat and Iridium monitoring. A summary and some references are provided here.

The ICAO North Atlantic System Planning Group (NAT SPG) maintains the SPG handbook where monitoring activities are described (http://www.icao.int/EURNAT/). Regular meetings of the SPG 'NAT TIG' (North Atlantic Technical Interoperability Group) address performance results of SATCOMs for FANS 1/A for both constellations for the Atlantic oceanic ANSPs. Data link performance reports are provided for in the common template format agreed by the NAT TIG in line with the ICAO Document 9869, PBCS Manual, as a means to assess the actual surveillance performance (ASP) against the RSP180 requirements and the actual communication performance (ACP) against the RCP 240 specification. An example report can be found here[29].

Inmarsat

The FAA Performance-based Operations Aviation Rulemaking Committee (PARC) also contributes to this performance monitoring and a detailed report for Inmarsat SwiftBroadband FANS1/A performance is available under[30].

An important point that can be found in that PARC report, section 7.1, is on the apportionment of the performance to the various technical elements in the end-to-end communication chain.

Satcom Data Unit (SDU) timestamping has been implemented in the terminals under evaluation and this enables new, previously unavailable, analysis of message delay 'on aircraft' to be conducted. This significantly enhances the aviation community's ability to analyse on-aircraft delay prior to the SDU.

The Inmarsat RSTP data provides timestamp information for segments A, D1 and D2. The addition of the SDU Timestamp (number 6 in the figure) allows for the first time the on-aircraft message delay to be accurately logged.

[29] NAT Data Link Performance and Equipage Report 2019 (Part A)

[30] 180703 PARC FANS 1/A over SwiftBroadband Report Recommendations (faa.gov)

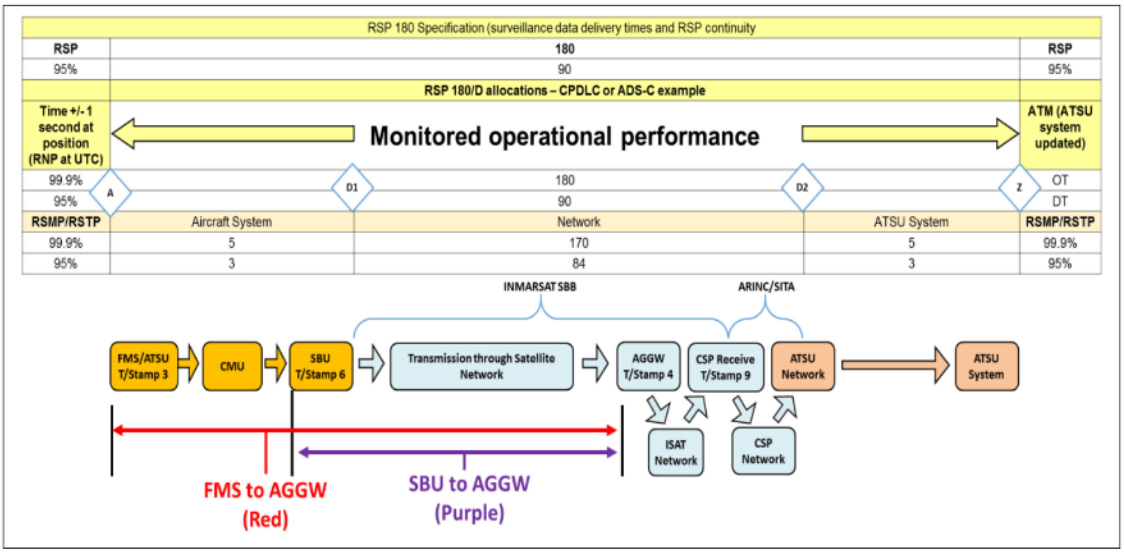


Figure 10: SATCOM Operational Performance Monitoring

Note.- ACARS Airborne Gateway AAGW

Note.- the figure from the PARC report relates to RSP but the same time stamping applies to RCP.

Iridium

Beyond the considerations above and from information presented at the EUROCONTROL FCI-Task Force#17 in March 2022, Iridium has developed a comprehensive quality monitoring and control process for Iridium Certus AMS(R)S services.

System Level:

- L-Band message headers (outside security wrapper) that contain:
  - Confirmation of message receipt/delivery
  - Time stamps of FANS message management in the Satellite Data Unit
  - GPS position
  - Aircraft ICAO address
- All data is collected for each AMS(R)S data exchange where Iridium can validate the successful transaction outside of ACARS protocol stack confirmations.
- For voice services, a transaction log is generated and sent to the Iridium ground servers for data monitoring

Ground Controls:

- Monitoring/Support 24/7 for, among others:
- Real-time monitoring tools and alarms management
- Data collection and reporting of AMS(R)S performance

Iridium is implementing data collection tools in support of analysis and continuous monitoring and historical records.

Data Collection:

- Decoding the ACARS data format to capture core content of ADS-C and CPDLC RCP/RSP technical performance
- Data import of other Iridium information of timing points and ground handling of the messages for a complete picture of on-going performance
- Ability to report on macro and micro level of aviation aircraft performance, area of operation, service level, etc.
- Technical support of any issues identified with operating aircraft in support of PBCS.

Results of performance measurements against RCP130/RSP160 requirements have been presented at the above meetings at EUROCONTROL, FAA and ICAO levels.

3.1.5.2 ICAO ATN

More details are arguably to be discussed at DPMG as this aspect develops but initial available information is summarized below.

Iridium

In this case, Iridium has plans to provide ATN/OSI-IPS connectivity in the future but details are not available at the time of writing. It is of course anticipated that a similar set-up to Inmarsat's below is to be provided.

Inmarsat

The ESA Iris programme features support of satellite communications over ATN/OSI in a multilink scenario with VDL2, with initial availability from 2023.

The Quality-of-Service (QoS) monitoring used for flight tests in these conditions is discussed in PJ38 deliverables.

SESAR PJ.14-W2 solution 107 addresses the next step over ATN/IPS in a multilink scenario with additional data links like LDACS etc. The solution's approach to Quality-of-Service Monitoring is documented in another SESAR deliverable from Solution 107 (D6.1.110 - PJ14-W2-107 "TRL 6 on-going" Final TS/IRS - Future Satellite Communication Link).

3.2 NAV performance monitoring

3.2.1 Ground-based navigation systems monitoring

In the ICAO PBN Manual [8] there are distinguished two types of Navigation Service Monitoring, where the first is related to Conventional Navigation, but taking into account the Performance-based Navigation Implementing Rule (PBN IR) [25], it will be used only for exceptional cases and as reversion scenario mainly. The second type is called Navigation Service Monitoring for RNAV and RNP applications, which are the basis of PBN concept. In comparison to previous type where the service provision depends on signal-in-space availability produced by a single station, for RNAV and RNP applications the Navigation Services provision are based on the simultaneous use of signals from multiple sources, either ground based or space-based, and the loss of an individual signal, or even of several ones, does not necessarily cause the loss of the navigation service.

In order to ensure Navigation service availability provided by ground-based NavAids, the monitoring service needs to be provided continuously, and consists mainly of assessing the operational status of any "critical" station (ICAO PBN Manual Volume II Part A Chapter 4.3.2).

In addition, there are commissioning and periodic service assessment. In general, there are two ways for these service assessments, such as ground analysis and flight tests. ICAO Doc 8071 [26] gives an overview of the assessment and flight inspection of DME that supports PBN RNAV applications. In case of GNSS and its support to RNP and RNAV applications, the monitoring of navigation service provided by space-based sources of signal, is addressed in Annex 10 [13] and Annex 11 [27].

The first part will be devoted to Ground-based navigation systems monitoring service provision. DME/DME fully supports PBN operations based on the RNAV 1, RNAV 2 and RNAV 5 navigation specifications. Consequently, DME/DME (for equipped aircraft) is the most suitable current terrestrial PBN capability. DME/DME provides a fully redundant capability to GNSS for RNAV applications, and a suitable reversionary capability for RNP applications requiring an accuracy performance of ±1 NM (95 per cent) laterally, where supported by an adequate DME infrastructure. In this case NavAids infrastructure should be validated by modelling, and the anticipated performance should be adequately assessed and verified by flight inspection. The assessments should consider the aircraft capability described in this specification. For example, a DME signal can only be used by the aircraft within the Designated Operational Coverage (DOC) as identified by the responsible ANSP, below 40 degrees above the horizon (as viewed from the facility) and if the DME/DME include angle is between 30 degrees and 150 degrees. The DME infrastructure assessment is simplified when using a screening tool which accurately matches ground infrastructure and aircraft performance, as well as an accurate representation of the terrain. Guidance material concerning this assessment can be found in PANS-OPS (Doc 8168, Volume II) [28] and the Manual on Testing of Radio Navigation Aids (Doc 8071) [26]. The individual components of the NavAid infrastructure must meet the performance requirements detailed in Annex 10 — Aeronautical Telecommunications [13].

Appropriate tools should be used to assess DME infrastructure. While the assessment could be conducted using manual analysis and flight inspection, the use of a software tool is recommended in order to make the assessment more efficient [29]. Such a tool could but does not have to be integrated with procedure design tools. In general, RNAV assessment tools should include a 3D terrain model with sufficient resolution and accuracy to allow predicting the line-of-sight visibility of NavAids along a procedure service volume, including an analysis of their respective subtended angles and a variety of other geometric constraints. Note that the accuracy of the terrain model in the near field of the DME antenna can have a significant impact on the accuracy of the line-of-sight prediction.

One of the software tools currently available is called DEMETER (Distance Measuring Equipment Tracer). This is a software tool that supports the implementation of PBN, the optimization and rationalization of ground-based navigation infrastructure [30]. The tool enables simplified collaboration between airspace planners, procedure designers, NavAids engineers and flight inspectors for establishing DME/DME positioning as a continuous ground-based back-up solution to the GNSS.

DEMETER is designed to assess the space performance of DME/DME signal in En-route and TMA airspaces. It can also be used to determine the ground infrastructure needed to support Area Navigation applications such as RNAV1, P-RNAV in these phases of flight. This is done in accordance with EUROCONTROL's guidelines on P-RNAV infrastructure assessment as developed in cooperation with the ICAO NSP and endorsed by the PBN Study Group [30]. The software tool also supports the assessment of VOR/DME coverage and redundancy in support of RNAV 5 applications.

When using DEMETER, the analysis of the coverage and performance of the ground-based NavAids will include as a minimum the following DEMETER assessments with respect to Article 7(3)g of NF IR [22]:

- Coverage and redundancy of DME/DME service for RNAV applications, at following flight altitudes:
    - 9 500 feet (FL95) – usual minimum En-route altitude for existing RNAV ATS routes
    - 15 000 feet (FL150 – lower limit for RNAV 5 implementation applicable on 03/12/2020
    - 31 000 feet (FL310) – lower limit for Free Routes Airspace implementation applicable on 01/01/2022
- Coverage and redundancy of VOR/DME service for RNAV applications at same flight altitudes
- Coverage and redundancy of VOR/DME service for conventional navigation (supporting contingency operations), at same flight altitudes

It should be noted that this tool does not provide the information which can be used directly for operational purposes or safety related decisions. The main objective of the service is to identify coverage gaps that could impact the network operations and support the process of planning the evolution of the network of ground-based NavAids in order to support PBN implementation.

In the SESAR Wave 2 framework Solution PJ14-W2-81 is carrying out R&D activities with the objective to develop an A-PNT system as a technical enabler to support PBN/RNP operations in case of a GNSS degradation or outage.

Within the solution there is a split between activities concerning evolutions of legacy technologies and new technologies such as:

- Multi-DME approach in FMS supporting RNP integrity requirements;
- Study of the enhancement of legacy DME system including DME system capacity assessment and frequency band optimization;
- Terrain aided navigation (including Inertial), vision-based navigation (additional airborne enabling capabilities to allow navigation in degraded conditions or in constrained environment);
- Assessment of modular integrity;
- Study of LDACS-NAV accuracy and integrity to complement the existing navigation infrastructure. LDACS is also a driver for navigation infrastructure rationalization.

In addition to Solution PJ14-W2-81 A-PNT systems, there is another technological solution called Mode N which has been developed outside SESAR framework by DFS. Mode N is a concept aimed at providing an A-PNT solution in a broadcast mode, using SSR Mode S signal formats and principles, with the possibility to emulate at the same time the DME/TACAN transponders. The system is intended to be ICAO PBN compatible and serve both civil and military aircraft.

3.2.2 Space-based navigation systems monitoring

The first part of this chapter will be devoted to Space-based navigation systems' monitoring service provision. The space segment of GNSS includes:

- Core satellite constellations (e.g. GPS, Galileo, Beidou, etc…)
- Satellite-based augmentation systems (SBAS, e.g., EGNOS, WAAS, GAGAN, etc…);
- Ground-based augmentation systems (GBAS)

3.2.2.1 GNSS

The objective of the Space-based navigation systems monitoring service is to provide GNSS information to support the implementation and operation of PBN and other CNS applications based on GNSS (e.g., ADS-B).

Today the impact of GNSS outages is limited as there are alternative means of navigation available in most situations. However, the dependency on GNSS is likely to increase as conventional NavAids are rationalised and more operations are based on PBN. With the introduction of next generation avionics capable to use GPS, Galileo and other GNSS elements on multiple frequencies (Dual Frequency, Multi-Constellation, DFMC), the goal is for GNSS to become more robust such that the failure of individual elements will have no, or only a very limited, impact on users. Because DFMC aviation applications are still under development, it is difficult to specify at this point which system performance issues will have a relevant impact on the network.

ICAO requirements for the status monitoring of navigation services and the provision of relevant information to ATS services are provided in Annex 10 Volume I [13], and Annex 11 [27]. Those requirements are covering the system itself, where the requirements to on-board equipment is described ICAO PBN Manual Volume II [8] per each navigation specification with references to geographically specific sensor guidelines (e.g., ETSO, FAA).

In Europe the Galileo Reference Centre (GRC)[31] has been established with the purpose of monitoring Galileo signals but they will also monitor other core constellations such as GPS, GLONASS and Beidou. The monitoring scope is to ensure that the user requirements regarding GNSS performance are fulfilled for different sectors, not just for aviation.

The main tasks of the GRC are:

- Performing independent monitoring and assessment of Galileo service provision;
- Assessing, when feasible, the compatibility and interoperability of Galileo vis-a-vis other GNSS;
- Providing service performance expertise to the EU Space Programme;

[31] The Galileo Reference Centre (GRC) is a cornerstone of the Galileo service provision. From Initial Services to full operational capability and beyond, it provides the European Union Agency for the Space Programme (EUSPA) with an independent system to evaluate the quality of the signals in space. In doing so, it helps ensure the delivery of high-quality navigation services so users can better rely on and benefit from Galileo. EUSPA is responsible for the management of the GRC, including its development and operations.

- Supporting investigations of service performance and service degradations;
- Providing an archiving service for performance data over the nominal operational lifetime of the system;
- Integrating data and products from EU Member States, Norway and Switzerland.

During the seventh meeting of the ICAO Navigation Systems Panel Joint Working Groups (JWGs/7) the European GNSS monitoring strategy [31] was presented where the key role was dedicated to GRC. This strategy aims to present the intended approach of GNSS performance monitoring and GNSS operational status monitoring in order to comply with ICAO SARPs requirements during aviation service lifetime.

Based on ICAO Annex 10, Volume I, 2.1.4.2 recommendation that a State that approves GNSS-based operations should monitor and record relevant GNSS data the ICAO GNSS manual defines the activities involving a GNSS monitoring function:

- GNSS Performance Assessment
- GNSS Operational Status Monitoring
- GNSS Data Recording
- GNSS Interference Monitoring

According to the ICAO GNSS manual, by approving GNSS-based operations a State or regional safety oversight organization (RSOO) accepts responsibility to ensure that such operations meet accepted safety standards. Because SARPs for core constellations and augmentation systems are developed to meet recognized target levels of safety, the monitoring of the compliance of GNSS services with the SARPs should be done by the State or delegated to an entity or other State.

GNSS Performance Assessment

This activity is described in ICAO GNSS manual [5] section 7.8.3 and planned to be carried out in order to verify that the system meets the requirements as defined in the Annex 10 SARPs. States need to perform GNSS performance monitoring or delegate it to ensure the usability of the GNSS services for the approved GNSS-based operations or to decide on the approval status of GNSS-based operations.

According to European GNSS monitoring strategy the European Union Agency for the Space Programme (EUSPA) will use GRC as the main technical enabler for this activity and EASA will perform supervisory role in confirmation approval that the performance of GNSS core satellite constellations compliant with ICAO standards. The list of key performance indicators will consist of GNSS navigation standards, such as ICAO Annex 10 SARPs [13], ICAO GNSS Manual [5], official performance specifications (e.g., service definition documents, interface control document), or other aviation standards produced at EUROCAE and/or RTCA.

GNSS Operational Status Monitoring

This activity is intended to provide timely information to technical staff and ATC services on the operational status of GNSS services and to notify of any degradation of the service, which is usually performed by the ATSPs.

States need to perform GNSS operational status monitoring or delegate it.

The EUROCONTROL Network Manager will monitor the performance of the infrastructure relevant for the execution of the Network functions. To this end, it will monitor the coverage of space-based navigation systems in support of the implementation and operation of navigation applications based on the information provided by GRC for the core constellation of GNSS and European Geostationary Navigation Overlay Service (EGNOS) provider (ESSP) for the EGNOS system. The EUSPA and NM will work on the development of notification mechanisms and procedures for GNSS performance degradations.

GNSS Data Recording

The activity is described in ICAO GNSS manual [8] section 7.8.4 and obliges to have historical data of GNSS parameters that can be used to support post-incident/accident investigations.

States need to perform or delegate GNSS data recording.

The EGNOS Service Provider (ESSP) is maintaining historical data on both GPS and EGNOS and are required to make it available to national authorities on request. The Galileo Service provider (EUSPA) through the GRC performs such task as was mentioned earlier in the section.

GNSS Interference Monitoring

To identify sources of radio frequency interference that may constitute a threat to GNSS, with a view to preventing or removing the threat. Experience with the use of GPS indicates that the occurrence of radio frequency interference (RFI) events has more impact on users than system events. Ongoing investigations are looking into technical solutions to support the identification of interference events (e.g., use of ADS-B data is a promising possibility) and how this information could be communicated to users and ATC.

Because the availability of GNSS services is becoming essential to maintain navigation services and traffic capacity in some airspace areas, e.g., in terminal areas with hight air traffic, ATM/ANS service providers are deploying local area solutions to detect and localize immediately interference sources to eliminate them in the shortest possible time. On the other hand, the absence of interference is checked before new GNSS-based operations are deployed or the use of a new GNSS service is allowed.

GNSS vulnerability can be split into ‘artificial’ RFI (e.g., intentional jamming) and ‘natural’ RFI (e.g., space weather event). The European Space Agency (ESA) launched a demonstration project in 2018 aiming to execute Space Weather and GNSS monitoring services for Air Navigation (SWAIR).

It is foreseen that the SWAIR service will enable:

- early warning, forecast and performance assessment of GNSS signal for the Air Navigation sector.
- increased confidence of airspace user in using EGNOS and GNSS signals.
- addressing the problem of intentional and unintentional interferences (e.g., jamming) and Space Weather events which can influence the performance and reliability of a variety of positioning systems.
- assessment of the sources of GNSS signal vulnerability in order to develop mitigation activities.

Current status of SWAIR project can be checked on the ESA Space Solutions website.[32]

Since 2019, ICAO is providing an operational space weather information service on a 24/7 basis. The service is provided by three global space weather centres operating on a rotation basis.

The providers of the global space weather centres are: The ACFJ Consortium (made up of Australia, Canada, France and Japan), the PECASUS Consortium (consisting of Austria, Belgium, Cyprus, Finland, Germany, Italy, Holland, Poland the United Kingdom) and the United States.

The ICAO space weather service provides space weather advisories which are disseminated through the aeronautical fixed network in cases of moderate or severe impacts of space weather phenomena of solar origin, with respect to high-frequency (HF) COM, Global Navigation Satellite System-based (GNSS) NAV and SUR, satellite communications and augmented radiation aboard aircraft

Advisories disseminated to civil aviation are text messages that specify potential impact and area of impact of several space weather phenomena. A detailed description is presented in Appendix F

Another source of space weather information will be the Galileo Service Centre (GSC) that will provide an Ionospheric Prediction Service focusing on its impact on GNSS navigation services.

3.2.2.2 NM GNSS monitoring

The EUROCONTROL NM GNSS monitoring service is composed of Receiver Autonomous Integrity Monitoring (RAIM) prediction service (AUGUR tool) and Support to the publication of GPS/RAIM NOTAM.

The EUROCONTROL AUGUR service is one of a number of means by which airspace users can comply with the EASA requirements to verify RAIM availability during pre-flight planning. This provides a web-based service (see interface layout on **Figure 11**) for RAIM availability prediction[33] and is also part of a NOTAM (notice to airmen) system for GPS based operations (see EAD catalogue of services). This service allows to perform such tasks as:

- track GPS satellites scheduled maintenance activities (NANUs) and assess impact on GPS's positioning availability and integrity for a flight.
- allow users to predict RAIM availability for such operations:
    - terminal areas where GPS-based RNAV 1 (including P-RNAV) or RNP 1 procedures are published.
    - final approaches at airports where RNP APCH procedures to LNAV and LNAV/VNAV minima are published.
- support GPS RAIM NOTAM services provided by national NOTAM offices (NOF) with the provision of NOTAM proposals.

[32] https://business.esa.int/projects/swair
[33] https://augur.eurocontrol.int

- generate NOTAM proposals containing GPS RAIM unavailability periods at destination airports where RNP APCH to LNAV and LNAV/VNAV minima will be flown.

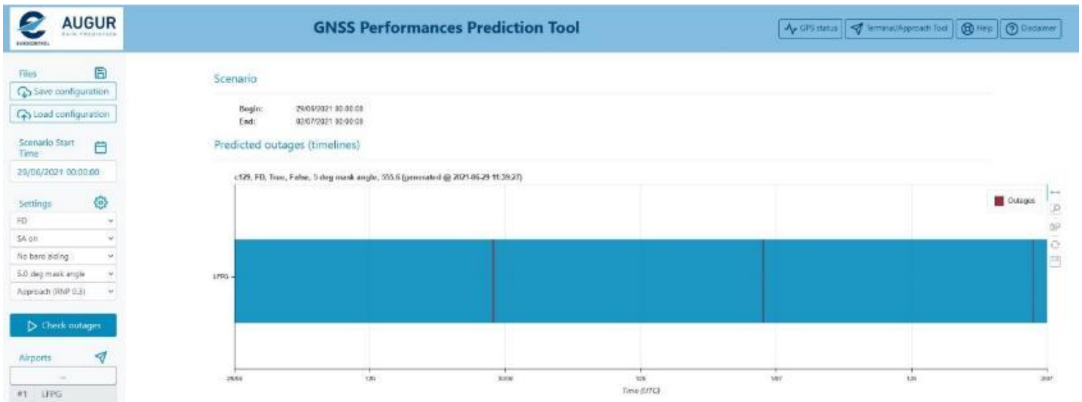


Figure 11: AUGUR HMI

3.2.2.3 SBAS

Satellite Based Augmentation Systems (SBAS) supports even the most stringent phases of the flight (i.e., approaches). As such SBAS provides full support to current RNAV/RNP operations.

In Europe, the SBAS system is called EGNOS (European Geostationary Navigation Overlay Service). It is owned by the EC and its operation is delegated to the EGNOS Service Provider, which in turn ensures the system performs nominally and the service is provided to users according to specific levels and current applicable standards. To do this the EGNOS Service Provider, continuously supervises the performance through appropriate and specific monitoring.

Currently EGNOS augments GPS using the L1 civilian signal for improving positioning, navigation and timing services over Europe (PNT). EGNOS will augment both GPS and Galileo in the future, using L1 and L5 frequencies, providing even further support to RNAV/RNP operations.

Safety of Life Service

Among the provided different EGNOS services, the Safety of Life service (SoL) is crucial to the aviation sector. Intended specifically to aviation, this service provides the following 3 levels:

- NPA, intended for Non-Precision Approach operations and other flight Operations covering other phases of flight than approaches (En-route, Terminal or other RNPs) by using only the lateral guidance
- APV-I, intended for Approaches with Vertical Guidance
- LPV200, for Category I precision approaches up to LPV minima as low as 200 ft

New services to fully support CAT I approaches are expected to be developed in future evolutions of EGNOS.

The detailed information and the commitments of the service above described are contained in the "Service Definition Document (SoL SDD)" [32].

On account of the SoL service levels enabling the PBN concept, for this reason the SDD also provides in its Annex D a crosscheck with the PBN Navigation Specifications:

- NPA supports all RNAV operations and RNP up to RNP0.3
- APV-I and LPV-200 supports RNP APCH with specific conditions depending on the LPV minima.

Since these correlations may be subject to change and evolve over time, the reader is advised to check directly on the latest version of the SDD document, to get the most up-to-date information [32].

Monitoring & Performance Indicators

In accordance with its service obligations, the ESSP has established the corresponding monitoring processes for the commitments detailed in the SDD:

- real-time monitoring
- together with monthly and yearly reporting monitoring.

The above information can be accessed through the EGNOS User Support website (EUSW) and more specifically, in the Aviation Dashboard of the Aviation Portal [33].

The SoL SDD provides the specific set of performance requirements that EGNOS offers for the different levels, in compliance with Annex 10 [13] wherein specific performance requirements for Accuracy, Integrity, Continuity and Availability are provided.

Detailed information, such as availability and continuity over the ECAC area, are presented through maps (**Figure 12**).

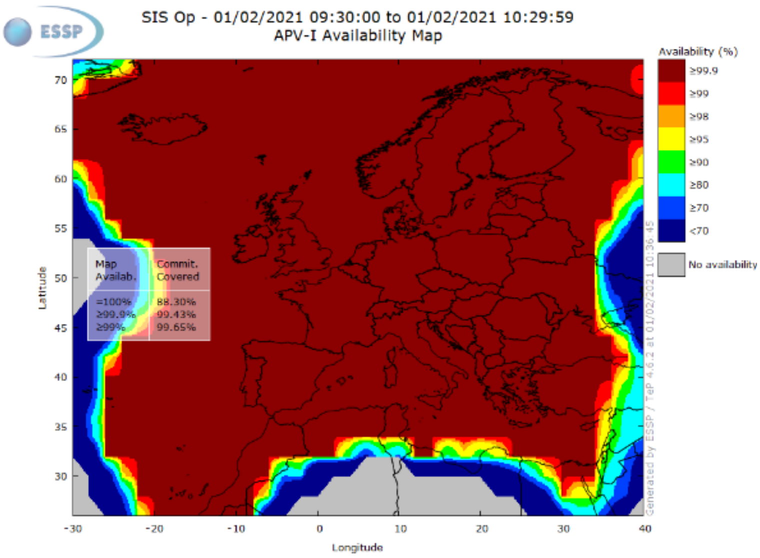


Figure 12: APV-I Availability Map on 01/02/2021

The full monitoring framework implemented by the ESSP also, provides the EUSW with both historical and forecast information with regards to system availability and expected outages.

To complete the process, specific interfaces are established for the organisation implementing an EGNOS based operation (principally ANSPs, other organisations if granted approval) through the EGNOS Working Agreement (EWA) which is signed by both parties. Within this framework, communications and the corresponding procedures are defined, mainly in terms of notifications and NOTAM proposals, and always in accordance with the requirements set in the SDD.

3.2.2.4 GBAS

GBAS applications are currently not defined as PBN navigation specifications but for the future Performance-based CNS framework it is important to cover all stages of flight. The GBAS ground subsystem or GLS (GBAS landing system) provides integrity data and corrections for the GNSS ranging signals over a digital VHF data broadcast to the aircraft subsystem. It is intended to support all types of approach, landing, guided take-off, departure and surface operations and may support En-route and terminal operations within the VHF data broadcast (VDB) transmitter's coverage area. Currently, as defined in Annex 10 [13] GBAS supports CAT I/II[34] precision approach and the provision of GBAS positioning service in the terminal area. A more detailed description of GBAS and the performance levels supported by GBAS are provided in Annex 10, Volume I, Attachment D, section 7.

The next step in GBAS evolution will be to extend the system to take advantage of multiple frequencies and multiple constellations. Use of multiple frequencies will allow more robust monitoring and detection of errors caused by ionospheric anomalies. Use of multiple constellations will enable higher availability of robust geometries in support of CAT II/III operations and mitigate common mode errors. In addition, CAT II/III operations based on GBAS will lead to more cost-efficient approach and landing operations on the airborne as well as on the ground side.

In the SESAR Wave 2 framework Solution PJ14-W2-79 conducts the R&D activity on GBAS GAST D and DFMC GBAS (GAST F) which can bring significant technical benefits by improving robustness and performance of the navigation solution. The use of dual frequencies will help to mitigate vulnerabilities in respect of ionospheric disturbance (important for high and lower latitude applications), whilst stabilizing the accuracy of the navigation solution over larger areas.

PEGASUS is among one of the available tools enabling the monitoring. The toolset analysis GNSS data collected from different SBAS and GBAS systems implementing the algorithms issued in the MOPS documents. This set of tools is designed to assist ANSPs and airspace users in evaluating the performances of satellite navigation signals in-space and their augmentation.

It assists air traffic service providers with analysis to aid site approval and to perform the verifications prerequisite for obtaining operational approval of a GBAS installation from their respective safety regulation authorities.

The modules are currently supporting single frequency, single GPS only functionality, CAT-I and CAT-II/III precision approaches but are intended to be extended to support multi-constellation, and multi-

[34] German national supervisory authority (BAF) certified an upgraded Honeywell GBAS ground station in March 2022 which supports CAT II approaches. Adequate GLS approach procedures at Frankfurt airport were published by July 2022.

frequency systems such as GALILEO. In the context of SESAR, the PEGASUS toolset is intensively used by the GBAS CAT-II/III precision approach work package partners.

3.3 SUR performance monitoring

3.3.1 Performance monitoring

The performance assessment of surveillance systems can be undertaken on the basis of one or more of the following approaches and in accordance with its associated priority:

- Opportunity traffic (priority 1),
- Flight trials (priority 2),
- Injected traffic scenarios based on real traffic taking into account user experience (priority 2),
- Proof offered through system design files or by system design assurance (priority 3),
- Test transponder (priority 3),
- Injected test target (priority 3).

The priorities have been allocated on the basis of the operational relevance of each approach. The approach based on opportunity traffic has priority 1 as it is fully representative of the operational traffic and of the operational environment. The last 3 approaches are rather partially representative of the operational traffic and operational environment and have the lowest priority.

The performance assessment of a surveillance system against the cooperative surveillance performance requirements shall be performed on the basis of cooperative and, if provided, combined target reports delivered by the system.

The performance assessment of a surveillance system against the non-cooperative surveillance performance requirements shall be performed on the basis of non-cooperative target reports delivered by the system except for requirements R2 & R3 for which combined target reports, if provided, shall also be taken into account.

It is to be noted that a statistical measurement uncertainty may be generated if a low number of data samples are used when performing the assessment of an individual aircraft. The application of an additional measurement margin or concession may be required to address such an eventuality.

The performance shall be verified for each of the system configurations that are explicitly identified and referenced in the surveillance system safety assessment.

The assessment shall be made periodically on each ground surveillance system and after each system or environment modification that may have an impact on its performance characteristics.

The periodicity of the conformity assessment is to be defined depending on the system design and the type of technology used.

When assessing the surveillance system performance on the basis of opportunity traffic, the system is only evaluated where there are flights. If airspace design modifications are to be implemented, a study will have to be undertaken to check that the system will still meet the required performance with the new traffic and specific flight trials may be needed.

The performance shall be assessed at the point where surveillance data is used to provide the service (e.g., 3 or 5 NM horizontal separation).

In practice, performance shall be measured at a point where surveillance data can be recorded in a digitised way, and which is as close as possible to where the service is delivered.

If a data processing stage is located in between that recording point and the point where the service is delivered, an analysis shall be performed to determine the contribution of this processing stage to the surveillance system end-to-end performance.

Should the provider of the 3/5 NM horizontal separation not be the provider of the surveillance data used to support the service, it is up to the separation service provider to derive the performance of the provided surveillance data, in order to meet the requirements described in this document and provided that he has chosen to apply the present specification.

It is recommended to investigate all performance issues and to apply corrective and/or risk reduction measures if necessary.

The surveillance performance must be measured using validated tools.

The Surveillance Analysis Support System for ATC Centres (SASS-C) is a software developed by EUROCONTROL. Validation is supported by the users in their different environments to predict and verify the performance of the surveillance infrastructure. The SASS-C VERIF tool verifies the compliance of the surveillance infrastructure with ESASSP.

In addition, it allows the support of specific analyses of issues and observations including air incident investigation, with a particular focus on surveillance aspects, and the support of the development and implementation of new ATM surveillance systems.

The verification tool has 5 steps for the performance analysis:

1. Acquiring and importing surveillance data at network level;
2. Reconstructing multi-sensor surveillance data (Mode S, SSR, PSR, ADS-B, WAM, etc.) to build a reference for each flight;
3. Comparing reported data to the reconstructed reference;
4. Aggregating and reporting comparisons against standard-defined thresholds;
5. Investigating, enabled via visual representation to the user.

SESAR solution PJ.14-W2-84e have been working on the harmonisation and new development of surveillance performance monitoring tools at sensor level. The scope of this solution covers:

1. Identification of baseline material driving performance requirements and assessment methods for surveillance sensors;
2. Implementation and verification of the “harmonized” tools (when possible);
3. Implementation Quasi Real-Time functionality and trend visualisation;
4. Validation of developed SPM Tools;
5. Derivation of the validated tools technical specification.

SESAR solution PJ.14-W2-84f aims as well for harmonisation and new development of surveillance performance monitoring tools but in this case applied to End-to-end Surveillance Chain following Performance-based Surveillance (PBS).

3.3.2 SUR performance anomaly monitoring

The performance of ATC in Europe relies on cooperative surveillance of aircraft. Certain surveillance anomalies affect the performance of the surveillance systems therefore reducing the efficiency and safety of the European Network.

The Commission Implementation Regulation (EU) No 2019/123 of 24 January 2019 (NF IR) [22] identifies components for monitoring and for common services. The surveillance interrogators and avionics, the ACAS and the Altimetry System Error monitoring are listed under Article 7(3)g:

" (iii) surveillance interrogators and avionics;

…

(v) airborne collision avoidance systems (ACAS);

(vi) airborne altimetry;"

The monitoring of surveillance interrogators (1030/1090 MHz) measures the use of the 1030/1090 MHz frequencies and detects the sources contributing to their overload. Based on these monitoring results, actions will be initiated to maintain the sustainability of these frequencies.

The monitoring of surveillance avionics and ACAS proactively detect anomalies in the surveillance system and ACAS systems by performing a systematic analysis of surveillance data. This process collects anomalies encountered by stakeholders, carries out investigations and provides solutions.

The monitoring of altimetry system error detects altimetry system errors. Pressure altitude correlated error due to the airborne system cannot be assessed by a ground surveillance system. It has to be assessed by specific systems like the Height Monitoring Unit (HMU) deployed in the frame of RVSM monitoring.

SI3AM service

The fulfilments of the surveillance monitoring is done through the EUROCONTROL SI3AM (Surveillance Interrogators and Avionics, ACAS & Altimetry Monitoring) service.

The main objective of SI3AM is to detect and report aircraft avionics or other surveillance systems with poor performance focusing on:

1. The good operation of surveillance avionics and ACAS;
2. The level of use of the 1030/1090 MHz surveillance frequencies generated by surveillance interrogators;
3. The good operation of aircraft altimetry systems.

The service is enabled by different central and distributed tools, which includes:

1. A tool that automatically detects surveillance avionics and ACAS interoperability anomalies;

2. A ticketing system to manage issues detected by the automatic tool or reported by ANSPs operational and technical teams;
3. A central database to store information collected for each aircraft monitored;
4. A network of 1030/1090 MHz receivers with a central application collecting and automatically analysing the information from the different receivers;
5. A 1030/1090 MHz RF model;
6. A system to measure altimetry error;
7. A RVSM approval database.

The SI3AM service is accessible by users through:

1. A ticketing system to report issues detected with surveillance interrogators, avionics, and ACAS;
2. An aircraft database dashboard providing lists of aircraft for different anomalies and capabilities;
3. A central Web application than gives access to the results of the 1030/1090 MHz measurements performed by the different receivers and provide alerts to registered users;
4. The reception of 1030/1090 MHz alert messages.

Monitoring of surveillance interrogators

The European monitoring of surveillance interrogators (1030/1090 MHz spectrum band) is performed through the European Monitoring of Interrogators and Transponders (EMIT) tool.

Several monitoring receivers have been installed across Europe, allowing a unique real-time picture of the situation of interrogations and aircraft transponder messages. The EMIT tool is able to produce immediate and programmed alert reports to perform its monitoring functions.

The **Figure 13** shows an example of the number of transponders messages per second detected by the EMIT tool.

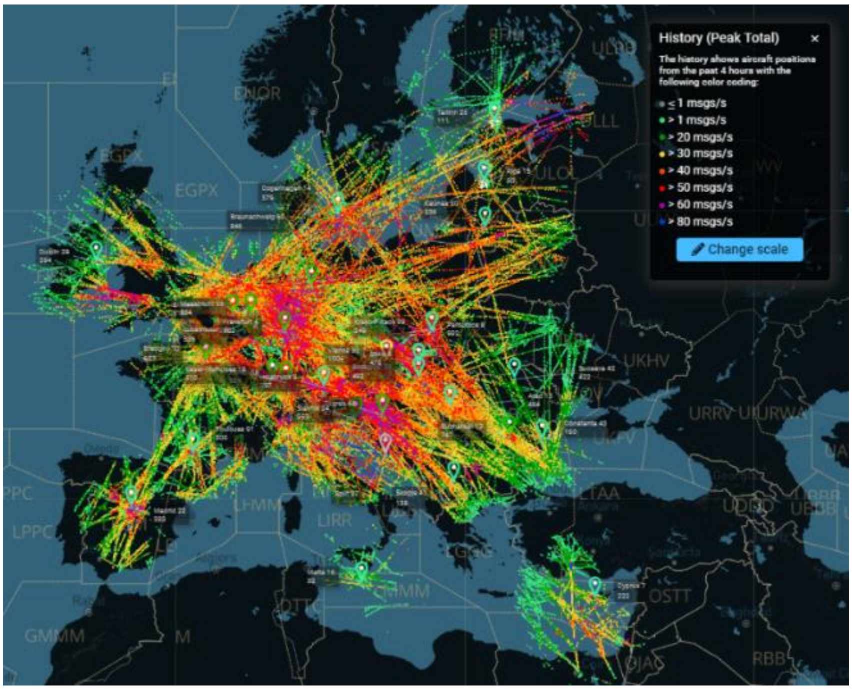


Figure 13: EMIT - Number of Mode S replies

The **Figure 14** shows an example of the EMIT tool detecting an aircraft exhibiting a performance exceeding the ICAO minimum reply rate capability.

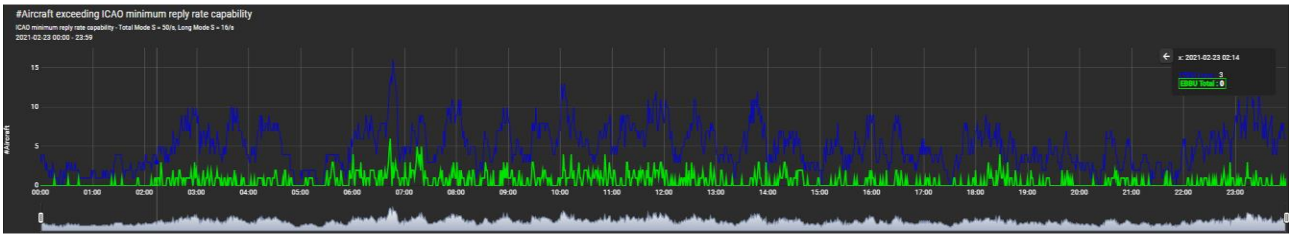


Figure 14: EMIT - 1090 MHz daily activity

Monitoring of surveillance avionics and ACAS

The monitoring of surveillance avionics and ACAS is performed through distributed (i.e., installed in ANSPs facilities) and centralized monitoring tools/databases.

This monitoring activity performs automatic analysis of the surveillance avionics and ACAS performance, including anomalies identification.

The **Figure 15** shows an example of monitored aircraft capabilities in the SUR avionics centralized database.

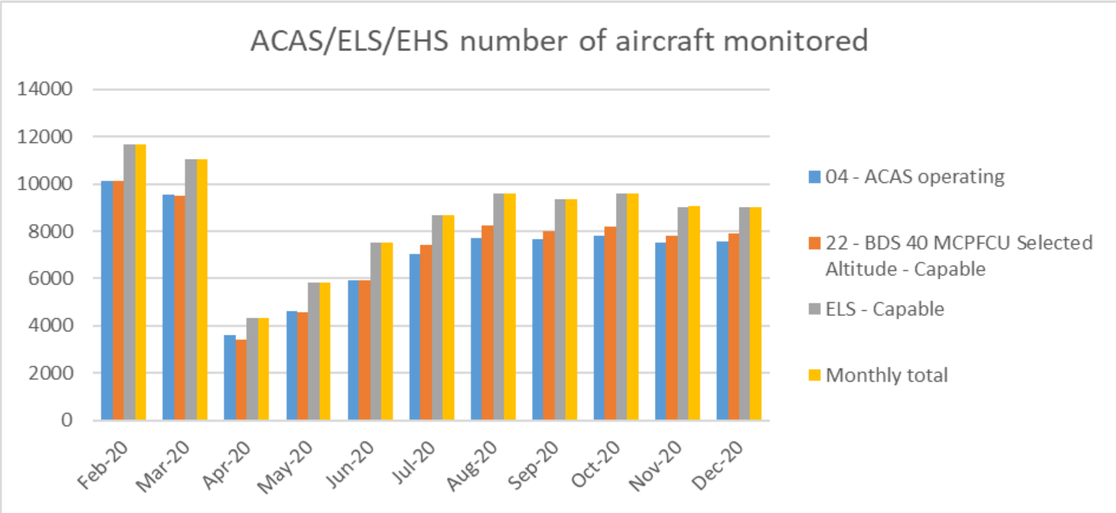


Figure 15: Number of monitored Mode S aircraft with FPL

The **Figure 16** shows an example of ADS-B equipped evolution in the ADS-B monitoring tool.

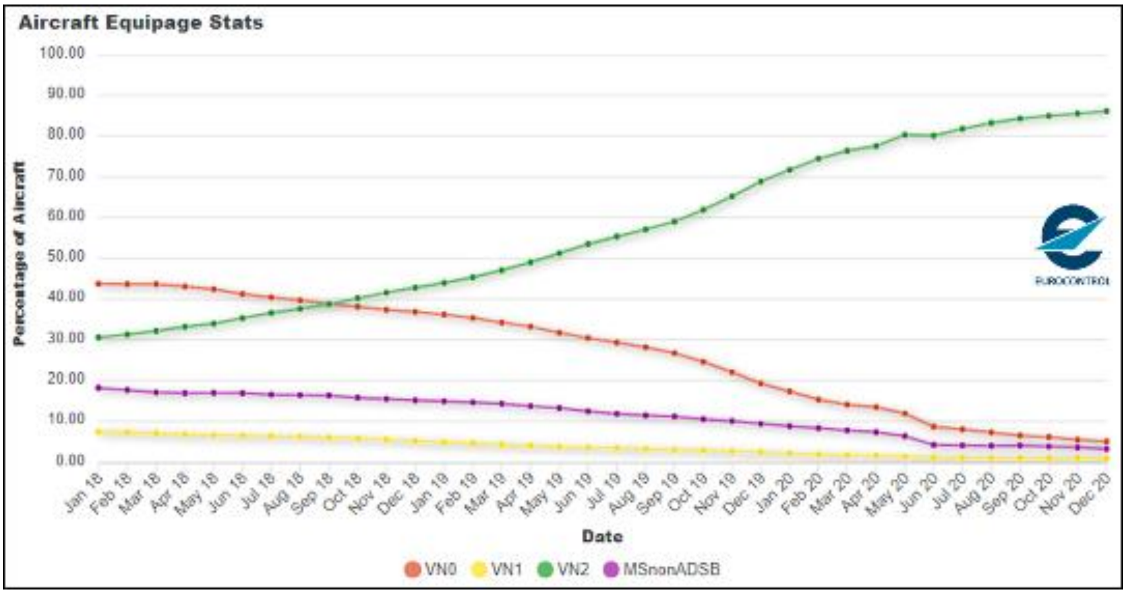


Figure 16: Percentage of aircraft with ADS-B v2 equipage

The **Figure 17** shows an example of the ticketing evolution for the surveillance anomalies database.

Co-funded by the European Union

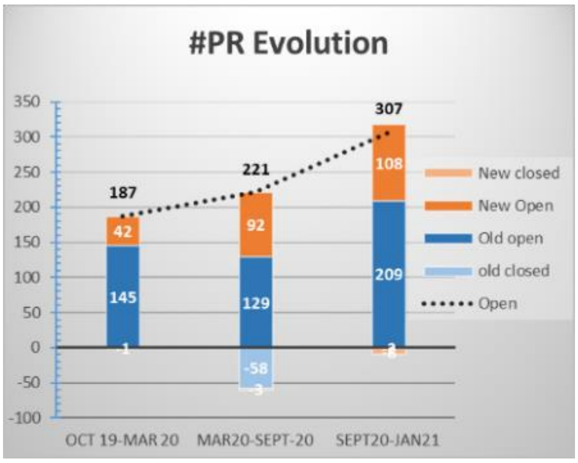


Figure 17: Evolution of the number of open surveillance tickets

Monitoring of airborne altimetry

The monitoring of altimetry system errors is performed on behalf of participating States in accordance with the requirements detailed in ICAO Annex 11 [27], ICAO Doc 9574 [34] and the Guidance provided in ICAO Doc 9937 [35].

This monitoring activity detects aircraft with poor altimetry performance and reports them to States and other RMAs. Once a year it verifies that the target level of safety is maintained in Europe. This service is not directly used by ANSPs.

The **Figure 18** shows an example of evolution of monitored aircraft with altimetry system errors.

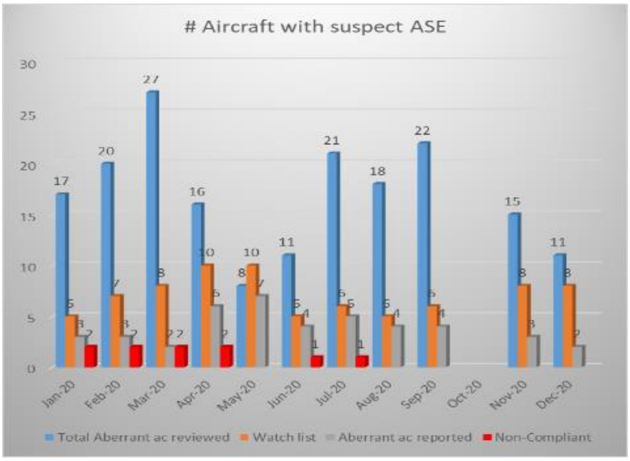


Figure 18: Number of aircraft with ASE checked during scrutiny review

3.4 CNS Security

CNS security and cybersecurity are not stand-alone attributes of any system, because of their interdependencies it is difficult to separate them. Proactive security management at national and international levels is leading to a comprehensive holistic approach to ATM/CNS 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 actors 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.

Threat information can come from a wide variety of sources, for example Information Sharing and Analysis Centres (ISACs), Computer Emergency Response Teams (CERTs), EUROCONTROL voluntary ATM incident reporting (EVAIR), 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.

Security risk is a combination of the impact of a successful attack and the likelihood that the impact will be achieved. The Risk matrix table that can be used for Risk assessment is presented in Table 24. 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. Regulation (EU) 2017/373 [3]).

	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 24 Risk matrix model used in SESAR

There are several ATM-specific controls which are designed to make the CNS system robust and to 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.

The CNS specific 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. Dual Frequency Multi Constellation GNSS);
- duplicate/back-up systems (e.g. Minimum Operational Network);
- the monitoring of signal-in-space performance (e.g. RAIM in NAV and EMIT in SUR);

- the obligation to implement a Security Management System (SeMS), including the need for a security risk assessment (SRA) which is updated on a regular basis (Regulation (EU) 2017/373 [3]);
- standard operating procedures (SOPs) in the event of CNS failure.

More infromation on CNS Security can be found in Appendix D of SESAR deliverable D2.2.200 - PJ14-W2-76 CNS Evolution Roadmap and Strategy Version 5 (2022).

4 Performance-Based CNS in a SESAR context

4.1 Overview of SESAR 2020 Wave 2 PJ14 CNS solutions

4.1.1 CNS roadmap

In the European ATM Master Plan [36] the CNS Roadmap was published with highlighted systems that give a view on the future Performance-based CNS infrastructure **Figure 19** . The time frame has been split into approximately 5-year blocks: present to 2025; 2025-2030; 2030-2035; 2035 and beyond 2035. These time references are playing an indicative role and do not intend to be an 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 is limited to the Safety-Of-Life applications, so some non-Safety-Of-Life applications are not indicated in the roadmap (e.g., open connectivity and applications based on 3G/4G/5G technologies).

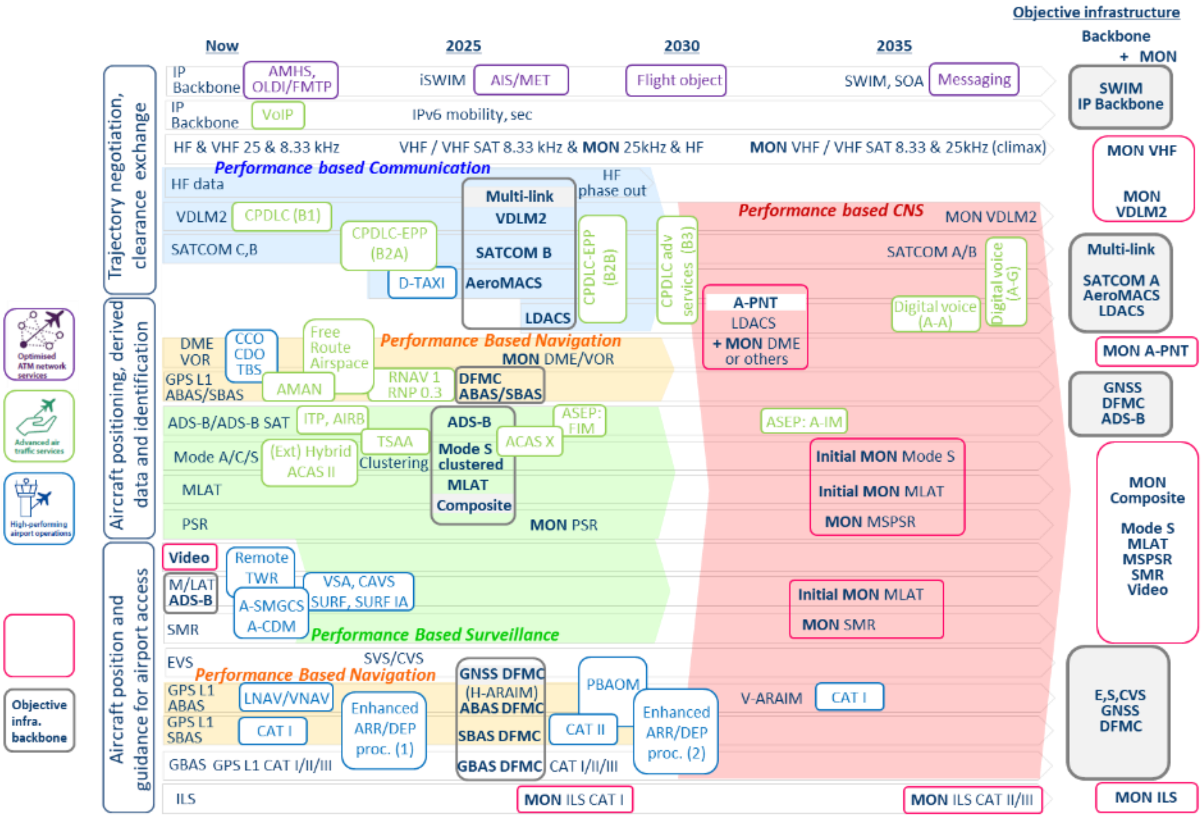


Figure 19: CNS Roadmap

From the roadmap it can be seen that the future CNS infrastructure will be based on an integrated CNS backbone comprising the Future Datalinks - Multilink, a Dual-Frequency Multi-Constellation (DFMC) Global Navigation Satellite System (GNSS) and ADS-B. This integrated backbone will be complemented by a minimum operational network (MON), composed of legacy ground infrastructure (e.g., VOR, DME, ILS, PSR, Mode A/C/S Radars, HF and VHF voice, VDLM2) systems rationalised to provide efficient support and operate as a backup for the integrated backbone.

In order to achieve the target Performance-based CNS infrastructure identified in **Figure 19** CNS roadmap, industrial research as well as demonstration of fit for purpose within the integrated CNS services will be required to foreseen and available technologies (e.g., SATCOM, AeroMACS, LDACS, etc.). Currently, this industrial research is carried out in SESAR 2020 and **Figure 20** shows the Technology Readiness Level (TRL) of those technologies. The main difference in comparison to the CNS roadmap is that in SESAR 2020 the development of ATM applications using commercially available services (e.g., 5G, open SATCOM) are also considered in order to contribute to a Hyper-Connected ATM system.

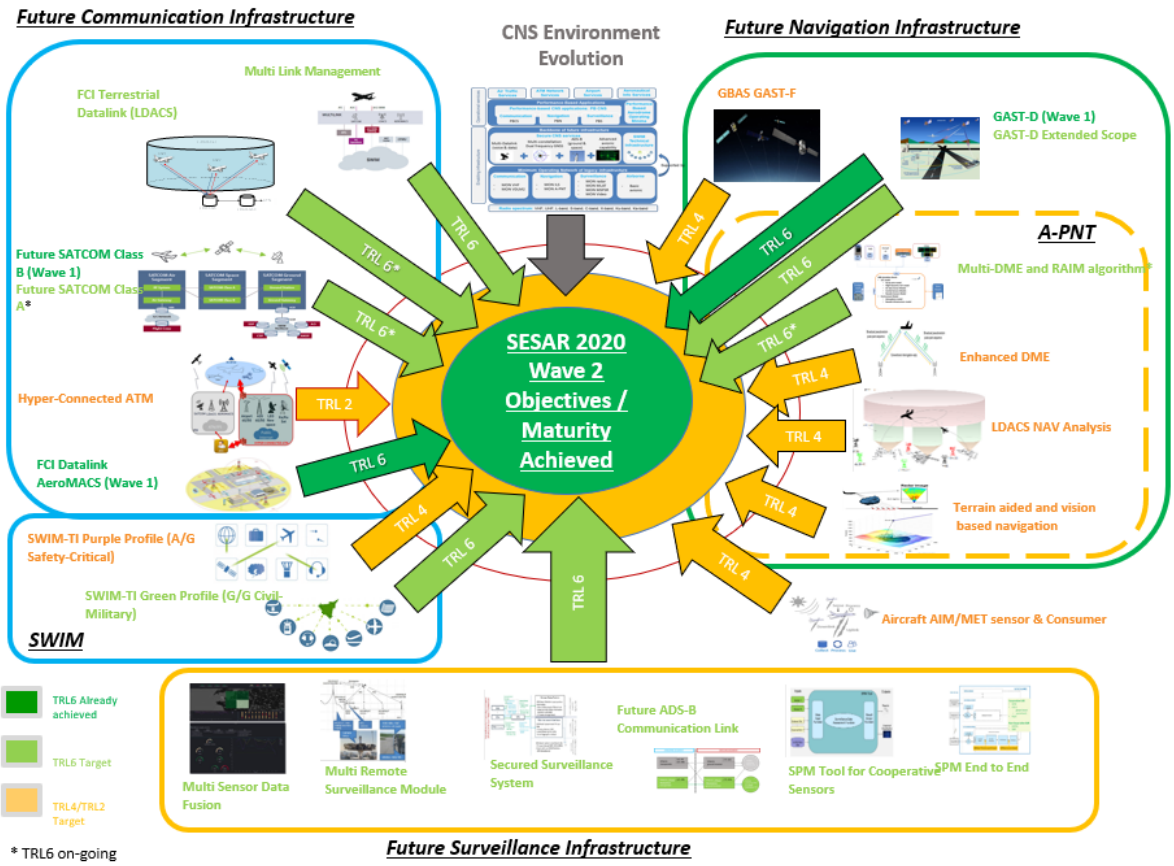


Figure 20: SESAR 2020 Wave 2 R&D activities

Acronyms:
ADS-B - Automatic Dependent Surveillance - Broadcast
AeroMACS - Aeronautical Mobile Airport Communication System
AIM - Aeronautical Information Management
DME - Distance Measuring Equipment
FCI - Future Communication Infrastructure
GAST D - GBAS Approach Service Type D (permits to support operations under CAT II/III conditions), based on GPS L1 corrections
GAST F - GBAS Approach Service Type F (permits to support operations under CAT II/III conditions), based on dual frequency (e.g., GPS L1/L5 and/or Galileo E1/E5a).

GBAS - Ground-Based Augmentation System
LDACS - L-band-Digital Aeronautical Communication System
MET - Meteorology
RAIM - Receiver Autonomous Integrity Monitoring
SATCOM - Satellite Communication
SPM - Surveillance Performance Monitoring
SWIM-TI - System-Wide Information Management Technical Infrastructure
TRL - Technology Readiness Level

4.1.2 Communication

PJ.14-W2-60 FCI Terrestrial Data Link (LDACS)

Objective: This Solution is developing and standardising the candidate future terrestrial datalink system L-band-digital aeronautical communication system (LDACS) covering both avionics and ground infrastructure. This solution will also address transversal topics and concepts, including the seamless transition from existing datalink technologies to LDACS and the provision of a ranging functionality in order to support Navigation services.

Performance specifications	Reference documents
COM: RCP130 SUR: RSP160	EUROCAE ED-228A/RTCA DO-350
Performance parameters	**SESAR references**
1) Round-Trip delay, 2) Latency (Transaction time), 3) Data Throughput (kbit/s), 4) Time stamps; Other parameters like **Availability** (required probability that an operational communication transaction can be initiated) or **Integrity** (required probability that an operational communication transaction is completed with no undetected errors per Flight Hour) apply to LDACS case, even if they might not be measured within this Technological Solution, as they require operational scenarios/counterparts not available.	D3.1.110 - PJ14-W2-60 TRL6 Initial TS/IRS LDACS A/G - Section 4.2 D3.1.300 - PJ14-W2-60 TRL6 TVALP - LDACS A/G - Sections 4.3, 5 D3.1.500 - PJ14-W2-60 TRL6 Interim TVALR- LDACS A/G D3.1.510 - PJ14-W2-60 TRL6 TVALR - LDACS A/G D3.1.120 - PJ14-W2-60 TRL6 Final TS/IRS LDACS A/G

Table 25 Performance specification and parameters for LDACS

PJ.14-W2-61 Hyper Connected ATM

Objective: This solution aims to develop a concept of operations, identify use cases, capture high level requirements, and assess options of architecture to integrate commercial public network services into the Future Communications Infrastructure (FCI).

Performance specifications	Reference documents
Current: - COM: RCP400, RCP240, RCP130, - SUR: RSP400, RSP180, RSP160 Future : The concept can aim at supporting future more stringent RCP/RSP, for instance RCP60 mentioned in Solution 77 concept of operation	ED-120/ED-122/ED-228A/Doc9869
Performance parameters	**SESAR references**
Those defined in ED-228A/DO-350A: 1) **RCP Transaction Time**, composed of: The Expiration Time (ET) i.e., the time within which 99.9% of operational transactions must be completed. The Nominal Time (TT95) i.e., the time within which 95% of operational transactions are completed. 2) **RSP Data Delivery Time,** composed of: The Overdue Delivery Time (OT) i.e., the maximum time for the successful delivery of surveillance data. The Nominal Delivery Time (DT95) i.e. the maximum nominal time within which 95 percent of surveillance data deliveries are required to be successfully delivered. 3) **Continuity**: the minimum proportion of relevant communications transactions to be completed within the specified time. 4) **Availability**: the required probability that an operational communication transaction can be initiated or that surveillance data can be provided. 5) **Integrity**: the required probability that an operational communication transaction is completed with no undetected errors.	D4.1.610 - PJ.14-W2-61 TRL2 Hyper Connected ATM concept definition Version 1 - Section 4.4 D4.1.620 - PJ.14-W2-61 TRL2 Hyper Connected ATM concept definition Version 2 - Section 4.4 D4.1.800 - PJ.14-W2-61 TRL2 Hyper Connected ATM – Transvers considerations - Section 3

Table 26 Performance specification and parameters for Hyper Connected ATM

PJ.14-W2-77 FCI Services

Objective: This solution will improve safety and security, enhancing the efficiency and flexibility of the overall datalink system through the provision of resilient multilink and mobile communications capabilities to the aircraft. It includes completion of specifications for the FCI network infrastructure, in order to support multilink capability and complete mobility between different datalink systems such as satellite communications (SatCom), LDACS, or AeroMACS. It also addresses civil-military interoperability requirements for ground/ground network interfaces, safety and security requirements.

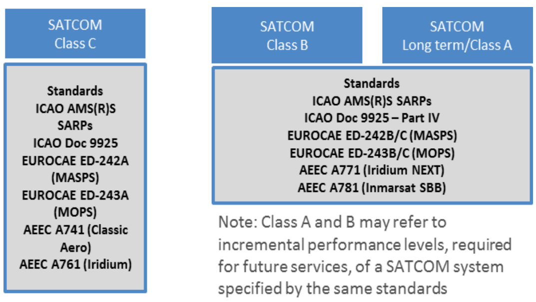
Performance specifications	Reference documents
Short-medium term - RCTP@95% (CPDLC) - RSTP@95% (ADS-C) Long term - RCTP requirement in RCP60 - RCTP requirement in RCP240 - RSP60	EUROCAE ED-228A
Performance parameters	**SESAR references**
1) **Latency** (Transaction time) 2) **Continuity** (probability that message is delivered within certain latency) 3) **Network availability** and **Availability** of use/provision 4) **Integrity** (rate of transactions without error)	D5.1.400 - PJ.14-W2-77 TRL6 TVALR – FCI services

Table 27 Performance specification and parameters for FCI services

The monitoring aspects are: normal network probing tools (e.g., iperf) and end-to-end roundtrip delay instrumented code in the CM/CPDLC/ADS-C Test Applications provided by AIRTEL-ATN, as a Solution 77 partner.

PJ.14-W2-107 SATCOM evolution towards IPS-based FCI

Objective: This Solution addresses the technical specification, development and validation of the future satellite data link technologies, also referred as "Long Term" or "Class A" SATCOM, for both the continental and remote/oceanic regions needed for supporting the future concepts beyond 2025. In terms of performance benefits, the solution will increase the datalink availability and capacity and will improve safety and security (resilience).

Performance specifications	Reference documents
For COM data link technologies, like SATCOM, the performance is driven by the RCP/RSP requirements defined in ICAO PBCS, ATN B1 SPR (ED-120) and ATS B2 SPR (ED-228) and reflected in SATCOM-specific standards (see next question).	
Performance parameters	**SESAR references**
The key RCP/RSP parameters are: 1) **Latency** (Transaction time); 2) **Continuity** (probability that message is delivered within certain latency);	D6.1.110 - PJ14-W2-107 "TRL 6 on-going" Initial TS/IRS - Future Satellite Communication Link - Section 4.2

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3) **Network availability** and **Availability** of use/provision; 4) **Integrity** (rate of transactions without error). Other important performance parameters are: Traffic Capacity (in bit/s); Link status reporting time; Geographical coverage	

Table 28 Performance specification and parameters for Future Satellite Communication Data Links

The monitoring aspects are based on the existing monitoring mechanisms which are outlined in applicable MASPS (ED-242) and detailed in relevant system definition documents (such as Inmarsat's System Definition Manual). Potential improvements are being studied under Solution 107 Task 2 and results of the study will be documented in deliverable D06.02.100 ("Future SATCOM QoS Monitoring for IPS"). The study covers both real-time and long-term monitoring capabilities.

The end-to-end datalink performance is monitored by ANSPs independently of the link being used (SATCOM, VDL2). This is done by analyzing the ground end system logs, reports from communications service providers etc. Performance monitoring within SATCOM boundaries is based on system-specific provisions and tools. For Inmarsat SB-S (a.k.a. Iris) the methods are described and used e.g., in Iris Flight Test Reports or in SESAR PJ.38 Demonstration Plan.

PJ.14-W2-100 SWIM TI Purple Profile for Air/Ground Safety-Critical Information Sharing

Objective: This Solution represents a technical enabler (only SWIM infrastructure layer) for the integration of the aircraft into the SWIM network giving it access to air/ground safety-critical SWIM services.

Performance specifications	Reference documents
Eurocae ED-228A and ED-175 (plus any further evolutions related to emerging SWIM services), any relevant OSED (R&D or standard) concerning candidate A/G SWIM service (including also U-space). Eurocae ED-228A and ED-175. Specifications about future needs should be under development in different contexts but current the view is not yet clear.	Eurocae ED-228A and ED-175
Performance parameters	**SESAR references**
	D7.2.110 - PJ.14-W2-100 TRL4 Initial TS/IRS – SWIM TI Purple Profile for Air/Ground Safety Critical Information Sharing - Appendix C and E.

Table 29 Performance specification and parameters for SWIM TI Purple Profile

PJ.14-W2-101 SWIM TI Green Profile for G/G Civil Military Information Sharing

Objective: This Solution aims at improving cost-efficiency and civil-military cooperation and coordination KPAs. The solution is based on additional specifications for security and performance on top of SWIM Yellow profile standard in order to maximize the civil-military interoperability for minimum cost.

Performance specifications	Reference documents
COM specifications applicable are based on EUROCONTROL Specification for SWIM Technical Infrastructure Yellow Profile Edition 1.1 dated 05/07/2020. There is no performance requirement applicable to the solution.	EUROCONTROL Specification for SWIM Technical Infrastructure Yellow Profile Edition 1.1.
Performance parameters	**SESAR references**
This Solution has three QoS assumptions about QoS at IP level (ground-ground communication => D8.1.110 – TRL6 TS/IRS Part I / section 6 / assumptions 0002 to 0004).	D8.1.110 - PJ.14-W2-101 TRL6 Initial TS/IRS – SWIM TI Green Profile for Ground/Ground Cvil-Military Information Sharing -

Table 30 Performance specification and parameters for SWIM TI Green Profile

PJ.14-W2-110 Aircraft as an AIM/MET sensor and consumer

Objective: One aspect of this Solution is the definition and design of Purple profile SWIM services for meteorological data and another aspect is examining novel and robust ways to support intelligent data pre-processing, smart filtering and integration, both on ground and on board the aircraft for the two-way exchange of meteorological data.

Performance specifications	Reference documents
Performance efficiency for MET and AIS services for strategic use: 1. In a strategic use, TE for MET and AIS services shall not exceed 500 seconds 2. In a strategic use, TT95 for MET and AIS services shall not exceed 120 seconds Performance efficiency for MET and AIS services for tactical use: 1. In a tactical use, TE for MET and AIS services shall not exceed 50 seconds 2. In a tactical use, TT95 for MET and AIS services shall not exceed 30 seconds	EUROCAE ED-89A, EUROCAE WG-76
Performance parameters	**SESAR references**
For the GNSS service - ICAO Annex 10	D11.1.115 - PJ.14-W2-110 – TRL4 Intermediate TS/IRS Aircraft as an AIM/MET sensor and consumer - Section 4.2.10

Table 31 Performance specification and parameters for SWIM meteorological data services

There will not be continuously monitoring, or real-time/post operation monitoring. These performance requirements will be validated during the EXE 4 (one time validation statistical outcome based on real operational data). The platform will be the Live EDR Viewer and information will be included in D11.1.210 - PJ.14-W2-110 – TRL4 TVALP Aircraft as an AIM/MET sensor and consumer.

SESAR VLD2 VOICE

Objective: The objective of VLD2 - VOICE is to demonstrate that with the use of Satellite based VHF systems providing Voice and Datalink ATS traffic in remote airspace can be handled as in a continental, and current separation can be reduced non-compromising safety.

Performance specifications	Reference documents
1) For the voice service, targeted performance requirements are specified in ED-136, ED-137 and ED-138. 2) For the data service, targeted performance requirements in terms of feasibility analysis are the ones required by ACARS-based FANS 1/A (ED-122), ATN/B1 (ED-120) and ATN/B2 applications (ED-228A). 3) For the surveillance service, ED-129B is the one applicable in order to generate the ASTERIX messages related to ADS-B service, while ED-102B enables the ADS-B concept itself. Both normative documents are in line with performance requirements listed in ESASSP.	Voice service: ED-136, ED-137B/C, ED-138; Data service: ED-120, ED-122, ED-228A; Surveillance: ED-102B, ED-129B
Performance parameters	**SESAR references**
	D8.1.110 - PJ.14-W2-101 TRL6 Initial TS/IRS – SWIM TI Green Profile for Ground/Ground Civil-Military Information Sharing

Table 32 Performance specification and parameters for VLD2 - VOICE

4.1.3 Navigation

PJ.14-W2-79a GBAS - GAST D Extended Scope

Objective: The objective is to advance GBAS (GAST-D) as a technical enabler and to take advantage of the operational benefits that GBAS can provide. The GAST-D will contribute to the enhancement of GBAS performance and robustness under ground threat conditions such as RFI and jamming occurrences, coverage of geographical areas that are subject to severe ionospheric conditions and complex airports.

Performance specifications	Reference documents
Performance requirements as specified in the ICAO Vol I Annex 10 standard are the main requirements.	ICAO Vol I Annex 10 ICAO Doc. 8071 Vol II
Performance parameters	**SESAR references**
See ICAO Vol I Annex 10 Appendix B sections 3.6 and 3.7 for the ionospheric and RFI scope, respectively. GBAS runway surface coverage at the airport is covered by ICAO Doc. 8071 Vol II Table II-4-2B	D9.1.110 - PJ.14-W2-79a-TRL6 Initial TS/IRS Dual Frequency / Multi Constellation DFMC GNSS/SBAS and GBAS -Gast D Extended scope - Section 2 Table 1 and Section 4.2

Table 33 Performance specification and parameters for GBAS - GAST D

Monitoring and detecting the ionosphere threat and the RFI threat in the GAST D Ground Station is the research area of solution 79a. Validation exercises defined in D9.1.200 TVALP and validation tools/results to be described D9.1.400 TVALR. On-board monitoring and detection are out-of-scope for solution 79a. Task T3.2 VDB Measurement Equipment addresses development of VDB measurement tools and procedures to validate the VHF field coverage in order to provide evidence to regulatory authorities that compliance is satisfied

See SESAR 1 GAST D solution documentation for compliance in nominal operational conditions. SESAR 2020 PJ14 solution 79a has further developed the monitor algorithms to detect adverse ionosphere/scintillation conditions. Real life ionosphere and scintillation data is collected at Tenerife Airport. Validation of performance will be documented in D9.1.400 TRL6 TVALR. Wave 1 D8.1.020 TRL4 TVALR provides intermediate results on this validation. In wave 1 and continuing in wave 2, RFI event data is being collected from many locations in Europe. This data is being used to characterize and model the RFI threat with the aim to detect the presence of this interference, as well as analyse the impact on the received GNSS signals. Validation results are to be documented in D9.1.400 TRL6 TVALR.

PJ.14-W2-79b DFMC GBAS - GAST F

Objective: The DFMC GBAS (GAST F) improves the robustness and performance of the navigation solution. The use of dual frequencies will help mitigate vulnerabilities in presence of ionospheric disturbances and stabilizes the accuracy of the navigation solution over larger areas.

Performance specifications	Reference documents
Signal-in-space performance; Service volume: General requirement of approach services; Service volume: Approach services supporting autolanding and guided take-off; Service volume: DF/MC GBAS positioning service	ICAO Vol I Annex 10 ICAO Doc. 8071 Vol II
Performance parameters	SESAR references
ICAO Annex 10, Vol I, SARPS, Amendment 92, applicable in November 2020. EUROCAE ED-114B MOPS for GBAS ground systems to support precision approach and landing (CAT III)	D9.2.110 - PJ14-W2-79b-TRL4 Initial TS/IRS - GAST-F - Section 4

Table 34 Performance specification and parameters for GBAS - GAST F

It is possible to monitor the compliance of the requirements post operation as it is described in D9.2.210 - PJ.14-W2-79b-TRL4 TVALP Dual Frequency / Multi Constellation DFMC GNSS/SBAS and GBAS - GAST F.

A post processing analysis can be done using EUROCONTROL Pegasus Tool, its functionality is explained in D9.2.210 - PJ.14-W2-79b-TRL4 TVALP Dual Frequency / Multi Constellation DFMC GNSS/SBAS and GBAS - GAST F.

PJ.14-W2-81a Mid-term Multi-DME and RAIM algorithm

Objective: The objective of solution is to further develop and consolidate the multi-DME+RAIM A-PNT system as an aircraft technical enabler to support PBN/RNP operations in terminal area in case of a GNSS degradation or outage.

Performance specifications	Reference documents
NAV specifications and performances are applicable to multi-DME	PBN Manual, RTCA DO-236(), DO-283(), DO-229() and EUROCAE ED-75()
Performance parameters	SESAR references
ICAO Annex 10, Vol I, SARPS, Amendment 92, applicable in November 2020. EUROCAE ED-114B MOPS for GBAS ground systems to support precision approach and landing (CAT III)	D10.2.100 - PJ14-W2-81a- On going TRL6 TS/IRS Alternative Position, Navigation and Timing- Multi-DME - Section 4.2.3

Table 35 Performance specification and parameters for Multi-DME

The monitoring criteria described in ICAO PBN Manual and DO283

PJ.14-W2-81b Long-term A-PNT - Enhanced DME

Objective: The Solution comprises enhanced distance measuring equipment (eDME) with capability to support more stringent A-PNT requirements. It aims to introduce, in addition to the actual range capability (interrogation-reply), a pseudo-ranging (one way ranging), and to ensure that the additional capability is fully backward compatible in order to support seamless deployment.

Performance specifications	Reference documents
The solution targets the support of PBN RNP1 and all those other operations where performances equivalent to RNP 0.3 are required	ICAO PBN Manual
Performance parameters	SESAR references
From sensors perspective it is compliant with ED54 (MOPS for DME Interrogator) and MOPS ED57 (MOPS DME ground transponder). Both standards are compliant with ICAO Annex X specifications. Such compliancy is stated in D10.4.110 - PJ.14-W2-81b- TRL4 Initial TS/IRS Alternative Position, Navigation and Timing - Enhanced DME - Section 4.2.1	D10.3.100 - PJ.14-W2-81b TRL2 FRD - Alternative Position, Navigation and Timing - Enhanced DME - Section 4.1.1

Table 36 Performance specification and parameters for Enhanced DME

In term of monitoring, for PBN some indications are present in Chapter 8 of ICAO doc 8071 Vol 1. The tools already used for validating PBN procedures based on DME/DME may be adopted. However, some modifications could be expected.

PJ.14-W2-81c Long-term A-PNT – LDACS

Objective: This Solution will further study LDACS as a complementary system for current navigation infrastructure, taking advantage of its development as a primary communication system. LDACS is one of most suitable candidates as it can be easily deployed with distance measuring equipment (DME) and is a driver for navigation infrastructure rationalisation, capable of meeting RNP0.3 requirements.

Performance specifications	Reference documents
The technology is compliant with currently existing Performance-based NAV concepts. This work focuses on accuracy and integrity, and this has to be further developed to fully account the PBN requirements: Deliverable ID: D10.5.110 - PJ.14-W2-81-c TRL4 Initial TS/IRS Alternative Position, Navigation and Timing – LDACS analysis - Section 3.1.1.6	1) ICAO Doc 9613 - Performance-based Navigation (PBN) Manual, Fourth Edition, 2013; 2) EUROCAE Minimum Operational Performance Specification for Distance Measurement Equipment (DME/N and DME/P) Ground Equipment, Edition 2, October 1992 (ED-57); 3) EUROCAE Minimum Aviation System Performance Standards: Required Navigation Performance For Area Navigation, November 2013 (ED-75C); 4) RTCA/DO-236C
Performance parameters	SESAR references
	D10.5.110 - PJ.14-W2-81-c TRL4 Initial TS/IRS Alternative Position, Navigation and Timing – LDACS analysis - Section 4.2

Table 37 Performance specification and parameters for LDACS-NAV

The description how to monitor on-board the compliance with performance requirements is written in the following deliverable:

1) Deliverable ID: D10.5.110 - PJ.14-W2-81-c TRL4 Initial TS/IRS Alternative Position, Navigation and Timing – LDACS analysis;

2) RTCA/DO-236C;

3) EUROCAE Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation, November 2013 (ED-75C);

4) ICAO Doc 9613 - Performance-based Navigation (PBN) Manual, Fourth Edition, 2013

This work focuses on accuracy and integrity, and this has to be further developed to fully account the PBN requirements. The tool for monitoring is described in the following deliverable:

1) Deliverable ID: D10.5.210 - PJ.14-W2-81c- TRL4 TVALP Alternative Position, Navigation and Timing – LDACS analysis;

2) Tool name: AT-One APNT performance simulation tool

PJ.14-W2-81d Long-term A-PNT - Terrain aided and vision-based navigation

Objective: This solution will support the identification and description of long-term selected candidates to provide on airborne side additional enabling capabilities which will allow flight in degraded conditions in a constrained environment, providing more efficient usage of airspace with focus on Terrain aided and vision-based navigation.

Performance specifications	Reference documents
The navigation system should comply with accuracy requirements derived from RNP0.3 requirements on total system error. Integrity, availability and continuity of the navigation system are not part of the project so far, because the project deals with technology at technology readiness level from TRL2 to TRL4. Focus of the project is to develop and mature the technology itself and achieve sufficient accuracy for intended use case. Integrity, availability and continuity of navigation system will be in scope of future successor projects dealing with maturity levels up to TRL6.	1) ICAO Doc 9613 - Performance-based Navigation (PBN) Manual, Fourth Edition, 2013; 2) ICAO Annex 10, Aeronautical communications, Volume I - Radio Navigation Aids, Seventh Edition, July 2018. 3) RTCA DO-245A Minimum Aviation System Performance Standards for the Local Area Augmentation Systems (LAAS)
Performance parameters	SESAR references
	D10.7.100 - PJ14-W2-81d- TRL4 Initial TS/IRS Alternative Position, Navigation and Timing – Terrain aided and vision-based navigation

Table 38 Performance specification and parameters for Terrain aided and vision based navigation

4.1.4 Surveillance

PJ.14-W2-84a SUR - Multi Sensor Data Fusion

Objective: This Solution aims to develop a performance-based data fusion based on an advanced monitoring of the tracker coherence. The objective is to ensure that the interfaces between the sensors and subsequent processing stages (e.g. the multi-sensor trackers) are correct and fit for purpose

Performance specifications	Reference documents
When integrating INCS data, the SDPS Tracking function shall perform in the expected performance boundaries regarding the following ESASSP requirements: 5N_N-R1; 5N_N-R2; 5N_N-R3; 5N_N-R4; 3N_N-R1; 3N_N-R2; 3N_N-R3; 3N_N-R4;	EUROCONTROL Specification for ATM Surveillance System Performance (volume 1), EUROCONTROL-SPEC-0147, rev01
Performance parameters	SESAR references
	D12.1.110 - PJ.14-W2-84a -TRL6 Initial TS/IRS - Multi Sensor Data fusion - Section 4.2.1: - REQ-14-84a-TS-FUSE.0010; - REQ-14-84a-TS-FUSE.1004

Table 39 Performance specification and parameters for SUR - Multi Sensor Data Fusion

The monitoring tool used is SPM SQOS TQOS tools. See description in:

1) D12.1.320 - PJ.14-W2-84a -TRL6 AN – EXE2 - Monitoring of the multi-sensor data fusion based on performance assessment;

2) D12.1.330 - PJ.14-W2-84a -TRL6 AN – EXE3 - Monitoring of multi-sensor data fusion based on sensor performance assessment;

3) D12.1.340 - PJ14-W2-84a -TRL6 AN – EXE4 - Supervision of multi-sensor data fusion based on surveillance integrity.

PJ.14-W2-84b SUR - Multi Remote Surveillance module

Objective: This Solution aims to provide a surveillance service to increase situational awareness for the multi remote tower controller in a cost-effective way. Also, it aims to enhance the video camera plot extraction used as a non-cooperative source for the tailored multi-remote tower surveillance layer, consisting of video and infrared cameras, multilateration (MLAT) and multi-sensor data fusion (MSDF).

Performance specifications	Reference documents
Performance requirements are oriented on ED-87c (overall and tracker), ED117 (for Mini-MLAT sub-sensor), ED-260 & ED-116 for camera as SUR-sub-sensor. Actual performance values differ. The current standards do not reflect the concept of SUR for small and regional airports. WG-41 has been approached for extension of standards. This is reflected in TORs of WG-41, Activities started.	ED117 (for Mini-MLAT sub-sensor), ED-260 & ED-116 ED-142B and ED-129B
Performance parameters	SESAR references
	D12.2.120 - PJ14-W2-84b -TRL6 Intermediate TS/IRS– Multi Remote Tower Surveillance (MRT-SUR) D12.2.400 - PJ14-W2-84b -TRL6 TVALR Multi Remote Tower Surveillance module (MRTSUR)

Table 40 Performance specification and parameters for Multi Remote Surveillance module

For monitoring description see TVALP descriptions for EXE#1 – EXE#3: D12.2.200 - PJ14-W2-84b -TRL6 TVALP- Multi Remote Tower Surveillance module (MRT-SUR). The monitoring aspect is presented in solution 84e for Mini-MLAT, proprietary tools for camera and tracker

PJ.14-W2-84c SUR - Secured Surveillance Systems (Single and Composite Systems)

Objective: This Solution is dedicated to the development of secured surveillance systems (focus on cooperative and cooperative dependent sensors) enabling the operational use of security functions. Its scope covers the sensor-based radio frequency related threat detection and validation capabilities, performance assessment and identification of interoperable detection forwarding mechanisms by a specific ASTERIX target validation message.

Performance specifications	Reference documents
Solution 84c TS/IRS (D12.3.110 - PJ.14-W2-84c-TRL6-Initial TS/IRS New use and evolution of Cooperative and Non-Cooperative Surveillance - Secured Surveillance Systems (Single and Composite Systems). Performance requirements are given therein The solution is new so that the way will be other way around: performances will be specified and validated by the solution and then forwarded to EUROCAE WG-51 for inclusion in ED-129D	ED-129D
Performance parameters	**SESAR references**
	D12.3.110 - PJ.14-W2-84c-TRL6- Initial TS/IRS New use and evolution of Cooperative and Non-Cooperative Surveillance - Secured Surveillance Systems (Single and Composite Systems) D12.3.400 - PJ.14-W2-84c-TRL6- TVALR Secured Surveillance Systems (Single and Composite Systems)

Table 41 Performance specification and parameters for Secured Surveillance Systems

The monitoring aspects are described in TVALP descriptions for EXE#1 D12.3.200 - PJ.14-W2-84c-TRL6-TVALP Secured Surveillance Systems (Single and Composite Systems).

Tool: THALES proprietary assessment tool to assess the performance of secured surveillance

PJ.14-W2-84d Phase Overlay for ADS-B

Objective: This Solution addresses the future ADS-B communications link, in particular Phase Overlay for Mode S and ADS-B datalink. Specifically, it aims to significantly improve the transmitted bit rate, increasing the data transmission from 112 to 448 bits (from 56 to 204 useful bits). The Solution will validate the waveform and performances required for the Phase Overlay transmitter and receiver.

Performance specifications	Reference documents
The technical specifications applicable to Solution 84d are extracted from ED-102B/ED-73F, more in detail from the sections defining the new communication link (Phase Overlay). This Solution is technological, not operational. Thus, it does not take into account PBS parameters, as the Solution’s objective is to validate the technology itself, not its operative applications, like surveillance service.	from ED-102B/ED-73F
Performance parameters	**SESAR references**
As this solution does not fall under an operational scope, and its objective is the development of a new	D12.4.110 - PJ.14-W2-84d-TRL6 - Initial TS/IRS New use and evolution of Cooperative and Non-

feature of the ADS-B technology, it has no additional performance parameters.	Cooperative Surveillance - Future ADS-B Communications Link

Table 42 Performance specification and parameters for Future ADS-B Communications Link

Solution 84e and 84f are developing these tools (Surveillance Performance Monitoring Tools or SPM Tools), although in this solution (84d) performance parameters are not measured.

PJ.14-W2-84e Surveillance Performance Monitoring Tool for Cooperative Sensors

Objective: This Solution aiming at enabling an improved performance monitoring of surveillance systems in line with the Performance-Based Surveillance (PBS) approach. Also, it focuses on the development of Surveillance Performance Monitoring Tools for cooperative sensors such as ADS-B, Wide Area Multilateration and airport Multilateration.

Performance specifications	Reference documents
All performance metrics as required in standards for WAM, ADS-B and airport MLAT (Probability of Update, Probability of Long gaps, Probability of Incorrect, Probability of Identification and False Identification, Maximum Update Delay, Horizontal Position Accuracy, Reported Covariance Assessment, False and Ghost Report/Tracks assessment, Latency)	for WAM ED142A Draft (based on GENSUR ED261 Draft), for ADS-B ED129B and draft C (both based on GENSUR ED261 Draft), for airport MLAT ED117A
Performance parameters	SESAR references
	D12.5.110 - PJ14-W2-84e-TRL6 Initial TS/IRS Surveillance Performance Monitoring Tool for Cooperative Sensors

Table 43 Performance specification and parameters for Performance Monitoring Tool for Cooperative Sensors

In the guidance section of the above mentioned standards there is usually a description of how to calculate the performance metrics. If not or not detailed enough, we put the computation in our TS-IRS. The monitoring checks that the calculated performance metrics are within the required thresholds as given in the standards and if not the case, it makes aware of it (e.g., by using specific color coding). The quasi-real time feature provides the visualization of the performance trend and provides means to identify degradation issues early.

PJ.14-W2-84f Surveillance Performance Monitoring – end-to-end

Objective: This Solution aims to improve performance monitoring of surveillance systems in line with the Performance-Based Surveillance (PBS) approach. It focuses on the development of Surveillance Performance Monitoring Tools for end-to-end surveillance chain. The objectives are to include tools specification aligned with existing and developing Surveillance Standards, quasi real-time assessment, development of tool prototypes and verification of these prototypes.

Performance specifications	Reference documents
Probability of Update (for horizontal position, pressure altitude and aircraft identity), Probability of Long Gaps, Probability of False Tracks, Forwarded Pressure Altitude Data Age, Data Accuracy (horizontal position, pressure altitude, aircraft identity, velocity, track angle and climb/descent rate), Density of False Target Reports.	SPM Tools for End-to-end Surveillance chain are specified and developed in line with ESASSP Ed 1.2
Performance parameters	SESAR references
The performance metrics to be measured, calculation methodology and the associated pass/fail thresholds are all given in the ESASSP (EUROCONTROL Specification for ATM Surveillance System Performance) Ed 1.2.	D12.6.110 - PJ.14-W2-84f- TRL4 Initial TS/IRS Surveillance Performance Monitoring – end-to-end

Table 44 Performance specification and parameters for Surveillance Performance Monitoring – end-to-end

There is detailed guidance in ESASSP Ed 1.2 for the measurement of performance metrics and associated thresholds for the type of operational environment (TMA or En-route).

5 Summary

This document provides a comprehensive description of existing Performance-based CNS landscape. A further step to improve Performance-based approach flexibility would be to express airspace support services and their Performance-based requirements in an alternative way, other than fixed to COM, NAV and SUR. These potential Performance-based requirements may be defined in terms of the level of interaction required with aircraft and the level of information that ATC would need from specific flight to maintain safe and efficient operation within future Trajectory-based Operations (TBO).

This section is summarising the main aspects of Performance-based approach for CNS. The approach requires a comprehensive number of performance-based specifications and requirements in order to meet operational needs while ensuring safety, security and cost-efficiency. It is important to make such developments in coherent manner across all the CNS domains. The current status of Performance-based CNS specifications was presented in Section 2.

Continuity, Availability, Integrity performance requirements are the same for CNS and positional Accuracy is a key parameter for NAV and by default is a requirement for SUR when we consider ADS-B (see Section 2). It is important to highlight that Accuracy parameter is strictly connected to Time Accuracy which is playing a key role for COM (datalinks), NAV (ranging function), and SUR (MLAT and data fusion). Performance parameters for Timing are described in Appendix C. CNS infrastructure monitoring described in Section 3 and presents the practical aspects like performance parameters or so-called metrics that are measured. The very first conclusion that is seen to the reader is the difference between performance requirements described in ICAO and EUROCAE standards (in Section 2) and parameters that are monitored (in Section 3), this confirms that there is a transition still ongoing from describing systems/technologies specifications to performance-based requirements or parameters.

Future Communication Infrastructure (FCI) Business Case is one of the good examples of applying a Performance-based framework to the Communication domain. In the Business Case 4 scenarios have been analysed with a strength on Cost-Benefit Analysis (CBA) but also considering operational aspects from point of Service Provider and Consumer. Leaving behind economical aspects, from the technical site it is important to note that those candidate technology LDACS, Off-the-Shelf, SATCOM and Multilink architecture in general are aimed to support ATC/AOC applications which means that the same data is planned to be transferred using different communication channels, which also make sense to developed a common set of communication performance parameters in order to prioritize those technologies use depending on the stage of flight and data criticality for safe operation. One of the recommendations proposed at FCI Business case workshop is to 'Invite EASA to encourage the enhancement of the DLS regulation with a performance-based approach to allow operation through new communication links.' The follow-up of this activity would be also to ensure a global interoperability and standardization at ICAO level.

Another example of making a benefit of applying Performance-based CNS approach is described in Appendix B of this document were Free Route Airspace (FRA) is considered as one of the Airspace Concepts. There are a few recommendations were drawn up based analysis Performance-based CNS applications within FRA. The following further steps were proposed:

- Establish a Required Data Performance framework as a part of Performance-based CNS approach, based on the needs of ATC tools to manage specific Airspace type.
- Integrate Security Performance Requirements into Performance-based CNS framework.
- Develop strong CNS governance functions in order to harmonise Performance-based approach implementation and maximise efficiency of deployment and interoperability aspects.
- Address flight and other ATM support data, in addition to CNS, in terms of Performance-based approach.
- Complete work to provide specifications within RCP/RSP frameworks necessary to adequately cover the needs of new Airspace Concepts and separation standards.
- Characterize each Airspace type with its Communication (Voice and Data), Navigation and Surveillance needs in terms of performance specifications (see example in Appendix B.2).

Future CNS solutions making use of emerging terrestrial data-link technologies and SATCOM which forming so-called Multilink (see Section 4.1.2 and **Figure 20**), as well as advanced Navigation and Surveillance, should enable a joint civil and military utilisation, reducing technical constraints and costs while maintaining appropriate levels of safety, security and environmental sustainability. The connectivity and access to CNS infrastructure also requires solutions ensuring security and appropriate levels of quality of service. At same time, the integration of CNS and spectrum consistency in terms of robustness, spectrum use, and interoperability is essential to define the future integrated CNS architecture and spectrum strategy (see 4). A service-driven approach, accommodating civil and military alike, is needed to describe how the CNS services are delivered for Communication, Navigation and Surveillance including cross-domain services (e.g., contingencies). Further military and civil interoperability is expected in terms of the common use of CNS, rationalising civil infrastructure and costs, taking into account the capacity of military legacy systems to evolve. The Civil-Military Performance-based CNS aspects are presented in Appendix A which highlights that the complex interdependencies between civil and military stakeholders need to be examined to enable appropriate performance measurements in a spirit of balanced consideration between commercial needs and security and defence requirements.

The Performance-based CNS approach by its nature gives the possibility to select the most appropriate equipment to perform a safe flight operation, but from the other side it could bring a wide range of potential CNS technologies that at some point will need to have an end-user equipment on-board of the aircraft and fit to the flight management system. The considerations about CNS airborne capabilities and requirements are described in Appendix E. The transition period requires a good planning as for getting the benefit the most fleet should be equipped with it. This is also opening the discussion related to the most sensitive resource for all CNS systems which is spectrum. There are two major paths for moving to performance-based CNS, the long-term path is to complete development and start deployment of new technology and the short term is to adapt and update currently installed on-board capabilities to be able to comply with ATM safety-of-life applications within aeronautical and non-aeronautical spectrum (currently, only the last one is only capable to provide a high-speed communication channel). In any case both ways would require a strong accent on cyber-security aspects and monitoring of a wider range of spectrum. The considerations about spectrum utilization within Performance-based CNS is described in Appendix D

SESAR 3 Bi-Annual Work Programme [37] considers one the key enablers shifting towards Performance-based CNS such as infrastructure as a service to facilitate the complete decoupling of CNS service provision from the physical location of the infrastructure, as outlined in the target architecture specified in the European ATM Master Plan. This is an initial but not exhaustive list of aspects that should be considered:

- enabling the deployment of a Performance-based CNS service offer;
- development of integrated, digital CNS solutions (e.g., LDACS, satellite-based CNS);
- data communication as the primary means of air–ground connectivity;
- solutions for Air-Air and Air–Ground connectivity;
- move from VHF voice to digital voice for controller–pilot communications;
- development of Internet of Things (IoT) for aviation (e.g., machine-to-machine communication for real-time and automatic decision-making);
- development of fully IP-based communications and use of higher bandwidth mobile networks, including satellite-based solutions;
- development of non-safety-of-life ATM applications using commercially available services (e.g., 5G, SATCOM) required for Hyper Connected ATM;
- Air–Ground and Ground–Ground data communication solutions for RPAS (including remote pilot–controller voice and CPDLC communications);
- operational use of datalink on the airport surface, incorporating the ICAO's flight and flow information for a collaborative environment (FF-ICE) TBO concept;
- development of advanced applications of the SWIM technical infrastructure;
- automation of next generation ATC platforms underlying technical processes (e.g., cybersecurity, maintenance, dataset updates).

CNS roadmap (see Section 4.1.1) shows Performance-based CNS as a composition of SATCOM, AeroMACS, LDACS, DFMC GNSS and supported by Minimum Operational Network (MON) of CNS legacy systems. The MON concept definition is evolving for each domain within Operational Excellence Program framework where European ANSPs are considering operation aspects of how to optimize CNS infrastructure. One of the important aspects that drives CNS infrastructure rationalization is related to cross-border CNS service provision which could allow to decrease an infrastructure redundancy by relying on neighbour facilities based on Service level Agreement (SLA), where the minimal level of performance is provided to ensure an acceptable level of service continuity for civil users and for critical military missions.

As a conclusion, Performance-based CNS can offer different technological solutions which could fit the need of the stakeholders. This risk appears in case of regional implementation of a specific technology so far it is mitigated through ICAO Global Air Navigation Plan (GANP) Aviation System Block Upgrade (ASBU) implementation. This is also planned to be ensured through the CNS Programme Manager proposed in CNS Advisory Group Report, where the mitigation to avoid 'excessive proliferation of technologies/solutions that would increase overall costs and technical/operational complexities' is planned to be done by a balanced approach using the CNS evolution plan that should define a limited number of interoperable solutions that AUs can choose and ANSP have to support to meet operational needs.

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Appendix A Civil-Military Implications from Performance-based CNS

A.1 Introduction

Edition 3.0 of the Civil-Military CNS Interoperability Roadmap, dated 7th October 2020[35], was endorsed by the Military ATM Board (MAB) and relies on the ICAO Global Air Navigation Plan (GANP) and the European ATM Master Plan as the basis to derive civil-military interoperability recommendations.

Performance-based CNS is covered in Section 8 of that document where the impact of such concept upon civil-military is described [38].

Some military platforms may be designed to meet some civil certification specifications or requirements. Some companies design and build State aircraft using civil and military standards; some focus only on the State mission and mission-oriented standards – these decisions are based on the culture and history of the company in question. Nevertheless, military aviation acknowledges the importance of certification activities and has built and refined national and/or common processes in order to prove, to their national competent authorities, and to the whole aviation community, that their flying activity is safe.

Nations are free to determine the capabilities and certifications required for State aircraft and foreign State aircraft in national airspace. In order to allow unhindered access to all airspace, State authorities need to build certification processes that instil confidence in both national and international airspace owners and authorities.

Different requirements, on civil and State sides, cause a clear mismatch between the capabilities of military systems and civil-derived ATM/CNS requirements. To overcome the difficulties caused by this mismatch, the National Authorities may decide to apply alternative Performance-based Certification (PBC) processes that allow the re-utilization of available military capabilities to comply with civil-derived CNS/ATM requirements, which are expressed as performance levels and attributes.

When a certain operational improvement related to a civil requirement needs to be certified for integration into an airborne military system, it must be understood that performance alone is not enough to claim equivalence. It must be complemented by interoperability and also by the verification of potential non-conformity issues created by operating such an additional system to support a given function.

There is never a guarantee that a performance approach will be successful. Any decision to implement an operational improvement based on the application of a performance approach has both operational and budgetary consequences. It is a decision to be taken by National Military Authorities. It is normally accompanied by a request to determine is a cost/benefit analysis is positive.

Performance cannot be disconnected from interoperability. Performance-based CNS must ensure that full interoperability is maintained within the context of the infrastructure operated by the airspace

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[35] https://www.eurocontrol.int/publication/civil-military-cnsatm-interoperability-roadmap

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users and service providers just like in the ICAO performance-based context. In the new ICAO performance context, where the operational requirements and the performance of a system are not based on technological dependencies, the underlying assumption is compliance of the system with the prescribed interoperability standards.

Performance targets must be identified to determine whether Dual Use CNS is viable on the basis of evidence that there is due regard for the resultant safety of navigation (airworthiness) of aircraft. Nevertheless, Performance-based CNS is only one of the options for compliance. When it cannot be implemented, other mitigation options can be investigated, ranging from full compliance with civil requirements to other special measures such as exemptions or specific accommodation procedures or arrangements to be developed.

National Military Authorities will decide if civil aviation standardised applications, functionalities, performance levels, QoS parameters, interface requirements and other quantified/qualified requirements, data metrics or descriptors are eligible to sustain military aircraft operations. Nevertheless, safety and due regard imperatives must be observed when operating under General Air Traffic (GAT) status.

EUROCONTROL work on interoperability targets supporting performance-based certification identified the domains suitable for the direct application of performance-based approaches.

A.2 Communication

Present trend is for civil data link capability based on ATN/VDL-2 or FANS/ACARS to be considered the eligible capability for transport-type military aircraft where civil Controller-Pilot Data Link Communications (CPDLC) capability is considered required. Other aircraft types are (at least initially) due to be accommodated on the basis of Air-Ground voice.

The 4D services that will comprise some trajectory management applications, relying on the ADS-C technique. Transport type State aircraft may adhere to such capability. More advanced Full 4D requirements (ATS-B3) will require the introduction of higher capacity data link technologies plus the bandwidth in the context of the Future Communications Infrastructure (FCI) initiatives comprising airport, terrestrial and satellite communications (SATCOM) data link solutions as well as a multilink environment.

Other alternatives for civil-military data link interoperability shall not be excluded but are still being subject of R&D investigation. Security and spectrum coordination aspects are crucial for any performance-based opportunities in this area.

Civil air-ground data link communications requirements for ATN-B1 CPDLC, and for 4D trajectory management based on ADS-C (ATS-B2), based on the use of VDL Mode 2, as currently defined, are NOT suitable for the direct application of a performance-based approach for military aircraft. Nevertheless, this situation becomes different when considering ICAO´s notion of Required Communications Performance (RCP) which will give precedence to performance/QoS considerations in terms of continuity, availability, integrity, transaction time, etc. RCP approach seems more viable for Future COM technologies (next generation of datalinks). Availability of software defined radio options may offer opportunities to pursue a performance-based approach in this domain.

A.3 Navigation

Military navigation architectures cannot easily comply with the majority of PBN navigation specifications due to the eligibility of sensors and to all the issues related to the flight path definition based on ARINC 424 data. It should be noticed that the display systems used on modern military aircraft can easily meet the civil requirements.

The various PBN specifications used in the en-route and approach context (RNAV or RNP for different levels of accuracy) entail the availability of a NAV avionics suite with a very high level of integration (RNAV computer and sensors). The GNSS signals used by military are predominantly GPS PPS. Relevance of TACAN for PBN remains to be assessed. Except those designed to support GAT/IFR navigation, the military navigation computers are not using the ARINC 424 data structure. They only implement some of the basic path terminators and military specific path definition and guidance.

ICAO PBN requirements, as currently defined, are already suitable for the direct application of a performance-based approach to a certain extent. ICAO Document 9613 PBN Manual prescribes defined sets of multiple system enablers allowing the selection of those that can fulfil particular airspace requirements and the identified levels of performance/particular specifications (e.g., GNSS, DME/DME, INS/IRS, etc.).

A.4 Surveillance

Mode S technology is a recognised requirement for State aircraft, influencing the interoperability of State aircraft aiming to fly in a Mode S-based aircraft identification environment. Mode S requirements, as currently defined, are NOT suitable for the direct application of a performance-based approach.

ADS-B implementation for transport type military aircraft is another recognised requirement but ADS-B requirements. As currently defined, it seems NOT suitable for the direct application of a performance-based approach. However, FAA indicated that “ADS-B requirements, as currently defined in the US, are a performance-based approach”. They justify with the statement that “from a US perspective, the US ADS-B mandate is performance-based as applied to the aircraft”.

A.5 Conclusion

Performance-based CNS applied to military aircraft systems, eligible to operate in mixed mode context, makes sense in the domains of advanced future communication data links and navigation (PBN). Nevertheless, the definition and validation of suitable technical solution requires in most cases research efforts and thorough feasibility assessments. The consolidated performance metrics and indicators to be used when seeking compliance must be those that are a common and harmonised reference guaranteeing appropriate levels of safety and flight efficiency.

Appendix B Exploiting Performance-based CNS frameworks to support Free-Route Airspace Operations

This appendix looks at how a Performance-based approach to CNS support can be beneficial to an advanced airspace management concept such as Free Route Airspace (FRA). This will consider the operational characteristics of Free Route, which type of airspace this can be applicable to and also what a suitable Performance-based framework would look like.

B.1 FRA Context

FRA is based around giving airspace users the ability to flight plan preferred lateral and vertical routes through a specified volume of airspace and is characterised by the absence of any fixed route structure within the airspace. Initially, fixed entry and exit points are published on the perimeter of each ANSPs airspace which must be filed within flight plans. As FRA evolves to include the cross-border aspects, the need to file these points is removed and flight plans are free to cross at any point between FIRs, as long as the flight is moving from and to FRA airspace. Cross-border FRA has its own specific requirements and is addressed in a following sub-section. Within the boundaries of the FRA however, operators are free to file routings as they wish between these points.

FRA, in general, is a very beneficial way to manage air traffic, and especially lends itself to managing higher altitude and less complex areas of airspace. FRA is also an enabler for ATC to move to a more supervisory role in their operation, as flights are predominantly flying to their own pre-determined flight plans and so ATC by nature will manage interactions much more by exception. This is in contrast to an operation predominantly managed through a tactical method of interacting with flights under their responsibility including a larger amount of impact to a flight's preferred routing. As ATC tools and capability increase in support of FRA, then this transition to a more supervisory role can accelerate.

In this way FRA provides a direction of travel to ATM heading towards a more digital communications based concept and enables a much larger use of tools such as CPDLC which is already heavily wrapped into a performance-based framework.

B.1.1 Characteristics of FRA

As an advanced and modern method of addressing ATM operations, FRA can benefit from an increased level of data and external/automated support for ATC, in order to operate most efficiently. Under more traditional airspace management concepts, the availability of an air route structure can allow ANSPs to 'disable' areas of their airspace-to-airspace users, where adequate support may not be feasible to provide, e.g., CNS coverage. When FRA is considered, an ANSP is obliged to avoid such operational restrictions, which means that there is an increased demand on the availability and coverage of CNS services across the entirety of the ANSPs area of responsibility.

Additionally, a conflict detection tool such as the established Medium-Term Conflict Detection (MTCD) function becomes even more critical to the success of the operation, especially in the area of airspace boundaries. This is due to an increase in variation of points at which aircraft may cross FRA boundaries. Correct support for a tool such as MTCD demands a higher requirement for aircraft position and/or intent data. The MTCD requires data for aircraft incoming to FRA which needs to be captured, significantly beyond the traditional FIR boundaries to be effective. Further along in this appendix, the benefit of adopting a performance-based CNS approach is considered, particularly to service this sort of application.

More complex demand balancing through flight plan processing will need to take place in the planning stages of flight (pre-departure), in support of FRA, as FRA traffic flows are more unpredictable. The likelihood of tactical intervention overall from ATC is reduced through FRA as the flight demand is naturally much better distributed within the airspace, but it is also harder to predict where any capacity issues may occur through airspace 'bottle-necks'. This co-ordination would most likely be achieved through a combination of improved data being received on the ground from adjacent ANSPs, as well as through the addition of downlinked information from flights themselves.

A further consideration for FRA with its more liberated approach to flight routings is that there will need to be a transition to a more structured route system at some point within FRA airspace. This is because there will always need to be a part of an ANSPs airspace that is managed in a structured and highly systemised manner in areas of higher complexity such as TMAs and approaches to busy airports. In this way, a flow management tool such as AMAN or similar can be used in order to manage the sequencing of flight's out of FRA, and into such a systemised area of airspace.

Ultimately, it can be envisaged that the sequencing function which provides final approach sequencing to airfields will be extended through a systemised portion of airspace and have greatest effect within FRA for this reason. In this way the impact on FRA operation will be significant of the efficient operation of this sequencing tool. Such sequencing tools will be very data hungry and so a performance-based approach to the input needs for this tool will be of great benefit.

This sub-section characterises how ATC will change through the implementation of FRA, and how ATC will evolve over time to manage airspace interactions by exception and focus on reacting to issues that may arise which are out of the routine.

The necessary support functions will all be much more heavily data driven than traditional ATC tools. In addition to the introduction of ADS-C capability, it is also true that this type of airspace and the more supervisory role for ATC, which is possible within FRA, also lends itself clearly to the increased use of CPDLC.

B.1.2 Cross-border FRA

In a cross-border FRA scenario, there will not be a published set of entry points to a FRA volume, specific to each ANSP's airspace. ANSP tools will still need to derive entry points to FIRs from the available data, and so ATC will be much more heavily dependent on points generated by trajectory calculation rather than reference to any fixed points. It is important therefore that ATC have a very good knowledge of initial agreed flight plans and any changes to flight intentions, including level changes, and planning throughout a flight so that they can properly determine where flights will enter their airspace. This will have impacts on Flight Data Processing (FDP) systems, providing direct information to ATCOs, but also for Airspace Capacity Management (ACM) systems which plan and balance sector loadings within a FIR. A further key point to consider will be the need to enhance safety net type functions for ATC, which are in turn, driven through conformance monitoring functions against current position and flight intent.

Again, all of these tools will be reliant upon increased amounts and quality of data in order to provide the high fidelity of synthesized crossing point information. This again is an area where a performance-based approach to capturing this data will be beneficial and open the way to the use of an increased number of data sources.

If these tools are not operating effectively then this will increase the burden and workload on controllers to co-ordinate with adjacent ANSPs and also obtain planned crossing point information directly from flights. That will obviously erode significantly the benefits of cross-border FRA to ATM.

B.1.3 FRA Applicability

The current target airspace for the application of FRA is at FL 305 and above as per the CP1 [39] requirements. This is very clearly within what is termed as upper airspace, where the density of traffic tends to be lower and the complexity in terms of aircraft proximity and interaction, vertical and lateral profile changes, and speed changes are also relatively low.

It should also be noted that a series of ANSPs have chosen to implement FRA down to levels lower than those prescribed by mandate. Examples of this are states such as Ireland (FL75+), Norway (FL135+) and UK (FL255+). This is largely driven by the specific complexities of the airspace managed by each ANSP/state but shows that there is great scope for FRA to be used at much lower levels over time.

In fact, it is very likely that the benefits achievable from the implementation of FRA will, in the coming years, create a desire to extend FRA operations into new areas. This would include lowering the base level of applicable airspace, to take into account further areas of high density/low density airspace, as well as extending the lateral extent which could include areas of high seas airspace such as the North Atlantic (NAT). It may be possible to characterise the necessary CNS and data support to FRA, through a set of established CNS and data requirements based upon support for the functions and tools identified earlier, and so these requirements may be largely ‘portable’ and be applicable wherever FRA is implemented. If the CNS support requirements for concepts such as FRA are performance-based, in nature, then it would be potentially easier to ‘port’ FRA implementations to other parts of the airspace.

For instance, if a set of Performance-based requirements can be established for low-density domestic airspace, then these may also be relevant to when applying FRA to an oceanic airspace environment. In this way Performance-based CNS and data requirements could be an enabler for FRA. It must be validated whether this approach is feasible.

B.2 Performance-based CNS Support

Table 45 provides a view of a set of possible functions and associated Performance-based specifications which could be used to support an FRA implementation. These are characterised in terms of the required inputs to the ATC operation from the perspective of the ATCO ‘user’, including the tool support described earlier, such as conformance monitoring capabilities and inputs to ACM, AMAN and ATFM type services.

The support column looks at the CNS-type services that can be envisaged as well as consideration for a ‘data’ category of service which may be received through ‘CNS-type’ infrastructure but are distinctly separate from traditional CNS-type services.

Airspace Requirement	Performance-based Specification	Support	Comment
Tactical Communications	(Tactical intervention)	**VHF/UHF Voice** [Now: DSB voice	FRA will drive a reduction in the need for tactical communications

Airspace Requirement	Performance-based Specification	Support	Comment
	Performance-based Specifications not currently available. They can be based on VHF/UHF Voice communication performance	Future: LDACS]	interactions with flights. This can enable the use of digital communications more widely, e.g., CPDLC, and also lead to a higher round trip delay requirement paving the way to CPDLC becoming primary tool
Planning / Strategic Communications	Now: RCP 130 (CPDLC) Future: RCP 60 (CPDLC), and beyond	**CPDLC** [Now: VDL Future: SATCOM/LDACS/ other] **VHF/UHF Voice** [Now: DSB voice Future: LDACS]	As interactions become more strategic in nature, can reduce Voice requirement significantly. CPDLC established will become established as primary means for strategic communications
Flight track keeping	Now: RNAV 5 or RNP2 (aircraft capability – no airspace requirement) Future: RNAV1 / RNP1 / A-RNP (Based upon separation standard in target airspace)	**Space** [Now: L1 GPS] [Future: L1 / DFMC GNSS] **Terrestrial** [Now: DME/DME / VOR/DME] [Future: DME/DME / LDACS/other] **Airborne** [Now: IRS/INS] [Future: IRS/INS] (to MON) **[Note: some of these sources will not support RNP requirements]**	Based on Performance-based fusion of navigation sources at the aircraft. Will be driven by airspace type where FRA is applied, and prevailing separation standard used PBN airspace is currently predicated on the availability of a 'voice' service, which could be reflected better as a Performance-based communication requirements
Position detection (surveillance)	(Frequency and quality of detection) **Now: Performance-based Specifications not available** **Future: Full electronic conspicuity driven by Performance-based Specifications**	Now: PSR, SSR/Mode-S, ADS-B, MLAT Future: ADS-B (terrestrial and space based), data derived from aircraft downlinked intent information	

Airspace Requirement	Performance-based Specification	Support	Comment
Aircraft derived data – Trajectory intent information	Now: RSP 160 Future: RSP 60 and beyond	Now: ADS-C Future: Fusion of ADS-C and aircraft derived data	Feeding ATC tools such as, safety nets, conformance monitoring, descent/climb profiles, and informing ground trajectories
Input to MTCD	**Now: Surveillance data** **Future: Performance-based Specifications TBD**	Now: PSR, Mode-S, ADS-B Future: ADS-B (terrestrial and space based), data derived from aircraft downlinked intent information, e.g., ADS-C	Expected to be based upon a fusion of the data sources
Pseudo FIR entry point information	Now: FDP plus surveillance data Future: **Performance-based Specifications TBD** Based upon RSP 160	Now: PSR, Mode-S, ADS-B Future: ADS-B (terrestrial and space based), data derived from aircraft downlinked intent information, e.g., ADS-C	Applicable to Cross Border FRA, where fixed FIR entry points are moved
Pseudo WP references	Now: FDP plus surveillance data Future: **Performance-based Specifications TBD** Based upon RSP 160	Now: PSR, Mode-S, ADS-B Future: ADS-B (terrestrial and space based), data derived from aircraft downlinked intent information, e.g., ADS-C	To provide dynamic reference WPs which are not published within an FIR
Capture of in-flight FPL changes	Now: Voice and data Future: Based upon RSP 160	Now: Voice Communication Future: ADS-C	
Uplink of complex clearances / trajectory updates	Now: Voice Communication Future: Based upon RCP 130 (CPDLC) and beyond	Now: Voice Communication Future: CPDLC	Including clearances consisting of Latitude/Longitude WPs
Flight demand information	Now: Voice Communication and FPL	ADS-C	Intent trajectory information used to inform forward demand profiles

Airspace Requirement	Performance-based Specification	Support	Comment
	Future: Based upon RSP 160 (ADS-C) and beyond		
Safety Net – FPL Conformance Monitoring	Now: Voice Communication and FPL Future: Based upon RSP 160 (ADS-C) and beyond	ADS-C	Triggering alert in supervisory ATC environment

Table 45 Performance-based specifications to support FRA

An additional benefit of developing Performance-based CNS requirements which support the functions above, is that the establishment of these requirements will lead to harmonisation. Each ANSP introducing FRA, would be able to refer to the same set of (possibly standardised) requirements, and so make use of a range of available data technologies and infrastructure. Naturally, this approach then lends itself to the exploitation of external providers, and common services, which in turn is the basis for the ATM Data Services Provider (ADSP) concept. These common services may be provided at pan-European or even global level. Such harmonisation would clearly provide benefits especially for the implementation of cross-border FRA, where the deployments of appropriate CNS services could best be made without any limitations on national or airspace boundaries.

B.3 Summary

In this appendix the links between an efficient implementation of FRA, and a Performance-based CNS approach have been proposed, in order to show the added benefit of exploiting Performance-based CNS when deploying such advanced airspace management concepts. It is clear that a Performance-based CNS approach, which largely enables the exchange of appropriate data between ground and airborne users, can add the flexibility and technical service coverage that FRA will benefit from. The major benefits are around flexibility of service provision where a series of data sources and / or providers can be candidates to provide the required connectivity, as well as flexibility in providing signal coverage, especially in more remote and isolated areas of airspace. Additionally, Performance-based CNS can also facilitate the portability of solutions such that FRA can be more easily applied in more types of airspace.

The Table 45 highlights how a series of new and modernised ATM tools and functionalities need to be available in order to support FRA. These tools and functionalities are there to enable the change of role for ATC within concepts such as FRA, and to provide additional flight data in order to provide the required awareness and information to ATCOs as part of a more supervisory role. The Performance-based CNS concept is then applied to the needs of these tools and functionalities to show potential benefits. The table also shows where there are some gaps currently within the Performance-based CNS framework which should be addressed in the near future in order to realise these efficiency and flexibility benefits. Once these gaps can be improved upon, then it will also make FRA a much more flexible and 'portable' solution, in that it can be more easily applied to a wider range of airspace volumes, where CNS, and data needs are better understood and can be more clearly characterised.

Clearly there is a need to fully characterise a concept of operation such as FRA, in terms of the functional and tool-based needs before the supporting CNS and data-driven applications and requirements can be derived. This work has not yet been completed in detail and it is recommended that this is done to enable the benefits described here.

The Performance-based CNS and data concepts described in this appendix, can be applicable for a variety of applications within ATM. FRA is used here as an example but the concept of capturing these integrated requirements is equally applicable to other airspace management concepts, e.g., systemised, and flexible use of airspace, as well as at the level of ATC tools, e.g., AMAN, ACM, depending how we wish to breakdown the architecture. This is illustrated in **Figure 21** below.

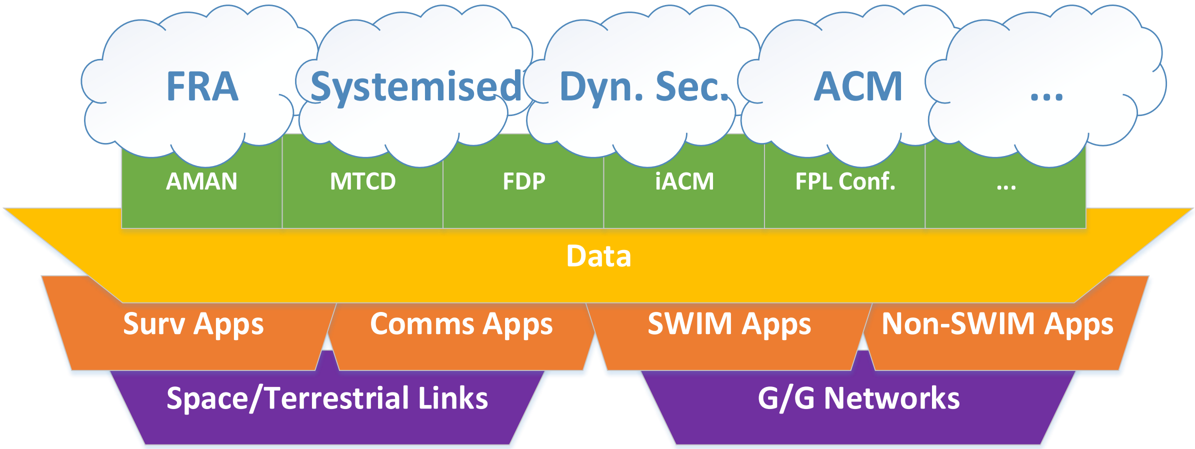

Figure 21: Performance-based specifications

Ultimately these requirements may be expressed in relation to these applications, e.g., Performance-based (FRA) [RCPx, RSPx, RNPx, etc…], or Performance-based (AMAN) [RCPx, RSPx, RDataPx, etc…]

The parameters to be monitored and measured as part of RCP, RSP and RNP are largely understood, even if further work is on-going to determine what the necessary values are to support specific airspace management concepts. However, in the case of a RDataPx type specification, the parameters that may be applicable would need to be established. It is recommended that work is begun to derive these in order to enable the improvements described here. These parameters may be based around things like data refresh rates, integrity of information, time of delivery, security level, etc.

Appendix C GNSS Timing Performance Parameters for CNS

Time and Synchronization are two terms often used together and seamlessly in timing contexts, but it is important to understand that they refer to two very different concepts. In fact, every clock can be considered as a device made of two parts: an oscillator to define the length of a clock cycle (e.g., a second) and a counter (also called integrator) to keep count of the elapsed cycles.

For an oscillator, or frequency standard, a physical phenomenon is needed that swings regularly in time and independently from position, velocity, epoch and external conditions. In 1967, the universal second definition was changed to allow a much better accuracy which is given by an atomic standard (based on the Cs133 atom). In simple terms, atomic oscillators provide a much more accurate frequency than any other physical phenomena and they are most suitable to be used for **Synchronization** purposes: different oscillators will be synchronized if they all run at the exact same rate.

The counter on the other side is related to **Timing purposes**. It keeps track of the seconds elapsed and marks it on a predefined timescale (or time coordinate) defined as an ordered set of scale markers with an associated numbering. UTC is the reference time scale for worldwide time coordination, serving as the base of legal times in each country and for different applications.

Precise time can be defined in various ways, and different levels of time precision are required depending upon the type of application. For example, milliseconds may be sufficient to measure the time in the 100m sprint, microseconds for computer clocks, or nanoseconds from a GPS time source for communications

Time and **synchronization** do not need to co-exist a priori, it depends on the application. Some applications just need their clocks synchronized between themselves; others need to have their clocks synchronized to a common “real time” (e.g., UTC). That implies that the “real time” has to be generated and made accessible wherever needed (distance factor).

GPS, GLONASS, Galileo systems or EGNOS (GNSS in general) all generate their own time scales from an ensemble of (atomic) clocks and steer them toward local representations of UTC (e.g., UTC-USNO, UTC-SU, UTC-GST) to offer both time and synchronization services[36]. The most desired qualities of a time scale are its reliability, stability and accuracy. Whilst its performance (or the service offered) is measured in terms of Accuracy, Stability, Availability, Continuity, Integrity, Robustness, Traceability.

To distribute the received absolute time from a precision reference time source, time transportation methods are needed that use special timing protocols. The most frequently used protocol is the network time protocol, or NTP, a software implementation used to synchronize the clocks of computer systems over packet-switched, variable-latency data networks. Time synchronized networks enable accurate time stamping by each of the computers on the network. This is important to properly sort events and transactions into chronological order so that any disturbances or problems in the data can easily be detected and resolved. Nonetheless the advent of GPS, and GNSS in general (Galileo,

[36] ICAO Doc. 9849

GLONASS, EGNOS, Beidou, etc..), led to a giant improvement in the dissemination of time (worldwide) whilst solving the necessity for synchronisation in inaccessible areas.

Precision time stamping is also important (such as used in ATM Surveillance systems Radar, ground ADS-B, WAM networks, etc...) for data that is used in financial audits or as evidence in court during legal cases.

Current and new timing applications[37] appearing every day are requesting more reliable and precise timing and synchronization sources that can guarantee high accuracy and availability performances to support their business. Time and Synchronization users in the ***telecommunication*** sector are the ones experiencing the most rapid growth due to investments in 4G/5G standards which need the highest accuracy for base stations' operations. GNSS derived timing is already vastly used as either primary or backup solution. Carrier operators need a very precise and accurate primary time reference to propagate time within their networks. In nearly all cases the primary reference is derived by signals transmitted by GPS satellites through a high-quality GPS receiver which calculates time from satellite signals, derives frequency and uses it as reference for synchronizing internal network oscillators[38]. Yet, there are significant concerns in GNSS-time implementations due to a low control over signal propagation, because they are e*xtremely week and corruptible*. Nevertheless, high expectations exist for Galileo improved accuracy, precision and integrity intended as *the signal authentication capability (OSNMA*[39]*) which will be* ensuring a higher level of robustness and trustfulness. Galileo is considered to be the next most common adopted Time and Synchronization source after GPS. Besides that, alternative transport technologies such as optical fibre dissemination is already being tested and improved for Time and Synchronization transport along vast distances[40]. In the **aviation sector** also, there is an increasing demand for high accuracy Time and Synchronization both on planes, at airports and on the ground infrastructures of ATM. Airports/ATM already largely use GNSS together with NTP protocols to ensure a smooth time stamping of events on ground, but planes only rely on the on-board GNSS receiver and sensors to estimate their position and time. On the other hand, new emerging technology as LDACS (ground-based CNS technology) have the potential to be a candidate for such support together with rebroadcasting through HAPS platforms.

On the ground side optical fibre time transportation can potentially bring a revolution in the Time and Synchronization community since it would eliminate the (most feared) risks of satellite signal vulnerabilities (both natural and artificial) together with a much faster and reliable signal processing over very large distances. It would be obvious to think that any time soon, global optical transmission

[37] Report on Time & Synchronization User Needs and Requirements – GSA, 2018

[38] Power grids for example count with local atomic oscillators for holdover whenever GPS fails. Finance and telecommunication use network protocols (e.g., NTP, PTP) and local atomic oscillators to increase resilience against GNSS disruptions. Other solutions such as T-RAIM already exist and provide redundancy even if their use strongly depends on the type of applications

[39] https://ec.europa.eu/defence-industry-space/tests-galileo-osnma-underway-2021-02-11_es

[40] http://rime.inrim.it/labafs/frequency-dissemination-through-optical-fibers/

lines could prevail over both satellite transmissions and network protocols such as NTP or PTP which already start failing to comply with most modern user application requirements.

A Time Service Provider (TSP) performs essentially two technical functions:

1. **Generates a Time Scale**
2. **Disseminates the Time Scale**

The most desired qualities of a time scale should be at least the following:

- **Reliable**. Physical clock devices are subject to failure as any other equipment so to avoid discontinuities in the time scale more clocks are used to reach redundancy and thus a higher reliability.
- **Stable**. The stability of a time scale is directly linked to the stability of the contributing clocks and the efficiency of the algorithm used for the processing. The general idea behind providing a good time service is to offer a time scale which stability is better than the single clocks stabilities.
- **Accurate**. The accuracy of a time scale is defined as its capacity to maintain a mean scale interval as close as possible to the (SI) second definition. National time scales for example are continuously frequency steered toward the frequency of a primary standard to reduce systematic errors.

UTC is calculated at the BIPM (*Bureau International de Poids y des Measures*) or other recognised centres (e.g., UTC OSNA is used by GPS) on the basis of readings and processing of atomic clocks in national laboratories worldwide: as any artificial device and for as much as reliable they can be considered, clock devices can still fail, and time laboratories need to keep multiple ones. GNSS is globally the most convenient way of disseminating and the KPIs monitored.

GNSS TSPs are monitored (and themselves monitor) on the basis of the following Key Performance Indicators:

- **Accuracy**: the deviation measured in seconds (*in GNSS normally nanoseconds to a maximum of 1 microsecond*) from a common reference time (e.g., UTC)
- **Stability**: the variance measured in PPM or PPB from the reference source over a specified interval. It is the factor that defines the quality of an oscillator. It affects both frequency and time domains.
- **Availability**: percentage of time over a specified interval when the user can compute a timing solution. It is divided in *System Availability* which the GNSS Interface Control Document refers to, and *Overall Availability* which depends on the receiver as well.
- **Continuity**: ability to provide the required performance without interruptions during intended operations.
- **Integrity**: measure of trust that can be placed in the time solution estimated by the receiver. It is usually expressed as probability to be exposed to an error larger than a predefined limit. This is entirely dependent on the type of application, whether they are safety critical or not.
- **Robustness**: ability to withstand intentional or un-intentional signal degradations such as interference, spoofing, jamming, etc. Signal authentication might help to increase robustness against intentional attacks but not against natural vulnerabilities.

- **Traceability**: it expresses the degree of relation between estimated time and national or international time standards as UTC.

	Maximum offset from reference timescale	Specified accuracy of corrections to reference timescale
GPST-UTC(USNO)	100 ns	40 ns (2σ), typically within 10 ns
BDT-UTC(NTSC)	100 ns	5 ns (2σ) to ground reference
ENT-UTC(OP)	50 ns (5σ)	20 ns 3σ (committed accuracy) 10 ns 3σ (experienced accuracy)
GLONASST-UTC(SU)	660 ns (2σ) – in 2014 4 ns (2σ) – in 2020	<40 ns – in 2014 <(1-2) ns – in 2020
QZSS[41] UTC(NICT)	20 ns	Not specified, but typically within 20ns
GST-UTC(k)	<50 ns (2σ)	28 ns (2σ)
WAAS[42] [RD-5]	25 ns	8ns[43]
IRNWT[44] UTC(INC)	20ns	N/A

Table 46 GNSS Timing performance parameters

[41] New concept tested: employment of a synchronization framework combined with lightweight steerable on-board clocks which act as transponders re-broadcasting the precise time remotely provided by the time synchronization network located on the ground.

[42] Alternate Position Navigation and Timing (APNT): program considering MT 12 as **potential** timing reference in absence of GPS signal. **MT12 in WAAS currently not implemented.**

[43] Real-time UTC via the WAAS is currently estimated to be kept within 8ns of the final BIPM value

[44] IRNSS Network Time) is determined from a clock ensemble composed of the caesium and hydrogen maser atomic clocks at the INC (Indian Navigation Centre) ground stations.

Appendix D Spectrum aspects in Performance-based CNS

Safeguarding continued access to interference-free radio spectrum is critical for sustaining future CNS capability for Air Traffic Management. Aviation spectrum relies on technical and political axioms, and has a number of complexities. The most notable are scarcity, harmonisation of bands, and interference management, among others. All of these have a profound impact on which bands, and how much of them, aviation will continue enjoying access to in the coming years and decades.

As with most natural resources such as atmospheric and maritime weather, radio spectrum is defined by energy and is a naturally chaotic environment, exacerbated by man-made signals and noise. The process of imparting some order to this natural chaos and allocating spectrum to different services, fixed and mobile, is not a perfect science and it relies on a *best-fit* approach for services that are allocated on a near-compatibility basis. Usually this results in compromise between signal quality versus service availability.

Occasionally over the scale of decades, free spectrum known as “white space” becomes available when wireless systems are decommissioned, the most obvious recent example is that of analogue TV which has been “switched off” in many countries. The spectrum left behind is then re-allocated to new services. Aviation is not normally the beneficiary of this process, because it already enjoys near-exclusive use of significant portions of radio spectrum globally. On the other hand, aviation spectrum is coming under increased scrutiny itself as a candidate for releasing and for sharing spectrum.

The scarcity of radio spectrum is a potent incentive to users across all industries to utilise the bands allocated to them as efficiently as possible. The most notable signs of spectrum scarcity are

- a “slow down” in allocation of new bands to new services over time, and
- a corresponding “ramp up” in the sharing of radio bands because there is less and less “useful” spectrum available to allocate.

These trends have direct implications for the evolution of aviation wireless CNS services, and on any transition planning. In particular, the intensifying competition for spectrum between different public and private services, and the implementation of various forms of incentives and measures by telecommunication regulators which are designed to extract more value from spectrum for the consumer. The most impactful and controversial of these measures is *spectrum sharing*. Aviation has been largely immune to sharing considerations for several decades, however in recent years this immunity is eroding, and this results in aviation spectrum being the target for sharing spectrum with other services.

In modern day spectrum policy trends around the globe, spectrum sharing is considered to play a complementary role to traditional spectrum licensing by allowing new services to access new bands where there are no other reasonable alternatives. Indeed, this is the main mechanism that allows the introduction of new aviation capabilities in bands that are already allocated to aviation, with the most recent examples being LDACS (albeit not yet fully standardised), space-based ADS-B and DFMC GNSS. In practice however, spectrum sharing comes with significant risks for aviation safety and productivity when the shared systems are not designed from the ground up for CNS in designated aeronautical spectrum bands. The principle of sharing is a significant consideration, because one cannot consider sharing (non-aviation) systems without also considering sharing the spectrum they are based upon.

EUROPEAN PARTNERSHIP

Co-funded by the European Union

The regulatory framework for spectrum is governed by an international treaty called the Radio Regulations administered by the International Telecommunications Union (ITU), akin to the Chicago Convention and the SARPs administered by ICAO. The Radio Regulations make specific provisions for “Special rules relating to the use of aeronautical frequencies under Article 43:

“Frequencies in any band allocated to the aeronautical mobile (R) service and the aeronautical mobile-satellite (R) service are reserved for communications relating to safety and regularity of flight between any aircraft and those aeronautical stations and aeronautical earth stations primarily concerned with flight along national or international civil air routes.”

Further provisions are made under Article 44 on the order of priority including flight safety messages, meteorological messages, flight regularity messages and other communications. However, the Radio Regulations do not make specific provisions for sharing spectrum allocated to safety of life services with non-safety of life services, as this is not its remit. Aviation sets its own policies on spectrum usage across the various CNS services, supported by a safety assurance framework. These are enshrined in ICAO documents with global applicability such as Doc 9718 (Handbook on Radio Frequency Spectrum Requirements for Civil Aviation) and also at regional level such as EUR Doc 011 (European Frequency Management Manual).

Significant advances in radio and signal processing technology over terrestrial networks and over space-based networks has made it possible to offer mobile services with elevated levels of performance, capacity and speed that were not previously possible. Commercial technology has emancipated to the point that genuine machine to machine connections connected to the Internet of Things (IoT) are now possible. If applied to aeronautical services, this has substantial potential to unlock productivity improvements on the basis of

- sharing data over a virtualised space,
- introducing analytics on *big data* generated by the Air Traffic Management system where it has a net benefit to the stakeholders, and of
- mitigations built into the technology to manage the effects of the interference environment and extract more productivity from the radio system.

For example it has become clear in recent years that the way in which aviation stakeholders are generating and consuming data is relying increasingly on mobility, and it is therefore not hard to imagine how these above benefits could be transferable to aviation stakeholders and to their day-of-operations in airspace and in airports. From an enterprise architecture and ROI standpoints it is also very appealing to introduce *Commercial Off The Shelf* (COTS) technologies and CNS delivered as a service over third-party commercially managed infrastructure. In this context, SESAR has dedicated specific work streams to identifying and exploring opportunities to exploit commercial technologies both on the ground and in airborne applications.

Consideration for the transition to Performance-based CNS have to go beyond the technical ability of commercial radio systems to deliver connectivity service for Air Traffic Management. The use of COTS and third-party services also come with important spectrum considerations, particularly where one radio system, be it terrestrial or satellite, delivers service to multiple applications with differing priorities. As alluded to above, the regulatory framework currently makes specific provisions for allocation of frequencies for safety and regularity of flight. The goal of this regulatory protection is to eliminate the possibility of radio interference and therefore to guarantee a high level of service integrity. Where such integrity can be demonstrably achieved by other technical means, regulatory consideration needs to be given to *how* a performance-based CNS framework can account for shared use of aeronautical spectrum where it is allocated for the use of safety and regularity of flight (such as is the case with aeronautical mobile (Route) service). *How* this can be demonstrated, and with which means of compliance, is yet to be established for performance-based CNS. What is clear is that, whichever method is chosen, safeguards likely in the form of performance monitoring will have to be put in place to ensure that the porous boundary between 'safety of life' and 'non-safety of life' use of aeronautical spectrum continues to meet the extant safety requirements.

It is undisputed that access to sufficient and appropriately protected radio spectrum supporting is essential for the aviation industry, without which airspace management would not be feasible. As the use of airspace increases, including the introduction of new users such as drones, and the management of that airspace becomes more complex, the demand for spectrum will also increase along with the requirement for improved communication capacity and navigation/surveillance accuracy. Therefore, the ability to secure and protect the spectrum aviation relies upon will be a significant factor to the long-term growth of aviation. In the same manner, many other industries outside of aviation are also growing and their demand for additional spectrum is also growing. This demand has reached a point where industries are competing with each other for access to this limited resource, with national and international regulatory bodies having to decide on who should have access. For these decisions to be made, spectrum regulators need to have the most accurate picture of the systems they are considering and how changes to the radio frequency environment can affect them. Therefore, aviation stakeholder collectively needs to demonstrate and justify that their systems are required, are spectrally efficient, and do not place undue burden on the adjacent bands. The justification will include, *inter alia*, why aviation requires a level of integrity that exceeds most other industries and how through its processes and procedures it delivers that level of integrity. Recent international spectrum proceedings have highlighted that aviation does not have sufficient detail of how all its systems interact at the *Radio Frequency* (RF) level, nor does it have comprehensive guidance for how new aviation radio systems should be designed and introduced in this modern day. In recognition of this, EUROCAE and RTCA have initiated a joint committee on spectrum to develop suitable guidance. The guidance is intended to be applied by other Working Groups to all new equipment standards developments (e.g., MOPS) or revisions of existing standards. The objective is to ensure that the RF characteristics of aeronautical systems are specified in a consistent and complete manner including, for example, receiver and transmitter performance, resilience, out of band emissions and spectral efficiency, with sufficient margins and protections to ensure safe system operations and facilitate compatibility with adjacent band systems. This work is being carried out between 2022 and 2024 and should assure robustness of aeronautical systems, facilitate any future evaluation of compatibility with other systems and ensure that the usage of the allocated spectrum is as efficient as possible.

The same risks that apply with spectrum sharing, apply for shared radio infrastructure. In this sense it is imperative that the deploying aviation wireless services on commercial radio platforms is considered from a wider perspective, including that of the spectrum that is allocated which is not in the pool of spectrum allocated to aviation. Principally this has implications on the integrity of the CNS services. This is because when spectrum is allocated to a given service, all the necessary spectrum compatibility studies and the associated technical and procedural mitigations put in place in the regulations are tailored to these commercial services, and with compromises that are suitable for these services, and not with the exacting safety and performance requirements associated with aeronautical CNS services. As a consequence, any industrial and cost-effectiveness gains of sharing radio infrastructure and associated non-protected spectrum (not designated to aviation) can be quickly lost to productivity losses in the day-of-operations when maintaining the target level of safety.

While studies are ongoing, it is widely recognised that the only means to sustaining the CNS infrastructure and its transition to future services is for aviation to continue protecting access to the bands allocated to it in the ITU, and to live within its means by deploying best practices and by using the allocated spectrum as efficiently as possible. The implications of this are that

- Infrastructure planners need to account for the strong influence of the spectrum environment in the overall end-to-end performance
- Performance-based standards for CNS delivery by “tech agents” is not a substitute for designated protected aeronautical spectrum
- It is as important as ever to understand the manner in which the environment surrounding (and also within) aeronautical spectrum bands are evolving through monitoring and collection of data.

Appendix E Consideration about CNS airborne capabilities

Airplanes are equipped with many radio systems that are installed to support Air operation, Air traffic Management, safety and regularity of flight, Airline operations and maintenance management and passenger connectivity. It is worth noting that radio systems installed in an aircraft are constrained by the limited space, by the antenna(s) location, by the power consumption and by the weight of the systems and their costs. As such, there is a need on one side to reduce the footprint of systems to be installed so that to contain the associated penalties and on the other side, to install systems which are able to cope with aeronautical regulation requirements and to satisfy the customer expectations in terms of operation and connectivity.

Amongst all the radio systems, CNS systems, used to support safety and regularity of flights, are highly regulated to enable aircraft operators to meet planned times of departure and arrival and adhere to preferred flight profiles with minimum constraints and no compromise on safety. Minimum CNS required capabilities are specified in local and global aeronautical regulations prescribed by ICAO and Civil Aviation Authorities (CAA).

This Appendix E provides a quick overview of CNS systems and associated standards which include essential requirements to which CNS systems shall comply with.

E.1 Minimum capabilities

Current capabilities are categorised along the three main functions Communication (COM), Navigation (NAV) and Surveillance (SUR).

Communication systems allow aircraft to communicate, notably with ground-based Air Traffic Controllers and Airline Operational Centres. Those systems are able to provide Voice and Data communication. The traditionally deployed systems rely on HF and VHF communications. Alternatively, to ensure non-line of sight communication with an increased capacity compared to HF/VHF communication, Satellite communications could be used especially over oceanic airspace. During the last decade discussions are ongoing on possible new ground communication networks offering better datalink capacity (namely AeroMACS, LDACS).

Navigation systems allow aircraft to adequately maintain a specified route of flight for a given destination. The global navigation infrastructure is composed of a multitude of ground-based beacons (NDB, VOR, DME, and ILS) which are able to provide bearing and distance information which support an aircraft to determine automatically its position. In complement to these traditional beacon networks, GNSS is also able to provide some information on the position of an aircraft but taking into account vulnerabilities of this system, ground networks are still required. In complement, Aircraft is also equipped with Low Range Radio Altimeter (LRRA) system to measure the distance from the airplane to the ground and outputs radio altitude data.

Surveillance systems allow air traffic controllers to track the location of individual aircraft. Surveillance systems rely notably on various ground radar stations either independent or dependent of airborne transmissions (some aircraft are equipped with transponders to respond to radar interrogations). Aircraft are also equipped with system used for surveillance operations which are:

- Automatic Dependent Surveillance – Broadcast (ADS-B) which relies on the broadcasting of aircraft localization information. This information could be received by ground stations, satellites or by other aircraft.
- Airborne Collision Avoidance System (ACAS/TCAS) which allows to track other aircraft in the surrounding airspace through replies from their transponders.

Table 47 summarises example of minimum CNS capabilities configuration required for flight operation depending on the aircraft category.

CNS	System	Single Aisle		Long Range	
		Basic / Optional	Min. radio system	Basic / Optional	Min. radio system
COM	HF (Voice/Datalink)	Optional	1 or 2	Basic	1 or 2
COM	VHF (Voice)	Basic	3 (or 2 MVDR)	Basic	3 (or 2 MVDR)
COM	VHF (Datalink)	Optional	1	Basic	1
COM	SATCOM	Optional	1	Basic	1
NAV	ILS	Basic	2	Basic	2
NAV	VOR	Basic	2	Basic	1 or 2
NAV	Marker Beacon	Basic	1	Basic	1
NAV	Low Range Radio Altimeter (LRRA)	Basic	2	Basic	2 or 3
NAV	GNSS	Basic	2	Basic	2
NAV	GBAS Landing System (GLS)	Basic		Basic	
NAV	DME	Basic	2	Basic	1 or 2
SUR	ATC Transponder	Basic	2	Basic	2
SUR	ADS-B In	Basic		Basic	
SUR	ADS-B Out	Basic		Basic	
SUR	ACAS/TCAS	Basic	1	Basic	2

Table 47 Example of minimum legacy system to serve CNS capabilities for flight operation

E.2 Minimum requirements

As indicated in preamble of this Appendix E, CNS systems contributing to safety and regularity of flights are highly regulated from the design to the validation of the good operation of the system to offer the expected interoperability and capacity.

Requirements are enforced through the applicable aeronautical regulation and especially through in airworthiness standards and other applicable guidance material that makes possible a certain CNS capability.

The regulations governing CNS systems are predominately operational regulations (e.g., 14CFR Part 121). The regulations along with applicable FAA Technical Standard Orders (TSOs)/European TSOs, FAA

Advisory Circulars, and EASA Acceptable Means of Compliance (AMCs) for the applicable CNS systems identified in this appendix are listed in Table 48 below.

CNS	System	14CFR Regulation(s)	TSO/ETSO	AC/AMC
COM	HF (Voice)	91.511, 121.99, 121.349, 121.351	C170()	N/A
COM	HF (Datalink)		C158()	
COM	VHF (Voice)	91.511, 121.99, 121.347, 121.349	C169()	AC 20-67(), CS-ACNS ()
COM	VHF (Datalink)		C128(), C160() [VDL]	
COM	SATCOM	121.99, 121.351	C159()	AC 20-150()
NAV	ILS	121.349	Localiser: C36() Glideslope: C34()	AC 120-28(), AC 120-29(), AC 120-118, AC 20-191 (Draft) NPA 2018-06 (Draft)
NAV	VOR	121.349	C40()	AV 20-138()
NAV	Marker Beacon	121.349	C35()	N/A
NAV	LRRA	121.354	C87()	AC 120-118()
NAV	GNSS	121.351	L1 frequency C145() C146()	AC 90-107() AC 20-138() CS-ACNS ()
NAV	GLS	N/A	GBAS: C161() VDB[45]: C162()	AC 120-118() AC 20-191 (draft) NPA 2018-06 (draft)
NAV	DME	121.349	C66()	AC 120-38()
SUR	ATC Transponder	91.215, 121.356	C112()	AC 20-151() CS-ACNS()
SUR	ADS-B In	N/A	RX: C166() Apps: C195()	AC20-172()
SUR	ADS-B Out	91.225, 91.227	C166()	AC 20-165() CS-ACNS()
SUR	ACAS/TCAS	121.356	TCAS: C119() ACAS-X: C219()	AC 20-151()[46]

Table 48 CNS systems related standards

[45] Very High Frequency Data Broadcast

[46] Only for TCAS. AC for ACAS-X ongoing.

Appendix F ICAO Space Weather Service

Operational context of the space weather service:

Civil aviation may by impacted by phenomena of solar origin, notably with respect to HF communications, GNSS-based navigation and surveillance, satellite communications and augmented radiation aboard aircraft.

ICAO has therefore organized a space weather information service whereby advisories will be disseminated through the Aeronautical Fixed Service (AFS), including the Aeronautical Fixed Telecommunications Network (AFTN) and the Aeronautical (or ATS) Message Handling System (AMHS), in cases of moderate or severe impacts to the 4 domains identified above. The advisories will be produced by 3 ICAO-designated global centres (ACFJ, PECASUS, SWPC) operating on a rotation basis.

Oversighted by the DGAC and supported by the French scientific community, ESSP, CLS and Météo-France form the SPECTRA consortium providing GNSS and Radiation service in the ACFJ consortium since November 2019.

Role of the ESSP within the SPECTRA consortium

One of the sources of ICAO Space Weather Monitoring data is setup by the ACFJ[47]/SPECTRA consortium where ESSP is among the responsible for issuing alerts relative to GNSS. To monitor the impact of the Space Weather situation on the GNSS services, the ESSP uses near real time TEC global data maps provided by the UPC and near real time scintillation maps provided by CLS within SPECTRA consortium to achieve a global awareness about potential GNSS disturbances. Using the collected TEC and Scintillation data, the ESSP issues GNSS alert advisories if TEC or scintillation data exceed thresholds defined by the ICAO Manual on Space Weather Information in Support of International Air Navigation [40].

The GNSS advisories generated by the ESSP are transmitted to Météo-France which is then in charge of disseminating the Alert toward the aviation community via its dedicated facilities. The alert advisory defines mainly the date and time of the event, the duration, the forecast over the next 24 hours, the region of impact and a description of the expected impact.

Within ACFJ/SPECTRA, ESSP is responsible for issuing alerts relative to GNSS. From a GNSS perspective, space weather events can affect the region of the Earth's upper atmosphere containing free electrons and ions, extending from about 60 to 1,000 km which is the ionosphere. GNSS signals passing through a disturbed ionosphere can experience two main phenomena: scintillations and total electron content (TEC) variation.

To monitor the impact of the Space Weather situation on the GNSS services, the ESSP uses near real-time TEC global data maps provided by the UPC and near real time scintillation maps provided by CLS within SPECTRA consortium to achieve a global awareness about potential GNSS disturbances.

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[47] The ACFJ: an international consortium that groups Australia, Canada, France and Japan

Using the collected TEC and Scintillation data, the ESSP issues GNSS alert advisories if TEC or scintillation data exceed thresholds defined by the ICAO. These thresholds define also the intensity of the space weather event in the generated advisory.

Advisories are text messages provided by space weather global centres designated by ICAO. They are disseminated to civil aviation, and they specify potential impact and area of impact of several space weather phenomena.

The GNSS advisories generated by the ESSP are transmitted to Météo-France which is then in charge of disseminating the Alert toward the aviation community via its dedicated facilities.

The alert advisory defines mainly the date and time of the event, the duration, the forecast over the next 24 hours, the region of impact and a description of the expected impact. Hereunder is an example of a GNSS Space weather advisory content according to AIC France A23/19 [41]:

FNXX01 LFPW 241425 SWX ADVISORY STATUS: TEST DTG: 20170908/1215Z SWXC: ACFJ ADVISORY NR: 2017/09 SWX EFFECT: GNSS SEV OBS SWX: 08/1215Z HNH HSH W180-E180 FCST SWX +6HR: 08/1900Z NOT AVBL FCST SWX +12HR: 09/0100Z NOT AVBL FCST SWX +18HR: 09/0700Z NOT AVBL FCST SWX +24HR: 09/1300Z NOT AVBL RMK: ACTIVE SEVERE SCINTILLATION DETECTED ABOVE CANADA AND MODERATE LEVEL DETECTED ABOVE NORTHERN EUROPE/RUSSIA LEADING TO POTENTIAL LOSS OF GNSS SIGNALS AND DEGRADED TIMING AND POSITIONING PERFORMANCE. NXT ADVISORY: WILL BE ISSUED BY 20170908/1900

Table 49 Advisory alert content (example)

Appendix G Acronyms and Terminology

Term	Definition
ABAS	Aircraft-Based Augmentation System
ACAS	Airborne Collision Avoidance Systems
ACM	Airspace Capacity Management
ACP	Actual Communication Performance
ACTP	Actual Communications Technical Performance
ADS-B	Automatic Dependent Surveillance - Broadcast
ADS-C	Automatic Dependent Surveillance - Contract
ADSP	Aeronautical Data Services Provider
AeroMACS	Aeronautical Mobile Airport Communication System
AIM	Aeronautical Information Management
AMAN	Arrival Manager
ANS	Air Navigation System
ANSP	Air Navigation Service Provider
A-PNT	Alternative Positioning, Navigation and Timing
APT	Airport
APV	Approach with Vertical Guidance
AR	Authorisation Required
ARINC	Aeronautical Radio Incorporated
ASE	Altimetry System Error
ASP	Actual (Operational) Surveillance Performance
ATC	Air Traffic Control

Term	Definition
ATC	Air Traffic Control
ATCC	Air Traffic Control Centre
ATFM	Air Traffic Flow Management
ATM	Air Traffic Management
ATN	Aeronautical Telecommunication Network
ATS	Air Traffic Services
ATSP	Air Traffic Services Provider
ATSU	Air Traffic Services Unit
AU	Airspace User
CDI	Course Deviation Indicator
CMS	Central Monitoring Server
CNS	Communication, Navigation and Surveillance
COM	Communication
CPDLC	Controller-Pilot Data Link Communications
CSP	Communication Service Provider
DCL	Departure Clearance
DFMC	Dual-Frequency Multi-Constellation
DLIC	Data Link Initiation Capability
DLS IR	Data Link Services Implementing Rule
DME	Distance Measuring Equipment
DPMF	Datalink Performance Monitoring Function
DRNP	Dynamic Required Navigation Performance

Term	Definition
DSB-AM	Double Side Band – Amplitude Modulation
EAD	European AIS Database
EASA	European Aviation Safety Agency
EGNOS	European Geostationary Navigation Overlay Service
EMIT	European Monitoring of Interrogators and Transponders
ENR	En-route
ESA	European Space Agency
ESASSP	EUROCONTROL Specification for ATM Surveillance System Performance
ESSP	European Satellite Services Provider
ET	Expiration Time
EU	European Union
EUSW	EGNOS User Support Website
EVS	Enhanced Vision System
EWA	EGNOS Working Agreement
FCI	Future Communication Infrastructure
FDP	Flight Data Processing
FMS	Flight Management System
FRA	Free Route Airspace
FRT	Fixed Radius Transition
FTE	Flight Technical Error
GAST-D	GBAS Approach Service Type D (CAT III)
GAST-F	GBAS Approach Service Type F (DFMC GNSS CAT III)

Term	Definition
GBAS	Ground-Based Augmentation System
GLS	GBAS Landing System
GNSS	Global Navigation Satellite System
GOLD	Global Operational Data Link Document
GPS	Global Positioning System
GRC	Galileo Reference Centre
H2020	HORIZON 2020 (research and innovation programme of the EU, 2014-2020)
HCE	Horizontal Coupling Error
HF	High Frequency
HMU	Height Monitoring Unit
HUD	Head-Up Display
ICAO	International Civil Aviation Organization
ILS	Instrument Landing System
IP	Internet Protocol
KPA	Key Performance Areas
KPI	Key Performance Indicators
LDACS	L-Band-Digital Aeronautical Communication System
LOC	Localiser
MET	Meteorology
MON	Minimum Operational Network
MTBF	Mean Time between Failures
MTCD	Medium-Term Conflict Detection

Term	Definition
MTTR	Mean Time to Repair
NAV	Navigation
NavAid	Navigation Aid
NDB	Non-Directional Beacon
NF IR	Network Function Implementing Rule
NM	Network Manager
NPA	Non-Precision Approach
NSE	Navigation System Error
NSP	Navigation Systems Panel
OBPMA	On-Board Performance Monitoring and Alerting
OSED	Operational Service and Environment Description
PANS	Procedures for Air Navigation Services
PBA	Performance-Based Approach
PBAOM	Performance Based Aerodrome Operating Minima
PBC	Performance-Based Communication
PBN	Performance-based Navigation
PBN IR	Performance-based Navigation Implementing Rule
PBS	Performance-Based Surveillance
PDE	Path Definition Error
PENS	Pan-European Network Service
PORT	Pilot Operational Response Time
PSE	Path Steering Error

Term	Definition
PSR	Primary Surveillance Radar
RAIM	Receiver Autonomous Integrity Monitoring
RAM	Reliability, Availability and Maintainability
RCMP	Required Communication Monitored Performance
RCP	Required Communications Performance
RCTP	Required Communication Technical Performance
RF	Radius to Fix
RFF	Radio Frequency Function
RFI	Radio Frequency Interference
RMU	Remote Monitoring Units
RNAV	Area Navigation
RNP	Required Navigation Performance
RSOO	Regional Safety Oversight Organization
RSP	Required Surveillance Performance
RVR	Runway Visual Range
RVSM	Reduced Vertical Separation Minimum
SARPs	Standards And Recommended Practices
SASS-C	Surveillance Analysis Support System for ATC Centres
SATCOM	Satellite Communication
SBAS	Satellite-Based Augmentation System
SDD	Service Definition Document
SESAR	Single European Sky ATM Research Programme

Term	Definition
SI3AM	Surveillance Interrogators and Avionics, ACAS & Altimetry Monitoring
SJU	SESAR Joint Undertaking
SoL	Safety of Life
SPI IR	Surveillance Performance and Interoperability Implementing Regulation
SPM	Surveillance Performance Monitoring
SPR	Safety and Performance Requirements
SUR	Surveillance
SWAIR	Space Weather and GNSS Monitoring Services for Air Navigation
SWIM-TI	System-Wide Information Management Technical Infrastructure
TBS	Time Based Separation
TMA	Terminal Control Area
TRL	Technology Readiness Level
TSE	Total System Error
UHF	Ultra-High Frequency
VDB	VHF Data Broadcast
VDL 2	VHF Data Link Mode 2
VHF	Very High Frequency
VLD	Very Large Demonstrations
VNAV	Vertical Navigation
VoIP	Voice over Internet Protocol
VOR	Very High Frequency Omnidirectional Radio Range

Co-funded by the European Union