

Initial Economic Evaluation (ECO-EVAL) for Data Driven Cost Effective 5G Integrated CNS As a Service – SESAR Solution 0521

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Abstract

This document describes the initial Economic Evaluation (ECO-EVAL) for SESAR Solution 0521 of the ANTENNAE project, regarding Data Driven Cost Effective 5G integrated Communication, Navigation and Surveillance (CNS) As a Service at Technology Readiness Level (TRL) 2. It presents the benefits provided by the solution and assesses at a high level their economic impact on the main stakeholders involved in its deployment and operation. The aim is to determine whether the solution is worth deploying in European Civil Aviation Conference (ECAC) airspace from an economic standpoint.

Authoring & approval

Author(s) of the document

Organisation name	Date
COLLINS	03/10/2025
VTT	03/10/2025
TID	03/10/2025

Reviewed by

Organisation name	Date
COLLINS	03/10/2025
VTT	03/10/2025
TID	03/10/2025

Approved for submission to the SESAR 3 JU by

Organisation name	Date
COLLINS	03/10/2025
VTT	03/10/2025
TID	03/10/2025

Rejected by¹

Organisation name	Date
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¹ Representatives of the beneficiaries involved in the project.

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ANTENNAE

DATA DRIVEN COST EFFECTIVE 5G INTEGRATED CNS AS A SERVICE

ANTENNAE

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1 Executive summary

This document provides the economic evaluation (ECO-EVAL) related to the European Civil Aviation Conference (ECAC) level deployment of **SESAR Solution 0521** “Data Driven Cost Effective 5G integrated CNS As a Service” targeting **TRL2** at the end of the **ANTENNAE** project.

The arrival of new users in ECAC airspace, such as Unmanned Aircraft Systems (UAS), coupled with the increase in aircraft traffic, requires a rethink of the use of communication, navigation and surveillance (CNS) services in order to guarantee quality of service, efficiency and safety. Solution 0521 proposes to unify the 3 domains by using **xG terrestrial and non-terrestrial networks for Low-Level (LL) and Very-Low Level (VLL) altitudes**, thus offering an Integrated CNS (ICNS) model that can guarantee a high data rate, low latency, and continuity between Air Traffic Management (ATM) and U-space Traffic Management, also referred to as UAS Traffic Management (UTM).

Consequently, deploying such a solution requires the collaboration of stakeholders covering both ATM and U-space domains. The main benefits expected are **interoperability between the organisations responsible for providing air navigation services**, such as Air navigation Services providers (ANSPs), and ensuring **the U-space operations**, such as Common Information Services Providers (CISP) and U-space Service Providers (USSP). Telecoms operators will also play a major role in setting up ICNS, responsible for providing access to the xG networks at the heart of the solution. The main costs for users of the solution will therefore come from subscribing to these services and adapting equipment to these networks.

This ECO-EVAL therefore makes it possible to carry out an initial evaluation of the solution in the economic context as conceived by SESAR, making it possible to determine whether the solution is worth deploying in ECAC airspace. The assessment presented in this document is **purely qualitative**. The conclusions drawn are intended to be **reinforced soon by the results of the validation exercises** to be conducted. It should also be noted that additional assessments, especially concerning the security implications, will be conducted to thoroughly evaluate the impacts of Solution 0521.

2 Introduction

2.1 Purpose of the document

This document defines the economic evaluation (ECO-EVAL) for SESAR Solution 0521 “Data Driven Cost Effective 5G Integrated CNS As Service” (ANTENNAE) at Technology Readiness Level (TRL) 2. ECO-EVAL places the solution and the problem it hopes to solve within the economic context of ECAC airspace.

The document provides a qualitative analysis of the costs and benefits of the solution. Particularly, its emphasis is placed on the economic implications and the impact that its deployment will have on the stakeholders as defined in the SESAR architecture.

2.2 Scope

The ECO-EVAL of ANTENNAE project (SESAR Solution 0521) aims to assess the impacts in terms of costs and benefits of the solution by placing it in the economic context defined in the SESAR architecture.

Current CNS technologies are facing the arrival of new users in ECAC airspace. The growing increase in legacy aviation traffic, coupled with the emergence of UAS, requires new resources to cope with the specific constraints of these new vehicles, while ensuring quality of service, efficiency and safety. This also demands coordination between legacy aviation and UAS. The solution proposes to unify the three domains, thus speaking of ICNS using terrestrial and non-terrestrial xG networks. This approach aims to ensure high data rate and low latency connectivity while providing continuity between ATM and U-space. Although not specifically aimed at U-space, the solution focuses on **VLL (up to 400 ft, 150 m AGL) and LL altitudes (up to 10 000 ft, about 3 000 m MSL), targeting both urban and rural areas.**

To establish a qualitative economic analysis of the solution, the focus is on the different stakeholders involved in its deployment or who will be directly impacted by it, resulting in investment and/or operational costs. These include (but are not limited to):

- USSPs,
- ANSPs,
- Network Managers (NM),
- UAS Operators,
- Vertical Take-off and Landing (VTOL) Capable Aircraft (VCA) Operators.

Solution 0521 targets 3rd Generation Partnership Project (3GPP) **xG (i.e. 5G, 6G, etc.)**, which **encompasses 5G and further standards**. For this reason, we will prefer the use of the term xG over 5G in this document. However, occasional references to 5G remain, as it is currently the generation defined and deployed under 3GPP mobile communication standards.

This analysis is carried out in the **third quarter of 2025**, using the latest resources made available by SESAR, 3GPP, aviation and telecommunication standards to date.

2.3 Intended readership

This document is addressed to a broad audience of stakeholders, ranging from ANTENNAE project partners and SESAR JU stakeholders to stakeholders involved in regulating and developing ECAC airspace. The audience includes, but is not limited to:

- **ANTENNAE project and solution partners:** collectively develop content and track its progress,
- **SESAR Joint Undertaking:** follow the progress of the project in its capacity and for its feedback on the present document,
- **ANSPs:** understand the purpose of the solution and potentially prepare for its integration,
- **ATM and U-space service providers:** understand how the ICNS solution supports both ATM and U-space,
- **Standardisation bodies:** establish new standards adapted to the new use of Airspace and U-space, CNS technologies,
- **Airport/Airfield and Vertiport owners/providers:** monitor developments in low-level (low altitude) air traffic,
- **Airspace users:** adapt to the arrival of low-altitude operations and to understand how they will be integrated into the airspace,
- **Aerospace industry:** understand advances in ICNS regarding the development and regulation of low-altitude operations,
- **Scientific community:** keep abreast of innovative advances in CNS technologies.

2.4 Background

Solution 0521 aims to consolidate the work carried out by several past projects, particularly on the concept of ICNS. The solution is also based on previous research on U-space. It includes the following projects:

- **SESAR PJ14-W2 I-CNSS** (Integrated Communication, Navigation and Surveillance System) [13]: The project brings together a suite of interoperable solutions, designed to meet operational requirements of ATM, bringing operational and efficient improvements by taking advantage of cross-domain synergies, satellite-based systems and digital technology. By addressing interoperability between the three CNS domains, and studying the various data links available, the PJ.14-W2-ICNSS project provides a solid basis for the study and development of ICNS as a service. Cost Benefit Analyses (CBAs) for some of the different solutions on which Solution 0521 is based are available:
 - Solution PJ.14-W2-61 Hyper Connected ATM [14],
 - Solution PJ.14-W2-81 Long-term alternative Position, Navigation and Timing (A-PNT) [15][16].
- **FACT** (Future All Aviation CNS Technology) [17]: The FACT project proposes a first assessment of 4G and 5G networks for the establishment of a performance-based ICNS with the aim of

complementing existing CNS technologies for ATM and U-space. No CBA nor ECO-EVAL is currently publicly available.

- **AiRMOUR** (Enabling sustainable AiR MObility in URrban contexts via emergency and medical services) [18]: The project focused on integrating Urban Air Mobility (UAM) into emergency medical services. It explored how drones and air taxis could support healthcare logistics, such as transporting doctors or medical supplies. Real-life demonstrations took place in Finland, Norway, and Germany, with simulations in Luxembourg and Dubai. The project proposes a CBA comparing the operation of UAS with traditional medical transport, enabling an estimate of the costs associated with the operation of UAS and the resulting infrastructure and technological developments [19].

Several ongoing projects fall within the areas covered by the solution

- **EALU-AER** (Enhanced Automation for U-Space/ATM integration) [20]: The project participates in U-space deployment and U-space/ATM integration through the development of an infrastructure platform structured around Shannon airport in Ireland. The experimental results and achievements of the project will be used for Solution 0521 validation exercises. No ECO-EVAL nor CBA has been carried out.
- **FCDI** (Future Connectivity and Digital Infrastructure) [21]: The project main objective is to improve the communication infrastructure's cost efficiency, by enabling a more extensive use of public networks, allowing communication infrastructure scalability and sustainability with an extended usable spectrum and the use of existing public infrastructures. In addition, FCDI will enable global communication infrastructure interoperability by allowing the use of alternative communication protocols and by accommodating specific technical, commercial and regulatory needs. A CBA is currently being written.
- **ETHER** (sElf-evolving terrestrial/non-Terrestrial Hybrid nEtwoRks) [22]: The project develops solutions for a Unified Radio Access Network (RAN) and for the energy-efficient, Artificial Intelligence (AI)-enabled resource management across the terrestrial, aerial and space domains, while creating the business plans driving future investments in the area. To that end, ETHER introduces and combines a series of key technologies under a unique 3D multi-layered architectural proposition that brings together: a User Equipment (UE) antenna design, a robust unified waveform, energy-efficient seamless horizontal and vertical handover policies, network orchestration, a flexible payload system, joint communication, compute and storage resource allocation, and energy-efficient semantics-aware information handling techniques. No economic assessment deliverables have been produced.
- **SPATIO** (U-Space Separation Management) [23]: The project aims to address the separation between UAS, particularly in the context of strategic and tactical conflict resolution, to enable dynamic, efficient and safe capacity management and avoid collision. A CBA is currently carried out.

2.5 Structure of the document

The present document is divided into nine chapters following this structure:

- **Chapter 1:** Executive summary: summarizes the key elements and concepts of the SESAR solution ECO-EVAL,

- **Chapter 2:** Introduction: presents the purpose and scope of the document. It also introduces the document's target audience and the background on which the project is based. A glossary of terms and a list of acronyms are provided for ease of reading,
- **Chapter 3:** Objectives and scope of the ECO-EVAL: describes the purpose of the ECO-EVAL as well as the problem that the solution intends to solve, while presenting its main characteristics,
- **Chapter 4:** Benefits: presents the benefits of the solution and how they are achieved, as well as their overall impact,
- **Chapter 5:** Cost assessment: describes the high-level costs involved in implementing the solution and how they relate to the stakeholders,
- **Chapters 6 to 8** are not applicable at TRL2 level and will be completed when the solution will reach TRL4. However, those sections are retained, in accordance with the instructions given in the SESAR template,
- **Chapter 9:** Next steps and recommendations.

The document also includes one appendix:

- **Appendix A:** Maturity criteria (self-assessment): provides a self-assessment of this ECO-EVAL based on the maturity criteria applicable to TRL2.

2.6 Glossary of terms

Term	Definition	Source of the definition
ECO-EVAL reference scenario	The scenario against which the solution is compared, i.e. the situation without the proposed SESAR solution (but including other improvements which have been implemented in the meantime).	DES transversal CBA team
ECO-EVAL solution scenario	The scenario with the proposed SESAR solution and other improvements which have been implemented in the meantime.	DES transversal CBA team
Economic evaluation (ECO-EVAL)	The economic evaluation assesses the potential benefits that an innovative idea or application under analysis by an exploratory research project could provide against an initial high-level estimation of the costs that it may imply.	SESAR 3 JU Project Handbook – Programme Execution Framework, edition 01.00, 11 April 2022
Implementation cost	All costs related to the acquisition and implementation of the SESAR solution.	SESAR 16.06.06_D26_03 Methods to Assess Cost and Benefits for CBAs, ed. 00.02.02
Investment cost	The investment cost covers the pre-implementation costs (e.g., feasibility studies) and the implementation costs (e.g., system	DES transversal CBA team

Term	Definition	Source of the definition
	integration). Note that the pre-implementation costs shall not consider the SESAR Research and Innovation (R&I) costs.	
Operating cost	All costs related to the change in daily operations that is brought about by the SESAR solution.	SESAR 16.06.06_D26_03 Methods to Assess Cost and Benefits for CBAs, ed. 00.02.02
Pre-implementation cost	All costs that need to be used up to define the needs, to develop solutions, and to decide which solution best serves the needs. Note that the SESAR R&I costs shall not be included as costs in any DES CBA/ECO-EVAL.	SESAR 16.06.06_D26_03 Methods to Assess Cost and Benefits for CBAs, ed. 00.02.02
Air Traffic Management	The dynamic, integrated management of air traffic and airspace including air traffic services, airspace management and air traffic flow management – safely economically and efficiently – through the provision of facilities and seamless services in collaboration with all parties and involving airborne and ground-based functions.	ICAO 4444 [24]
Exploratory Research	Explores new concepts beyond those identified in the European ATM Master Plan or emerging technologies and methods. The knowledge acquired can be transferred into the SESAR industrial and demonstration activities.	European ATM Master Plan [25]
Integrated CNS	A unified system that enables interdependency between communication, navigation, and surveillance (CNS) technologies, taking full advantage of cross-domain synergies to improve service quality, spectrum efficiency, and CNS capabilities.	ANTENNAE project initial definition [11]
Low-Level Altitude	Altitude within 8 300 metres or 27 230 feet above Mean Sea Level (MSL) 10 000 ft MSL is an upper limit for low-altitude Innovative Air Mobility operations.	ANTENNAE project initial definition [11]
Very Low-Level Altitude	Altitude below 150 meters or 500 feet AGL	ICAO UTM Framework Edition 4 [26]

Term	Definition	Source of the definition
Unmanned Aircraft System	Unmanned aircraft system (UAS) means an unmanned aircraft and the equipment to control it remotely	Commission Delegated Regulation (EU) 2019/945 of 12 March 2019 on unmanned aircraft systems and on third-country operators of unmanned aircraft systems, European Commission, 2019, C/2019/1821 [27][28]
U-space	<p>U-space airspace means a UAS geographical zone designated by Member States, where UAS operations are only allowed to take place with the support of U-space services</p> <p>U-space service means a service relying on digital services and automation of functions designed to support safe, secure and efficient access to U-space airspace for a large number of UAS</p>	<p>Commission Implementing Regulation (EU) 2021/665 of 22 April 2021 on a regulatory framework for the U-space (C/2021/2671) [29]</p> <p>SESAR Smart ATM U-space and urban air mobility [30]</p>

Table 1: glossary of terms

2.7 List of acronyms

Term	Definition
3GPP	3 rd Generation Partnership Project
5G	5 th Generation of Cellular Network
ACARS	Aircraft Communication Addressing and Reporting System
ACAS	Airborne Collision Avoidance System
ADS-B	Automatic Dependent Surveillance - Broadcast
ADS-C	Automatic dependent surveillance – contract
ADS-L	Automatic Dependent Surveillance-Light
AGL	Above Ground Level
ANSP	Air Navigation Service Provider
AOC	and Aeronautical Operational Control

Term	Definition
A-PNT	Alternative Position Navigation and Timing
A-SUR	Alternate Surveillance
ATC	Air Traffic Control
ATCO	Air Traffic Control Officer
ATM	Air Traffic Management
ATSU	Air Traffic Services Unit
BIM	Benefit Impact Mechanism
BLOS	Beyond Line-Of-Sight
BVLOS	Beyond Visual Line-Of-Sight
C2	Command and Control
CAP	Capacity
CAPEX	Capital Expenditure
CBA	Cost benefit analysis
CEF	Cost efficiency
CISP	Common Information Service Provider
CNPC	Control and Non-Payload Communication
CNS	Communication Navigation Surveillance
CONOPS	Concept of Operations
CPDLC	Controller-Pilot Data Link Communication
DAA	Detect And Avoid
DES	Digital European Sky
DME	Distance Measuring Equipment
DSP	Datalink Service Provider
E911	Enhanced 911
ECAC	European Civil Aviation Conference

Term	Definition
ECO-EVAL	Economic evaluation
ENV	Environment
eVTOL	electric Vertical Take-Off and Landing
FAA	Federal Aviation Administration
FOC	Final Operating Capability
FR2	Frequency Range 2
FR3	Frequency Range 3
FRD	Functional requirements document
GA	Grant agreement
GBAS	Ground-Based Augmentation System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HCATM	Hyper Connected ATM
HE	Horizon Europe
HF	High Frequency
IAM	Innovative Air Mobility
ICAO	International Civil Aviation Organization
ICNS	Integrated CNS
ID	Identifier
IFR	Instrumental Flight Rules
IOC	Initial Operating Capability
IP	Internet Protocol
JCS	Joint Communication and Sensing
KPA	Key Performance Area
KPI	Key Performance Indicator

Term	Definition
LL	Low-Level
LOS	Line-Of-Sight
MIMO	Multiple-Input Multiple-Output
MNO	Mobile Network Operators
MSL	Mean Sea Level
NM	Network Manager
NMOC	Network Manager Operations Centre
NOI	Noise
NTN	Non-Terrestrial Network
OPEX	Operating Expenses
OSED	Operational Service and Environment Description
PI	Performance indicator
PSAP	Public Service Answering Point
PSR	Primary Surveillance Radar
QoS	Quality of Service
R&I	Research and Innovation
RAN	Radio Access Network
RES	Resilience
ROI	Return on Investment
RPAS	Remotely Piloted Aircraft System
SAF	Safety
SBAS	Satellite-Based Augmentation System
SEC	Security
SESAR	Single European sky ATM research
SESAR 3 JU	SESAR 3 Joint Undertaking

Term	Definition
SIM	Subscriber Identification Module
SOD	Start Of Deployment date
SSR	Secondary Surveillance Radar
SWaP	Size Weight and Power
TDOA	Time-Difference Of Arrival
TMA	Terminal manoeuvring area
TN	Terrestrial Network
TRL	Technology readiness level
UA	Unmanned Aircraft
UAS	Unmanned Aircraft Systems
UAT	Universal Access Transceiver
URLLC	Ultra-Reliability Low-Latency Communication
USSP	U-space Service Provider
UTM	UAS Traffic Management
VCA	Vertical Take-off and Landing Capable Aircraft
VDLM2	VHF Data Link Mode 2
VFR	Visual Flight Rules
VHF	Very High Frequency
VLL	Very Low-Level
VTOL	Vertical Take-Off and Landing
xG	x th Generation of Cellular Network

Table 2: list of acronyms

3 Objectives and scope of the ECO-EVAL

3.1 Problem addressed by the SESAR solution

Developments in ECAC airspace capacity, and in particular the emergence of U-space, are leading to the arrival of new LL and VLL entrants. Those aircraft, often identified as Unmanned Aircraft (UA) or VCA, differ from legacy aviation in their CNS capabilities, currently not designed and optimised for such aircraft. In addition to the new requirements that these vehicles need to ensure their operation, they face constraints in terms of Size, Weight, and Power (SWaP), making it necessary to find solutions to overcome these limitations for embedded CNS systems.

The increase in air traffic, both for new and existing aircraft categories, also raises concerns with regard to spectrum scarcity. Indeed, the spectrum allocated to the Communication (C), Navigation (N) and Surveillance (S) functionalities is fragmented and poorly integrated. Each domain uses different aircraft onboard hardware transceivers, diverse ground infrastructures and different frequency bands. New CNS needs mean rethinking the use of the spectrum, to maintain efficiency, avoid the congestion that threatens to occur on some of the most widely used frequencies, and ensure sufficient resources for all new users.

Finally, even though the interoperability between ATM and U-space appears essential to ensure a high degree of safety for all operations while minimising the impact on current airspace users, and the convergence of those two domains is expected in the future, there are many technological and organisational obstacles to achieving that. The ATM world has developed over a century, and both the processes and the technological excellence have matured significantly, while remaining a closed, mostly self-contained ecosystem. The widespread use of IP-based connectivity brought significant disruption to ATM by introducing new threats, e.g., related to cybersecurity. Now, the new entrants are bringing even further disruption due to the infancy of the Innovative Air Mobility (IAM) operations and associated technologies, while safety requirements cannot be sacrificed.

3.2 SESAR solution description

The emerging U-Space/UTM concept envisages a new generation of small, highly manoeuvrable, and highly automated aircraft operating at low altitudes alongside existing helicopter and general aviation users. The VCA are intended to operate outside the U-space airspace, but those will likely need to penetrate it for take-off and landing. The coordination and the deconfliction of large numbers of such aircraft operating in primarily urban environments require new CNS infrastructure to ensure safe and reliable service is provided to passengers, the public, and other stakeholders while supporting complex low-altitude operations.

To meet this need, the **ANTENNAE project (SESAR solution 0521) proposes to use xG Terrestrial Networks (TNs) and Non-Terrestrial Networks (NTNs) to provide the full range CNS services at LL and VLL by integrating communication, navigation and surveillance.**

Indeed, the current CNS infrastructures offer limited coverage at low altitudes, due to terrain masking, obstacles and low line-of-sight (LOS) probability and airspace surveillance signals. By using 3GPP standards and xG technologies for TNs and NTNs, Solution 0521 aims to offer the full range of CNS

services to all classes of aircraft operating at low altitudes while supporting key ATM and U-space stakeholders, including USSPs, ANSPs, and aircraft operators. The CNS framework as envisioned by the solution would allow interoperability between ATM and U-space, as shown in Figure 1, where Icons are made by multiple authors (Freepik, Smashicons, Prosymbols Premium, mynamepong, Konkapp, vectorsmarket15, Luvdat, Kanyanee Watanajitkasem, Triangle Squad, and Ylivdesign) from www.flaticon.com.

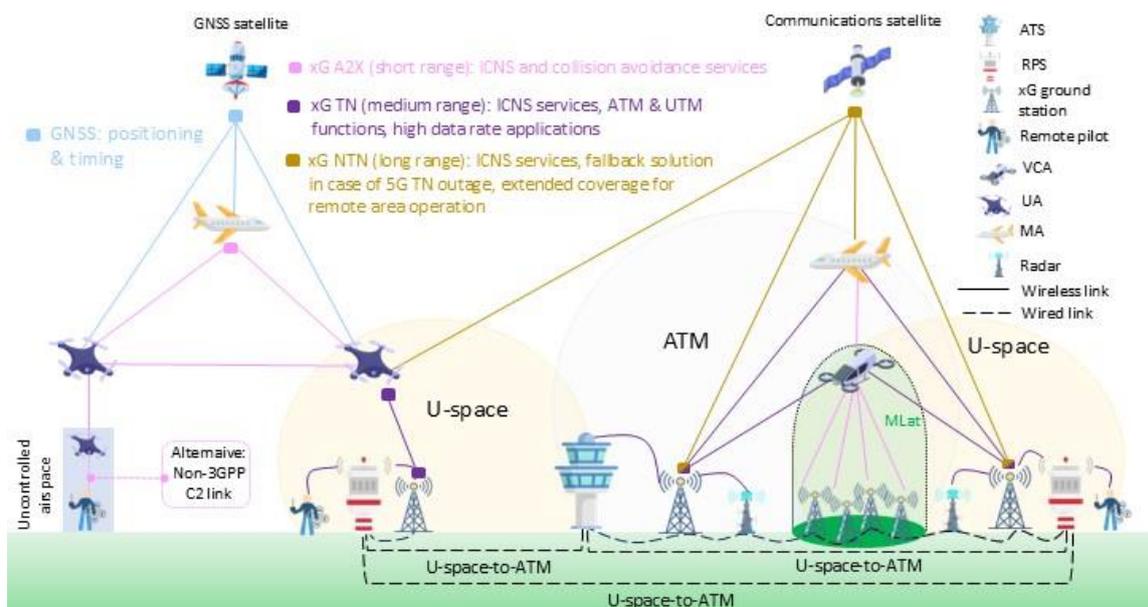


Figure 1: Integrated CNS using xG/5G TNs and NTN

However, the actual CNS landscape remains fragmented: each domain is allocated its own equipment on board aircraft and on the ground, sending information over different frequency bands, resulting in inefficient use of spectrum and higher costs. ICNS is a contemporary concept that considers the communication, navigation, and surveillance domains as a harmonised framework, allowing one domain to support and complement another one. Given this, all the systems for communication, navigation, and surveillance services might be combined and harmonised into one system, as shown on Figure 2. This integration, proposed by the ANTENNAE project (SESAR solution 0521), will improve service quality, spectrum efficiency, communication capacity, navigation predictability, and surveillance capabilities.

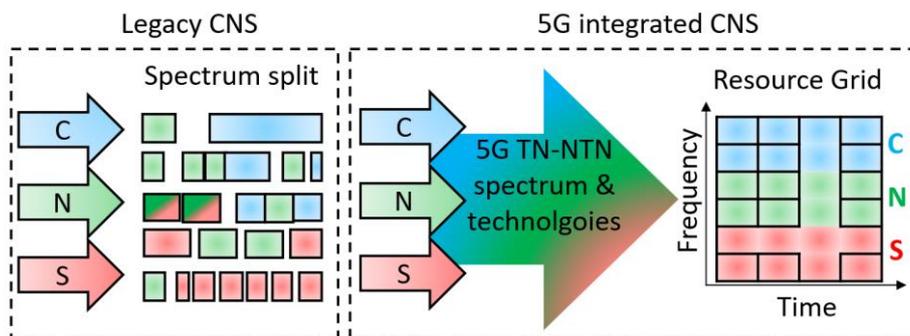


Figure 2: Current CNS system vs 5G/xG ICNS

Among the improvements envisaged are the use of Alternative Position, Navigation and Timing (A-PNT), Alternate Surveillance (A-SUR) and Joint Communication and Sensing (JCS), using the xG network to complement the functionalities of their respective domains for LL and VLL.

3.2.1 SESAR solution interdependencies

The development of Solution 0521 is being carried out simultaneously with other SESAR solutions, as presented in section 2.4. The solution is also based on past projects, which have strongly influenced the direction taken by ANTENNAE, such as **PJ14-W2 I-CNSS** and **FACT**.

If no deployment is strictly required, the solution would benefit from the implementation of certain solutions that would greatly facilitate its implementation. The Hyper Connected ATM (HCATM) as described by **FCDI**, proposing the use of public wireless networks to complement existing aeronautical communication systems, would be ideally combined with the use of ICNS. Solution 0521, by improving the CNS capabilities for LL and VLL, could also help to manage the separation between UAS, a subject at the heart of the **SPATIO** project.

It's also worth pointing out that, although there is no dependency in terms of deployment, Solution 0521 uses **EALU-AER** data to define experimental parameters for validation exercises.

At present, **no known SESAR solution is exclusive** with Solution 0521.

3.3 Objectives of the ECO-EVAL

The objective of this TRL2 ECO-EVAL is to help building an assessment of whether SESAR Solution 0521 is worth deploying across ECAC, from an economic perspective for the involved stakeholders. This ECO-EVAL provides a consolidated assessment of the costs and benefits of deploying SESAR Solution 0521 in LL and VLL, as explained in the ECO-EVAL solution scenario (see section 3.5.2).

This ECO-EVAL includes the evidence gathered to estimate the benefits and costs of the solution. The output is an overview of the high-level impact of costs and benefits per stakeholder group, recommendations and next steps.

3.4 Stakeholder identification

Table 3 presents the stakeholders who would be impacted by a deployment of Solution 0521 for LL and VLL altitudes in ECAC airspace.

Stakeholder	Deployment locations (or sub-operating environments)	Cost drivers	Benefits in operations	Involvement in the ECO-EVAL analysis
ANSP	LL and VLL airspace	<p>Network infrastructure acquisition and deployment</p> <p>Air Traffic Control Officer (ATCO) and technician initial training on new data source</p> <p>System maintenance and software licenses</p> <p>Ongoing training and proficiency checks</p> <p>Increased labour costs to meet the workload growth</p>	<p>Improved ANSPs CNS capabilities</p> <p>ATM-U-space data integration facilitated through the common use of xG</p>	Not involved
Airport operators	ECAC airport areas	Not applicable	Not applicable	Not Applicable
Network manager (NM)	NM Operations Centre (NMOC)	<p>Network infrastructure acquisition and deployment</p> <p>System software update to handle ICNS data via xG TN and NTN networks</p> <p>System maintenance and software licenses</p>	Not applicable	Not involved

Stakeholder	Deployment locations (or sub-operating environments)	Cost drivers	Benefits in operations	Involvement in the ECO-EVAL analysis
		Increased labour costs to meet the workload growth		
Scheduled airlines (mainline and regional)	Not applicable	Not applicable	Not applicable	Not applicable
Business aviation	Not applicable	Not applicable	Not applicable	Not applicable
Rotorcraft	LL and VLL airspace	Software and hardware upgrade to make rotorcraft compatible with xG for ICNS Subscription to 5G and NTN services	Increased C, N and S capabilities	Not involved
General aviation IFR	Not applicable	Not applicable	Not applicable	Not applicable
General aviation VFR	LL and VLL airspace	Software and hardware upgrade to make aircraft compatible with xG for ICNS Subscription to 5G and NTN services	Increased C, N and S capabilities	Not involved
UAS operators	VLL airspace	UAS operator initial training on new data source Software and hardware upgrade to make the aircraft compatible with xG for ICNS (done by UAS manufacturers) Product design, operation, and safety certification	Increased C, N and S capabilities	Involved – provided inputs and reviewed this document (VTT and Collins Aerospace)

Stakeholder	Deployment locations (or sub-operating environments)	Cost drivers	Benefits in operations	Involvement in the ECO-EVAL analysis
		cost (done by UAS manufacturers) Ongoing training and proficiency checks		
Military	Not applicable	Not applicable	Not applicable	Not applicable
U-space Stakeholder: Common information service provider (CISP)	VLL airspace	U-space and ATM xG data integration Network infrastructure acquisition and deployment System software update to handle ICNS data via xG TN and NTN networks Maintenance of integration software/hardware	ATM-U-space data integration facilitated through the common use of xG	Not involved
U-space Stakeholder: U-space service provider (USSP)	VLL airspace	Network infrastructure acquisition and deployment Data processing and storage hardware System software update to handle ICNS data via xG TN and NTN networks Maintenance of integration software/hardware	Improved USSPs capabilities ATM-U-space data integration facilitated through the common use of xG	involved – provided insights and participated in the document conception and revision (Collins Aerospace)

Table 3: SESAR Solution 0521 ECO-EVAL stakeholders and impacts

3.5 ECO-EVAL scenarios and assumptions

This section describes the scenarios that are compared in the ECO-EVAL. The aim is to reflect the delta (difference) between the ECO-EVAL reference scenario (where the SESAR solution is not deployed, bottom box in Figure 3) and the ECO-EVAL solution scenario (reflecting the proposed deployment of the SESAR solution across ECAC, top box in Figure 3). The comparison between the ECO-EVAL scenarios considers the point in time when the solution is available to be deployed and hence differs for each solution.

The delta approach means that the focus is on identifying the impact of the changes between the ECO-EVAL reference and ECO-EVAL solution scenarios. For example, new systems to be deployed, training requirements or changes in operating costs.

Defining the ECO-EVAL reference scenario has proven to be challenging because of the assumptions that need to be made regarding the ‘ongoing deployments’ that are relevant for the solution and their impacts.

To avoid being blocked by this issue, some elements of this TRL2 ECO-EVAL focus on the difference between the current situation and the ECO-EVAL solution scenario. This is reflected in the following scenario descriptions.

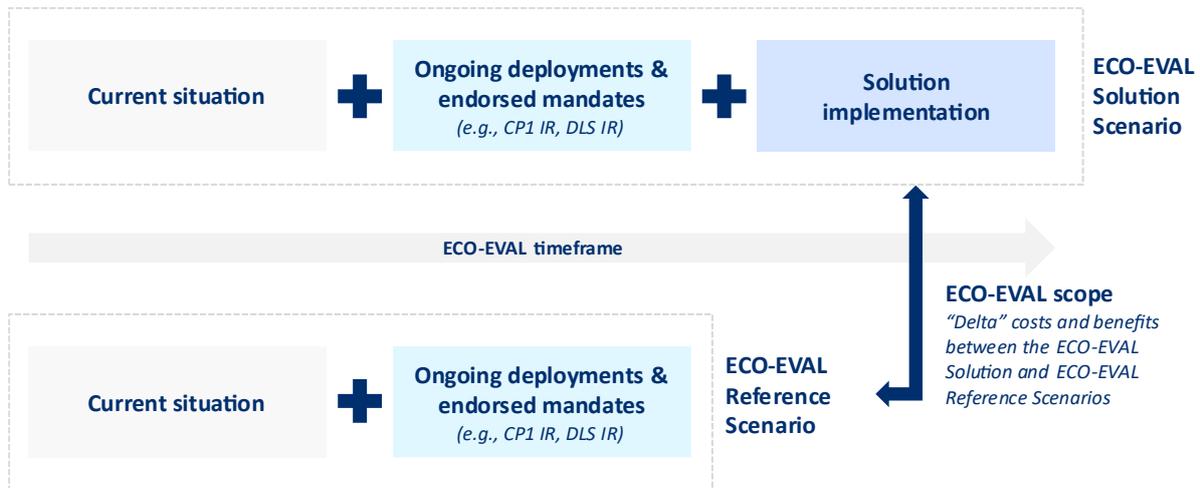


Figure 3: ECO-EVAL scenario overview

3.5.1 ECO-EVAL reference scenario

The ANTENNAE project (SESAR solution 0521) focuses on providing an integrated CNS as a service solution for low altitude operations. Regarding CNS, the current mode of operation is through fragmented communication, navigation, and surveillance functions, as depicted in Figure 4. Several challenges arise from this fragmented approach, such as the number of different airborne equipment that perform individual functions but share similar circuitry or functionalities, increasing the aircraft SWaP. Consequently, most CNS technologies focus on high-altitude large carrier aeroplanes, which reduces the availability of certain technologies for low altitude operations. Additionally, each one of the CNS domains has several existent services occupying different parts of the spectrum, which is a

scarce resource, aggravating the problem for deploying new technologies. Next, we will detail how each one of the CNS domains operates.

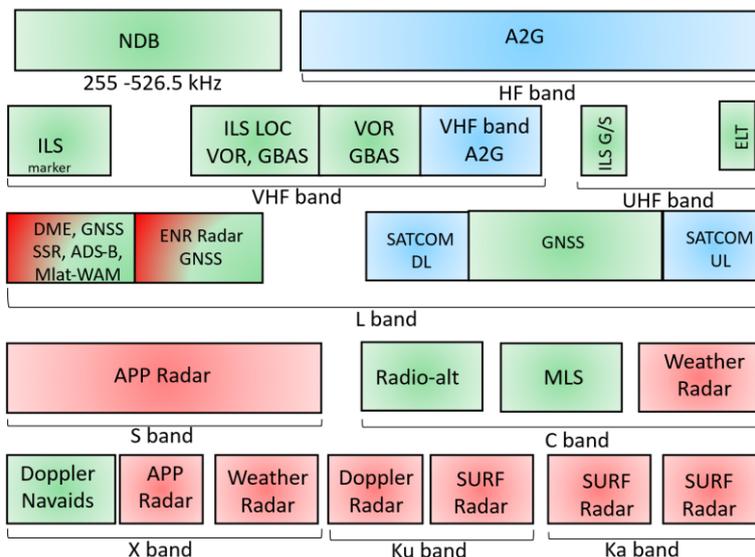


Figure 4: current fragmented CNS technologies and spectrum distribution
 Blue: Communication, Green: Navigation, Red: Surveillance

3.5.1.1 Communication

The communication service exchanges information, including the voice, messages and data for aeronautical fixed and mobile services. The main communication applications are voice and text data exchange between airborne crew and the ATM/U-space using amplitude modulated High Frequency (HF)/Very High Frequency (VHF) signals. The most used protocol is Controller-Pilot Data Link Communication (CPDLC) that allows the transmission of pre-formatted messages between pilot and Air Traffic Control (ATC), containing instructions, clearances, acknowledgements, and requests. Similarly, Aircraft Communication Addressing and Reporting System (ACARS) protocol also uses VHF for weather information, aircraft health status, and flight plans. All these three examples use VHF frequency bands, which provides limited data rate and is prone to congestion, but the terrestrial VHF Data Link Mode 2 (VDLM2) is still the preferred data link.

Considering U-space, Command and Control (C2) link is essential for Beyond Line-Of-Sight (BLOS) operation and requires a dedicated and reliable link. Besides, voice communication between remote pilot and USSP will also become crucial to UAS services. However, most drones operate in close distance to the remote pilot using direct RF links on unlicensed spectrum bands. Such links are range limited, as well as subject to interference, jamming, and spoofing. Alternatively, Control and Non-Payload Communication (CNPC) radios and custom designed point-to-point radio links can be used for transmitting telemetry, voice, and navigational commands data.

3.5.1.2 Navigation

Global Navigation Satellite System (GNSS) is the most popular positioning and timing technology. Although world-wide available and widely embedded in many devices, GNSS is susceptible to jamming, has low vertical accuracy, and is not robust to weather and atmospheric bad conditions. Several augmentation techniques exist to improve GNSS accuracy, such as Ground-Based Augmentation

System (GBAS) and Satellite-Based Augmentation System (SBAS). Alternatively, Distance Measuring Equipment (DME) can be used at VLL as a ground-based back-up for GNSS [31][32], providing accuracy distance measurement based on UHF beacon transmissions and Time-Difference Of Arrival (TDOA) calculations to establish the distance to the ground-based infrastructure. Although depending on beacons transmission is viable on crewed aircraft, it may become a problem in energy limited aircraft such as VCA or UA, also the accuracy is poor for such applications, about 180 m [33]. Additionally, vertical take-off and landing depends on the vertical accuracy, which in manned aircraft is possible due to barometric and radar altimeters, the latter is specific for low altitude, which may not be available in smaller aircraft, such as UAS. Another important navigation functionality is geofencing for UAS system, which is becoming a factory-installed features by many UAS manufacturers and might drive the feasibility of U-space. Such mechanism relies on position sensors, such as Global Positioning System (GPS) sensors, and is designed to impede those pilots mistakenly entry into controlled or restricted airspace areas, which might be two or three-dimensional area [34].

3.5.1.3 Surveillance

The surveillance services provide high-accuracy information on the position and movement of the aircraft to ATM and U-space systems for ensuring safe separation between aircraft. In manned aviation, the commonly used surveillance technologies include Airborne Collision Avoidance System (ACAS), Automatic Dependent Surveillance - Broadcast (ADS-B), Automatic Dependent Surveillance - Contract (ADS-C), Primary Surveillance Radar (PSR), and Secondary Surveillance Radar (SSR). Together, these technologies enhance situational awareness and improve the management efficacy of manned airspace.

ADS-B relies on aircraft broadcasting their essential information, such as, identity, position and other information derived from on board systems, such as GNSS. ADS-B signal is transmitted on UHF band, usually via Universal Access Transceiver (UAT) data links, and can be used by ground or on-board other aircraft to improve the traffic situational awareness, spacing, separation and self-separation. ADS-C uses the same systems as ADS-B and transmits similar information but operates under a contract that specifies the terms with ground services, for instance, Air Traffic Services Unit (ATSU) and Aeronautical Operational Control (AOC). ADS-C operates on VHF or SATCOM links, which are integrated by a Datalink Service Provider (DSP) that feed the ADS-C information to ATC and AOC.

To avoid UAS mid-air collisions, if strategic and tactical deconfliction do not prevent it, Unmanned Aircraft (UA) must feature Detect and Avoid (DAA) technology onboard. ACAS is a DAA system, and it works independently of the ATM system. ACAS Xu is the latest version of ACAS designed for UAS; it enables UA with DAA capabilities [35] by combining traditional ACAS sensor information with other sources of situational awareness like ADS-B. The UAS Remote ID broadcasts UA identification and location information for surveillance [35]. The UA can be equipped with ADS-B and ADS-C, Automatic Dependent Surveillance-Light (ADS-L) and FLARM to provide situational awareness and surveillance services to U-space.

3.5.2 ECO-EVAL solution scenario

How will Solution 0521 work:

The ANTENNAE project (SESAR solution 0521) aims to use the ubiquity, flexibility, and high-performance of xG mobile wireless networks to provide integrated communication, navigation, and surveillance as a service. The recent innovations in xG standards extended its capabilities beyond data

communication enhanced broadband, but positioning and radar sensing capabilities became available in the latest releases and may be beneficial for airspace users with limited or compromised navigation and surveillance.

Employing a hybrid network combining terrestrial and non-terrestrial networks, the solution will explore cost-effective, secure and safe alternatives using network orchestration, which is able to coordinate the data traffic to switch links in case of failure, congestion, lack of coverage, and cost optimisation. In addition, due to xG flexibility it is also possible to provide low-cost ground coverage in remote areas where the Mobile Network Operators (MNO) presence is insufficient to complement the satellite service.

Three use cases arise from the use of xG to extend and integrate the CNS functions.

1. **Cellular network optimisation for aerial users:** A key feature of xG network is the ability to swiftly reconfigure the networks, that are originally designed for ground users, using, for instance, down-tilted antennas that poorly cover the sky. Additionally, such networks only support low ground mobility, based on static parameters, which is not the case for dynamic, high-maneuvrable, high-speed aircraft. Therefore, assessments and network optimisations are required to (1) enable the coexistence of ground and aerial users with the minimum agreed Quality of Service (QoS), and (2) improve the network mobility performance for aerial users.
2. **Hybrid connectivity framework:** The hybrid-connectivity framework, merging terrestrial and non-terrestrial networks, was designed to ensure coverage in areas where the ground network signal is unavailable or insufficient, increasing the safety and resilience of the solution. This hybrid architecture exploits the emerging satellite networks that are migrating to an xG-compatible regenerative payload elements and the widespread xG ground networks. The hybrid use of TN and NTN demands, in the first place, the establishment of a handover between them, which is not yet standardised. Besides, xG ground networks were deployed focusing on urban dense areas, which are commercially profitable, and lacking infrastructure in remote areas. In order to maintain cost efficiency, we shall assess the coverage and strategically deploy network ground infrastructure where necessary. Also, it is necessary to establish network control policies that maximise the network overall performance, avoid traffic congestion, and minimise the operating costs.
3. **Alternative CNS safety applications:** Given GNSS inaccuracies and tendency to outage, plus congestion at 1090 MHz frequency used by ADS-B, the navigation and surveillance services may not deliver enough bandwidth to the new airspace entrants. Being the high communication performance brought by xG broadband capabilities, recent xG standard releases include positioning features and further releases are being designed to include joint communication and sensing waveforms.

These capabilities can potentially be used to increase the navigation and surveillance performance without demanding extra equipment, reducing the payload and energy footprint. First, communication functions, such as C2 and CPDLC, fits into Ultra-Reliability Low-Latency Communication (URLLC) category of xG use cases. Applying strong correlation properties signals xG networks can provide TDOA to perform multilateration as a backup or cross-checking positioning information. At higher frequencies and using Multiple-Input and Multiple-Output (MIMO), as in Frequency Range 2 (FR2), which includes frequency bands from 24.25 GHz to 71.0 GHz, and Frequency Range 3 (FR3), ranging from 7.125 GHz to 24.25 GHz, xG enables radar capabilities with JCS at centimetre accuracy for hundreds of metres range.

The high-performance broadband connectivity necessary to retrieve CNS data combined with TN-NTN integration, might result in a potential performance-driven cost efficient ICNS platform.

What is to be deployed:

ANTENNAE project (SESAR solution 0521) aims to build an xG provisioned ICNS as a service based on a hybrid TN-NTN architecture. Hence, the first step towards the solution deployment is to establish a cost-efficient business model for telecommunication operators as well as TN and NTN integration. Several aspects need to be addressed to allow the realisation of the ANTENNAE framework, such as technical recommendations of network control policies and RAN optimisations to increase performance, enable the coexistence of ground and aerial users, and make the business model profitable. Complementary to this, if necessary, the USSP can work in the integration of TN and NTN as well as improving ground coverage by deploying additional ground base stations.

In terms of infrastructure, the ANTENNAE project (SESAR Solution 0521) relies on the gradual integration of ATM and U-space. In the beginning, the solution targets U-space, which still lacks certified CNS services, but afterwards it is expected to reach general aviation aircraft operating under Visual Flight Rules (VFR) as an extra and cost-efficient CNS solution. Therefore, the solution will require the physical connectivity between ATM and U-space entities, such as ANSP, NM, Network Manager Operations Centre (MNOC), USSP, and CISP, as well as the data processing and storage infrastructure. Where it is applicable, the staff should receive additional training to operate using the CNS data provided, including ATCO staff, pilots, and UAS operators.

Finally, Unmanned aircraft and VCA manufacturers will need to design, test, and certificate xG-based ICNS avionics hardware and software. On the other hand, National and Civil aviation authorities will need to certificate and implement regulations and inspection routines to ensure the safe use of the solution.

Interdependencies:

As explained in Section 3.2.1, although this scenario can benefit from the implementation of certain other solutions, it does not consider their deployment necessary or absolutely effective. It should be pointed out, however, that the validation exercises, which will enable us to study its implementation and obtain quantitative data on its impacts and benefits, use data from the **EALU-AER project**.

ECO-EVAL timeline:

The ECO-EVAL covers the period from 2026 to 2050 as defined in the common assumptions [5]. This means that the net present value is calculated by discounting the cash-flows back to 2026 (the end of DES wave 1).

Table 4 lists the key dates used in the ECO-EVAL based on the dates in [36] and Figure 5 shows them over a timeline.

Dates	SESAR Solution 0521
Start of deployment date (SOD): the start of investments for the first deployment location	2030

Dates	SESAR Solution 0521
End of deployment date: the end of the investments for the final deployment location, same as FOC	2040
Initial operating capability (IOC): the time when the first benefits occur following the <i>minimum deployment</i> necessary to provide them. Costs continue after this date as further deployment occurs at other locations.	2035
Final operating capability (FOC): maximum benefits from the <i>full deployment</i> ² of the SESAR solution at applicable locations. Investment costs are considered to end ³ here although any operating cost impacts would continue.	2040

Table 4: ECO-EVAL investment and benefit dates

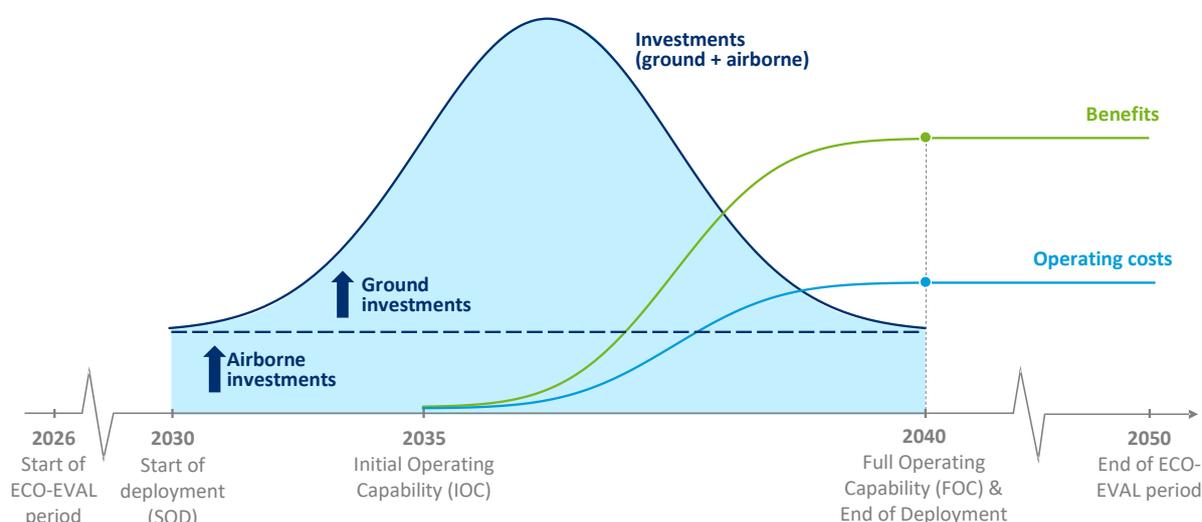


Figure 5: overview of ECO-EVAL dates

Figure 5 shows that:

- Investment costs are the addition of the (i) ground investment costs (spread following a bell curve⁴ between the start and end of deployment dates), and (ii) airborne investment costs (spread linearly between the start and end of deployment dates);
- Benefits ramp-up following an ‘S’ adoption curve⁴ between IOC and FOC and then continue up to the end of the ECO-EVAL period;

² Where *full deployment* means deploying the SESAR solution in all the locations where it makes sense to deploy it (i.e. it does not mean it has to be deployed everywhere)

³ The basic assumption is that infrastructure does not need to be replaced during the ECO-EVAL period.

⁴ The bell curve is based on the diffusion of innovation theory (see [Investopedia](#) for further reference).

- Operating cost impacts (increases or decreases) would also start at IOC and ramp-up following an ‘S’ adoption curve to FOC before continuing for the rest of the ECO-EVAL duration.

Geographical scope:

Solution 0521 is designed for LL and VLL. All ECAC airspace at these altitudes is impacted, from airports to urban areas to rural areas where the coverage of TNs is not sufficient and requires the use of NTN, particularly LEO satellites.

Discount rate:

As defined in the latest DES Common Assumptions [5], the recommended discount rate for any SESAR solution, including Solution 0521, is 8%.

Traffic evolution:

The traffic trends follow those presented in the last DES Common Assumptions [5], which are themselves extracted from the 2022 STATFOR long-term forecast. These forecasts are detailed in section 3.5.3.1.

3.5.3 Assumptions

This section describes the assumptions considered during the development of the Solution 0521. There are two main categories, divided into two different sub-sections:

- Common assumptions, related to the global nature of the evolution of ECAC airspace and the associated costs,
- The assumptions specific to Solution 0521, which, as their name suggests, are specifically induced by the deployment of the solution.

3.5.3.1 Common assumptions

The assumptions presented in this subsection are mostly taken from the SESAR DES Common Assumptions document [5], and follow the recommendations recommended therein. This ECO-EVAL uses in particular the recommendations made for the CBA. Although the current assessment is qualitative, these figures are given in the case of a potential continuation of the project.

As explained above, the discount rate is assumed to be 8%. The discount year for annual cash flows is 2022, the year from which STATFOR traffic data are also derived. During solution deployment, an increase in traffic is therefore expected, as shown in Table 5. This increase is one of the main reasons behind the introduction of A-SUR.

Year	Constrained forecast (movements)	Unconstrained forecast (movements)
2030	12 073 624	12 073 642
2035	12 190 291	12 668 366
2040	13 729 993	13 730 014

Year	Constrained forecast (movements)	Unconstrained forecast (movements)
2045	14 749 398	14 829 813
2050	15 964 536	16 447 396

Table 5: STATFOR 2022 air traffic data, from the DES Common Assumptions [5]

Table 6 contains fuel prices and CO2 values used over the deployment period, enabling environmental and consumption impacts to be assessed.

Year	CO2 (€ /tonne)	value	Oil Price (€ /barrel)	Jet Fuel price (€/tonne)
2030	78		72	604
2035	89		80	669
2040	99		88	800
2045	110		92	735
2050	120		96	866

Table 6: STATFOR 2022 fuel price and CO₂ data, from the DES Common Assumptions [5]

3.5.3.2 Solution 0521 specific assumptions

The implementation of the Solution 0521 scenario is also based on specific assumptions necessary for its deployment, and which must be considered for the economic evaluation. These assumptions, written for the initial version of the ECO-EVAL will be completed and specified for the final version of the document.

Regulatory:

- It is assumed that U-space and Innovative Air Mobility services will have been successfully deployed and regulated by the corresponding authorities prior to solution implementation.
- It is assumed that standards will have been developed allowing the solution deployment.
- It is assumed that A-PNT, A-SUR and JCS will be included in CNS procedures.

Technological:

- It is assumed that aircraft and UAS equipment will support ICNS use.
- It is assumed that the ground infrastructure will support ICNS use.
- It is assumed that 3GPP xG network (TN) will be available for ICNS deployment.
- It is assumed that 3GPP xG satellites network (NTN) will be available for ICNS deployment.

4 Benefits

This chapter describes the benefits provided by the ANTENNAE Project (SESAR Solution 0521) following the scenario described in Section 3.5.2. This section gives a brief overview of these areas before going into more detail, particularly with regard to the associated Performance Indicators (PIs) and Key Performance Indicators (KPIs).

4.1 Benefits overview

The benefits identified within the Operational Service and Environment Description (OSED) and Exploratory Research Plan (ERP) of Solution 0521 cover Key Performance Areas (KPAs) and PI related to U-space and ATM. They highlight the impact of ICNS on areas such as capacity, cost efficiency, safety, security, environment and interoperability. These benefits are detailed in the following subsections.

4.2 Benefit summary

Table 7 summarises the solution benefits showing the benefit impact mechanisms (BIMs) impact (positive, negative or neutral). It explains how the solution provides estimates.

KPI / PI	BIM impact	How the solution provides the benefit and evaluation (low, medium, high impact)
U.CAP1 U-space maximum number of drones	Positive - Increased number of drone operations per unit of time.	How: Providing easier access to CNS services for U-space. Contribution: Low Impact. Note: Evaluated through simulation exercises.
U.CAP2 Route Corridor throughput	Positive - Increased number of drone operations per 4D volume.	How: Providing easier access to CNS services for U-space. Contribution: Low impact.
U.CAP4 Number of ATM-U-Space handovers	Positive - Decreased the maximum number of handover drones to ATM and vice versa	How: Increasing the availability of U-space CNS services. Contribution: Medium Impact.
U.CAP7 Vertiport maximum number of drone operations	Positive - Increased Maximum number of drone operations which can be accommodated in all vertiports in a given area per time unit.	How: Providing easier access to CNS services for U-space. Contribution: Low Impact.

KPI / PI	BIM impact	How the solution provides the benefit and evaluation (low, medium, high impact)
U.RES2 Loss of Vertiport capacity	Positive - Decreased difference between the maximum number of drone operations which can be accommodated in a vertiport per time unit in nominal conditions and the maximum number of drone operations which can be accommodated in a vertiport per time unit considering the ongoing disruption.	How: Allowing the use of ICNS in case of traditional CNS services disruption, allowing the use of A-PNT and A-SUR. Contribution: Low Impact.
U.CEF1 Technology cost per drone operation	Negative - Increased USSP cost changes related to technology and equipment per flight profile.	How: Upgrading UAS with xG-compatible equipment. Contribution: Low impact.
U.CEF4 USSP Cost of additional ground infrastructure	Negative - Increased total cost of the USSP for all ground equipment needed to connect with U-space.	How: Deploying new infrastructures or networks when the technology is not provided by telecommunication operators or increased fees for the provided. Contribution: Medium impact. Note: Evaluated through simulation exercises.
U.SAF1 Total number of estimated	Positive - Expected decrease , but not directly measurable. Determined by Safety practitioners via the AIM Models	How: Providing alternatives to traditional navigation and surveillance methods, overcoming GNSS vulnerabilities.

KPI / PI	BIM impact	How the solution provides the benefit and evaluation (low, medium, high impact)
accidents with U-space Contribution per year	and validated with the support of the Safety PIs	Contribution: Medium impact. Note: Evaluated through simulation exercises.
U.SEC1, U.SEC2, U.SEC3 Security	Security risks will be determined through the SecRAM 2.0 Methodology	How: A security assessment will be carried out following the SecRAM 2.0 methodology [10]. Contribution: Medium Impact. Note: A security assessment will be carried out following the SecRAM 2.0 methodology.
U.NOI2 Area-based exposure	Negative - Increased number of people exposed to noise within an area during a period of time	How: Facilitating the development of VLL traffic. Contribution: Low impact. Note: The quality of the ICNS services provided may allow a greater density of traffic at a non-perceptible altitude for the population, even at VLL, mitigating noise pollution.
U.NOI6 Visual area-based exposure	Negative - Increased number of people who reported visible drone operations within an area during a period of time	How: Facilitating the development of VLL traffic. Contribution: Low impact. Note: The quality of the ICNS services provided may allow a greater density of traffic at a non-perceptible altitude for the population, even at VLL, mitigating visual pollution.
U.ENV1 Actual Average CO ₂ Emission per flight	Positive - Decreased amount of fuel burnt x (CO ₂ emission index/kg of the fuel used e.g.: Conventional Fuel or Sustainable	How: Additional xG TN-NTN coverage may enable shorter aircraft flight routes and allow electricity-powered UAS and VCA to perform missions currently reserved for fuel-consuming vehicles and aircraft.

KPI / PI	BIM impact	How the solution provides the benefit and evaluation (low, medium, high impact)
	Aviation Fuel) divided by the number of flights	Contribution: Low Impact. Note: Evaluated through simulation exercises.
U.ACCESS5 Access to U-space services	Positive - Decreased percentage of operations that cannot comply with the U-space services technical requirements.	How: Democratising an efficient access to all U-space CNS services through xG. Contribution: High Impact.
U.IOP4 Interoperability Operators /USSP_1	Positive - Decreased % of operations that cannot start or be completed due to unshared information	How: Improving UAS operators/USSPs information sharing with the help of ICNS. Contribution: High Impact.
U.IOP7 Interoperability between USSP_2	Positive - Decreased % of unshared information between USSPs that degrades operational performance	How: Improving USSPs' information sharing with the help of ICNS. Contribution: High Impact.
U.IOP8 Interoperability between UTM and ATM	Positive - Decreased % of unshared information between U-space/UTM and ATM that degrades operational performance	How: Improving ATM/U-space/UTM information sharing with the help of ICNS. Contribution: High Impact.

KPI / PI	BIM impact	How the solution provides the benefit and evaluation (low, medium, high impact)
CAP1 Terminal Manoeuvring Area in challenging airspace, per unit time	Positive - Increased Relative change of movements (% and number of movements)	How: Providing easier access to CNS services for low and very low altitudes. Contribution: Low impact.
CAP3 Peak Runway Throughput	Positive - Increased % and also the total number of movements per one runway per one hour for specific traffic mix and density	How: Providing easier access to CNS services for low and very low altitudes. Contribution: Low impact.
CEF3 Technology cost per flight	Negative - Increased Gate-to-Gate Air Navigation Services cost changes related to technology and equipment.	How: Upgrading aircraft with xG-compatible equipment. Contribution: Low impact.

Table 7: solution performance benefits

4.3 U-space Capacity (U.CAP1, U.CAP2)

Impact - Positive: Increased number of drone operations per unit of time, **Increased** Number of drone operations per 4D-volume.

How the benefits are provided: By providing easier access to CNS services, the deployment of Solution 0521 would help to facilitate an increase in U-space capacity, although this is not the primary objective of the solution. The solution also aims to ensure that services can continue to operate even in the event of high aircraft and/or UAS density, making it compatible with capacity increases that may also be envisaged in the future.

Contribution: Low Impact.

Note: U.CAP1 evaluated through simulation exercises.

4.4 U-space Capacity (U.CAP4)

Impact - Positive: Decreased maximum number of handover drones to ATM and vice versa

How the benefit is provided: With the approach focused on the use of ICNS via xG for low altitudes, an increase in the availability of communication, navigation and surveillance services is expected regarding U-space. The development of U-space would lead to a reduction in the need for UAS to perform handovers from U-space to ATM or vice versa.

Contribution: Low Impact.

4.5 Vertiport Capacity (U.CAP7)

Impact - Positive: Increased maximum number of drone operations which can be accommodated in all vertiports in a given area per time unit.

How the benefit is provided: By providing easier access to CNS services, the deployment of Solution 0521 would help to facilitate an increase in U-space capacity, although this is not the primary objective of the solution. The solution also aims to ensure that services can continue to operate even in the event of high aircraft and/or UAS density, making it compatible with capacity increases that may also be envisaged in the future.

Contribution: Low Impact.

4.6 Resilience (U.RES2)

Impact - Positive: Decreased difference between the maximum number of drone operations which can be accommodated in a vertiport per time unit in nominal conditions and the maximum number of drone operations which can be accommodated in a vertiport per time unit considering the ongoing disruption.

How the benefit is provided: Solution 0521, by offering the possibility for all aircraft in a vertiport to use CNS services via xG as well as to use alternative navigation and surveillance methods, would increase the resilience of the area, especially in the event of disruptions to more traditional communication, navigation and surveillance services.

Contribution: Low impact.

4.7 Cost-Efficiency (U.CEF1)

Impact - Negative: Increased USSP cost changes related to technology and equipment per flight profile.

How the benefit is provided: By establishing xG as the primary technology for CNS operations, Solution 0521 will have a negative impact on the cost of UAS operations related to the need to upgrade UAS with the appropriate equipment, but this impact will certainly be limited. Indeed, xG equipment is inexpensive, and standards are already established. Moreover, the use of ICNS could make it possible to dispense with certain equipment, and thus further limit additional costs.

Contribution: Low impact.

4.8 Cost-Efficiency (U.CEF4)

Impact - Negative: Increased total cost of the USSP for all ground equipment needed to connect with U-space.

How the benefit is provided: As the use of xG increases, Solution 0521 will inevitably require the deployment of new ground infrastructures or networks. The private or public nature of these infrastructures remains to be defined. An increase in the cost for USSP is expected when telecommunication operators do not provide the required technologies or charge extra for delivering them.

Contribution: Medium impact.

Note: Evaluated through simulation exercises.

4.9 Safety (U.SAF1)

Impact – Positive: Expected decrease, but not directly measurable. Determined by Safety practitioners via the AIM Models and validated with the support of the Safety PIs.

How the benefit is provided: In addition to meeting all existing safety standards, Solution 0521 hopes to help reduce the total number of accidents with U-space Contribution per year. Indeed, the use of new navigation and surveillance techniques (A-PNT and A-SUR respectively), would help to overcome the known vulnerabilities of GNSS and the risk of congestion on the 1090 MHz frequency as well as providing redundancy.

Contribution: Medium impact.

Note: Evaluated through simulation exercises.

4.10 Security (SEC1, SEC2, SEC3)

How the benefit are provided: The security **KPA won't be measured directly from the validation exercises**. A security assessment will be carried out following the SecRAM 2.0 methodology [10], to identify potential security risks associated with the use of ICNS-as-a-service.

It should also be noted that the use of A-PNT could reduce the security risks associated with GNSS vulnerabilities.

Contribution: Medium Impact.

Note: A security assessment will be carried out following the SecRAM 2.0 methodology.

4.11 Noise (U.NOI2, U.NOI6)

Impact - Negative: **Increased** number of people exposed to noise within an area during a period of time, **Increased** number of people who reported visible drone operations within an area during a period of time.

How the benefits are provided: Since the deployment of the solution is designed to facilitate the development of low-level traffic, its implementation would lead to an increase in the population's exposure to UAS. This exposure would be accompanied by an increase in noise and visual pollution.

Contribution: Low impact.

Note: It should be noted that the quality of the ICNS services provided may allow a greater density of traffic at a non-perceptible altitude for the population, even at VLL. Therefore, it will mitigate the negative effects of noise and visual pollution.

4.12 Emissions (U.ENV1)

Impact - Positive: **Decreased** amount of fuel burnt divided by the number of flights.

How the benefit is provided: Despite the need to deploy new infrastructure, Solution 0521 would largely reuse existing xG network, limiting the CO₂ emissions that its implementation would generate. Then, the additional coverage offered by the hybrid xG TN-NTN may enable more efficient shorter aircraft flight routes. Additionally, enabling the use of electricity-powered UAS and VCA to perform cargo delivery missions and eVTOL air taxis can reduce the number of car and helicopter travels, respectively.

Contribution: Low Impact.

Note: Evaluated through simulation exercises.

4.13 Access & Equity (U.ACCESS5)

Impact - Positive: **Decreased** percentage of operations that cannot comply with U-space services technical requirements.

How the benefit is provided: Solution 0521 aims to democratize the use of xG to deliver ICNS-as-a-service at low altitudes. The solution wants to democratize access to the various U-space CNS services in the most efficient way possible through xG, while complying with existing standards.

Contribution: High Impact.

4.14 Interoperability (U.IOP4, U.IOP7, U.IOP8)

Impact - Positive: **Decreased** % of operations that cannot start or be completed due to unshared information, **Decreased** % of unshared information between USSPs that degrades operations performance, **Decreased** % of unshared information between U-space and ATM that degrades operations performance.

How the benefit is provided: The implementation of ICNS via xG is expected to improve information sharing between ATM, USSPs and UAS operators in terms of communication, navigation and surveillance, increasing their interoperability.

Contribution: High impact.

4.15 Capacity (CAP1, CAP3)

Impact - Positive: **Increased** Relative change of movements, **Increased** % and also the total number of movements per one runway per one hour for specific traffic mix and density.

How the benefits are provided: By providing easier access to CNS services, the deployment of Solution 0521 would help to facilitate an increase in LL and VLL airspace, although this is not the primary objective of the solution. The solution also aims to ensure that services can continue to operate even in the event of high manned aircraft and/or UAS density, making it compatible with capacity increases that may also be envisaged in the future.

Contribution: Low impact.

4.16 Cost-Efficiency (CEF3)

Impact - Negative: **Increased** Gate-to-Gate Air Navigation Services cost changes related to technology and equipment.

How the benefit is provided: The use of ICNS through xG would reduce the amount of equipment normally required by aircraft to operate the associated technologies. This would translate into lower costs, both in terms of ground infrastructure and on-board equipment. However, as the deployment of the solution requires an initial increase in costs to upgrade the aircraft, the impact is estimated to be negative.

Contribution: Low impact.

5 Cost assessment

This chapter describes the high-level qualitative costs stemming from the implementation of the new ICNS solution, which leverages xG terrestrial networks and emerging regenerative xG payload satellite networks to provide integrated communication, navigation, and surveillance as service for very-low- and low-level altitude airspace users. The assessment covers both the initial investment costs required for system development and integration, and the recurring operating costs for long-term system maintenance and use. The following sections provide a detailed rationale for the cost drivers and deployment locations identified for each stakeholder in Table 3, offering sufficient detail to support a future quantitative cost-benefit analysis (CBA).

Stakeholder	Cost category	Yes/No	Cost driver	Deployment locations (or sub-operating environments)
ANSPs	Investment cost	Yes	Network infrastructure acquisition and deployment ATCO and technician initial training on new data source Cost level: High	All operational ATC centres
	Operating cost	Yes	System maintenance and software licenses ATCO and technician recurrent training and proficiency checks Increased labour costs to meet the workload growth Cost level: Medium	
Airport operators	Investment cost	No	No direct investment costs	N/A
	Operating cost	No	No direct operating costs	

Stakeholder	Cost category	Yes/No	Cost driver	Deployment locations (or sub-operating environments)
Network manager (NM)	Investment cost	Yes	Network infrastructure acquisition and deployment System software update to handle ICNS data via xG TN and NTN networks Cost level: Medium	NM Operations Centre (NMOC)
	Operating cost	Yes	System maintenance and software licenses Increased labour costs to meet the workload growth Cost level: Low	
Airspace users: Scheduled airlines (mainline and regional) and Business aviation General aviation IFR	Investment cost	No	No direct investment cost	Not applicable
	Operating cost	No	No direct operating cost	
Airspace users: Rotorcraft General aviation VFR	Investment cost	Yes	Software and hardware upgrade to make aircraft compatible with xG for ICNS Cost level: Low	Entire applicable aircraft fleet
	Operating cost	Yes	Subscription to xG and NTN data services Cost level: Low	

Stakeholder	Cost category	Yes/No	Cost driver	Deployment locations (or sub-operating environments)
Military	Investment cost	No	No direct investment cost	Not applicable
	Operating cost	No	No direct operating cost	
U-space Stakeholder: UAS operators	Investment cost	Yes	<p>UAS operator initial training on new data source</p> <p>Software and hardware upgrade to make the aircraft compatible with xG for ICNS (done by UAS manufacturers)</p> <p>Product design, operation, and safety certification cost (done by UAS manufacturers)</p> <p>Cost level: Low</p>	All UAS operational centres
	Operating cost	Yes	<p>Ongoing training and proficiency checks</p> <p>Cost level: low</p>	
U-space Stakeholder: Common information service provider (CISP)	Investment cost	Yes	<p>U-space and ATM xG data integration</p> <p>Network infrastructure acquisition and deployment</p> <p>System software update to handle ICNS data via xG TN and NTN networks</p> <p>Cost level: High</p>	At least one CISP per Member State

Stakeholder	Cost category	Yes/No	Cost driver	Deployment locations (or sub-operating environments)
	Operating cost	Yes	Maintenance of integration software/hardware Cost level: low	
U-space Stakeholder: U-space service provider (USSP)	Investment cost	Yes	Network infrastructure acquisition and deployment Data processing and storage hardware System software update to handle ICNS data via xG TN and NTN networks Cost level: High	U-space service provider infrastructure
	Operating cost	Yes	Maintenance of integration software/hardware Cost level: low	
	Operating cost	Yes	Maintaining the network infrastructure and software for ICNS as service provisioning which implies possible ANSP/USSP services and additionally ICNS services supporting UAS/VCA operations Cost level: Medium	
	Operating cost	Yes	Review and update of the regulations	

Stakeholder	Cost category	Yes/No	Cost driver	Deployment locations (or sub-operating environments)
			Inspection and monitoring of the ICNS services Cost level: Medium	

Table 8: identification of solution’s cost drivers and deployment locations

5.1 ANSPs costs

The ANSP is mainly responsible for providing air traffic management, relying on meteorological services, CNS data, and aeronautical information service (AIS). For this reason, ANTENNAE project (SESAR solution 0521) may be capable of offering an expansion to CNS data by offering extra data from the potential ICNS aircraft, such as UAS and VCA.

Investment cost: For the ANSPs operating only in ATM, the first cost driver in an integration with U-space is the interconnection with the USSP. Such a connection may demand the deployment of new U-space services, such as Traffic Information Services, Collaborative Interface with ATC, Procedural Interface with ATC, and those might require new physical links, adequate hardware, and software capable of receiving CNS data from the relevant systems, processing this data, making it available for ATC, and storing this data whenever required. Even though deployment of U-space services is the duty of USSP, integrating those services to ANSP operation will require additional investment to infrastructure and information systems. Furthermore, ATCO and technical staff will need to receive training and be qualified to operate in this new environment with the same proficiency to ensure the required level of safety.

Operating cost: The operating costs are primarily driven by the maintenance of the added infrastructure, including hardware and software, which demand updates and technical support. In addition, recurrent training and staff assessment are necessary to maintain the level of safety and evolution of the system. Additionally, due to the potentially increasing workload of ATCO that cannot be avoided, even though minimised, the labour cost will also increase.

Due to the network, software, and processing data hardware that will require upgrade or acquisition if lacking, plus the operator's training, we define the investment and operating costs level as medium.

5.2 Network manager costs

The Network Manager (NM) operates the ATM network of a Continent, country, or region, with the goal of ensuring a fluent and safe air traffic operation. At the NMOC, the NM collects data from the member states and gathers this data in a centralised way to allow an informed and fluent operation of the traffic flow. Therefore, Solution 0521 may increase the amount of inbound data, acting as an extra source of CNS data to improve aviation safety and efficiency, providing ICNS connectivity to a larger number of aircraft through xG terrestrial and non-terrestrial networks.

Investment cost: The NM investments will be on upgrading its systems at the NMOC to allow connection with the U-space and to improve the capacity of data ingestion. Thus, some of the existing physical links and data processing resources will require upgrade and new equipment to acquire in order to enhance the data processing, storage and visualisation capabilities.

Operating cost: The operating costs at the NM will be primarily driven by the maintenance of the newly added infrastructure, which comprises maintenance costs, technical support, software licences and upgrades, and faulty hardware replacement.

The acquisition of new network infrastructure and the possibility of demanding network link upgrades elevate the investment costs level to medium; meanwhile, the operating costs are related to the maintenance of such systems and the augmented data processing demands, which can be considered low if maintenance and support services are agreed prior to the infrastructure procurement and acquisition. To sustain current safety standards amid growing NM data traffic, additional personnel may be required to handle the operational demands of LL and VLL flows.

5.3 Airspace user costs

In this category, Solution 0521 directly impacts rotorcrafts and general aviation operating by VFR. Such airspace users operate in the altitude aimed by the ANTENNAE project (SESAR solution 0521), i.e., very low-level and low-level altitude, coexisting with other categories of aircraft, such as unmanned aircraft. Although the general aviation VFR and rotorcrafts might be equipped with CNS instruments onboard, some equipment, such as ADS-B and TCAS, are non-mandatory. Thus, the Solution 0521 could improve their situational awareness and flight safety by offering xG integrated CNS capabilities.

Investment cost: The main investment cost driver is the acquisition of avionics hardware and software with xG and ICNS-as-a-service capabilities, and the setup of the equipment in the existing aircraft fleet. These capabilities (xG/ICNS) are optional for VFR and rotorcraft. So, the use of the solution as part is subject to the aviation authorities' regulation, but at the time this document is being written, this capability is optional for such category of aircraft, thus it applies to all the aircraft fleet eligible to receive such equipage as the pilot's training, size, weight, and power consumption permits.

Operating cost: The operating costs involve the subscription to xG and NTN services in order to provide the connectivity for the ICNS functions. To better meet the demands of aeronautical users, the telecommunication operators might need to set up services and deploy extra network infrastructure. These updates will not only take place at the network sites, but also at the network operations centre, where the operators configure, monitor the network, and provide the maintenance of the added infrastructure, including hardware and software, which demand updates and technical support. Although the subscription cost is still low if compared to other cost drivers, the services provisioned by telecommunication operators to airspace users differentiates from the ones provided for ground users due to their different natures and might result in higher a price per data unit (giga bit or mega bit allowance).

Due to the high availability of COTS xG transceivers and the low computational requirements demanded by CNS functions, the estimated per-aircraft cost for ICNS avionics equipment is considered low, and the operating cost for xG subscription is low, even if the subscription to multiple MNOs is recommended, allowing redundancy.

5.4 U-space stakeholder costs

The ANTENNAE project (SESAR solution 0521) targets very low-level altitude, which mostly encompasses U-space operations. Hence, the actors involved in U-space are directly impacted by the Solution 0521 and may benefit from the further deployment of the solution. As new entrants in the airspace, the U-space Stakeholders should simultaneously comply with safety levels and information sharing of ATM, while applying innovative technologies with potential to be also used in ATM in the future. Besides that, due to the automation necessary to provide the capacity estimated for the U-space, making informed decisions is essential, which entails reliable and largely available flight data. Solution 0521 may provide the necessary CNS connectivity and data availability required to enable safe and efficient U-space operations by provisioning ICNS as a service on xG networks.

Investment cost: whenever new technological solutions are required that cannot be purchased as a service, an investment cost will be required. Utilising the xG networks may help to reduce the investment costs.

Operating cost: when the U-space stakeholder owns the technological enablers, the maintenance and labour costs are assumed; otherwise, the fees for the use of xG-based services are envisioned.

5.4.1 UAS Operators

The UAS operators, particularly the ones operating Beyond Visual Line of Sight (BVLOS) missions, must be aware of all the relevant factors to the flight operation, such as telemetry of the operating aircraft, weather, terrain, surrounding airspace users, and other conditions. It is essential that this information is available to the UAS operators in a reliable and secure fashion, as well as with low latency, to provide the proper reaction time. Solution 0521 might complement the current CNS equipment and enhance the UAS operator situational awareness by minimally increasing the unmanned aircraft payload, power consumption and using cost-efficient high-performing xG TN-NTN. Consequently, access to U-space operations is estimated to increase, as well as the number of missions complying with U-space CNS and safety requirements.

Investment cost: For UAS operators, the main investment cost regards their training to operate the unmanned aircraft using the new instruments and data sources, which might also change the current workflows for pre- and post-flight planning and checks. Indirectly, the aircraft price might increase due to the investments done by the UAS manufacturers to design and produce an UAS that incorporates xG technology. Preceding the manufacturing costs, the UAS and VCA manufacturers must fund the research and development of hardware and software compatible with xG and that also meets all the safety and security standards defined for such a category of aircraft. Afterwards, once the product design is complete, the manufacturers must apply for product certification from the respective aviation authority. When the product becomes an approved device, the manufacturing costs will also be added up, resulting in a final price that is comparatively higher considering a non-xG/non-ICNS UAS. In the event of xG ICNS becoming mandatory, non-compliant UASs will need to be upgraded accordingly requiring either the acquisition of additional equipment or a maintenance agreement that covers such update, both resulting in costs for the UAS operators.

Operating cost: To ensure safety and high-performance, it is important to have continuous training and assessment of the operators; thus, such qualifications and labour costs are the main operating costs for UAS operators.

The UAS operator costs involve initial training to operate on the CNS data source and the subsequent training and proficiency checks, which are considered low.

5.4.2 Common Information Service Provider (CISP)

In the context of U-space, the CISP is responsible for managing and delivering information about the U-space, and interfaces with different stakeholders, such as the aeronautical information service (AIS) interface for the USSP, and interfaces with aviation authorities and UAS operators. For the Solution 0521, it is essential that the CISP, as a central node that concentrates the U-space CNS data, shall have an interface with xG telecommunication operators so the ICNS data can also be available at the U-space level with minimal overhead and latency, benefiting all the other Stakeholders connected to the CISP.

Investment cost: For the CISPs, the first cost driver is the interoperability and interconnection with the ATM. Such a connection may require new physical links to the ATM gateway, internetworking and data processing hardware and software, as well as data storage equipment. Additionally, it is necessary to have a connection with the xG network, so the ICNS data exchanged via xG networks is available to the USSP, ANSP, and NM.

Operating cost: The operating costs are primarily driven by the maintenance of the added infrastructure, including hardware and software, which demand updates and technical support.

Being the data aggregation point of the ATM-U-space integration, the CISP will require the upgrade of multiple interfaces with the Telecommunication operators, USSP, ANSP, and NM. Considering the volume of data and requests being exchanged with the aforementioned Stakeholders, the CISP investment costs might be substantial to contract high-data-rate links and acquire network interfaces, gateways, and data processing/storage hardware. These costs figures can be considered high, and the maintenance of such infrastructure to keep the operation adequate are estimated to be medium.

5.4.3 U-space Service Provider (USSP)

The USSP is the entity certified to offer unmanned aircraft operation enabling services. The USSP role is similar to ATM, but for the U-space airspace, and its attributions include providing at least network identification, geo-awareness, flight authorisation, and traffic information services. It is considered that the USSP will be operated with a certain degree of automation due to the high volume of simultaneous U-space operations. For this reason, the Solution 0521 is expected to increase the data availability per aircraft and also the number of missions, requiring a capacity increase in the USSP.

Investment cost: For the USSP, the main investment cost driver is the interconnection with UAS operators and the CISP gateway and increasing the processing power and communication demand. The USSP sources all relevant airspace data for the provision of U-space services, and with the deployment of the Solution 0521, it is expected a surplus of data with the use of the xG networks and the increased accessibility to the U-space it will bring, in comparison with the default U-space deployment. Thus, such connection may require new physical links, additional networking hardware,

data processing and storage hardware and software. Consequently, the connection to the UAS operators may require similar updates.

Operating cost: The operating costs are primarily driven by the maintenance of the added infrastructure, including hardware and software, which demand updates and technical support, and the labour costs.

The connection to the CISP and UAS operators, combined with the increase in UAS missions, will raise the USSP investment costs. However, the operating costs are estimated to be medium because of the number of connections with the UAS operators and the infrastructure required to maintain them.

5.5 Other relevant stakeholders

In the scope of the ANTENNAE project, other Stakeholders might be impacted, e.g. telecommunication operators and National and Civil aviation authorities. Due to the innovative character of the solution, exploiting xG networks' flexibility, multiple functionalities, such as positioning and JCS, and further evolution, it is necessary that the telecommunication operators, in partnership with aerospace Stakeholders, work collectively on a cost-efficient business model that provides assured performance in terms of safety, reliability, and availability. These last three characteristics need to be instituted and regulated by the National and civil aviation authorities, who will need to participate since the business model conception, hardware design, and future deployment with investigation task forces, release of resolutions and standards, assessment of services, hardware, and software, and inspection and regulation of ongoing operations.

6 CBA model

In this initial version of the ECO-VAL, we consider the potential variables regarding the applicable cost drivers described in Table 8, what benefits (potential revenues) could balance the applicable costs, and what funding sources could be considered to support (cover) specific stakeholders' costs.

Funding costs: The investment costs and the operating costs may be balanced by the revenue telecommunication operators would gain from the increased number of xG devices using their network infrastructure. Access to xG networks is expected to continue to use Subscriber Identification Module (SIM)-based authentication. Additionally, xG networks are expected to support emerging cybersecurity standards which will provide further attestation, ensuring the trustworthiness of network nodes and SIM-based devices. It is expected that each UAV equipped with one or more xG transceivers would house one or more SIMs, allowing secure SIM-based access to multiple xG networks. Each SIM would require a service subscription from a telecommunications operator. Therefore, telecommunications operators are expected to gain revenue from the additional number of SIM-based devices (xG equipped UAS) accessing their network. Where Revenues from the sale of additional SIM-based service subscriptions is forecasted to exceed operating costs and where the resulting profits are expected to provide a reasonable Return on Investment (ROI) timeframe, telecommunications operators would be motivated to maintain required service levels.

Telecommunication operators such as MNOs within some markets such as North America currently fund additional safety services such as Enhanced 911 (E911) emergency services. For terrestrial MNO users within North America, a surcharge labelled "E911" is added to each SIM subscriber's monthly mobile service bill. This surcharge covers costs associated with the building and operating of additional infrastructure and the services of additional stakeholders (entities) such as emergency Public Service Answering Points (PSAPs) which dispatch the appropriate emergency services (police, ambulance, fire brigade) and support critical information exchange such as the user's location based-on xG positioning. For future ariel MNO users (users of xG equipped UAS), a new "UAS" surcharge could be introduced to help fund the Investment and Operational costs associated with stakeholders (USSPs, CISPs, UAS Operators, NMs, and/or ANSPs).

USSP Networks: USSPs may use Telecommunications operator's networks (MNOs' networks) or USSPs could deploy and operate a private, dedicated xG network to provide ICNS services. Or, as described in the ANTENNAE Preliminary Concept of Operations (CONOPS) deliverable, a hybrid ICNS involving both private, dedicated xG network providing targeted xG network coverage and commercial MNOs' networks providing broader area or regional coverage. For private networks, investment costs, i.e., Capital Expenditure (CAPEX), is expected to be higher due to the cost of deploying dedicated network infrastructure, yet operational costs may be less since xG SIM-based service subscription costs may be mitigated. Conversely, Operating Expenses (OPEX) would be expected to be higher than CAPEX regarding the use of commercial MNO networks, as SIM subscription costs would be higher, yet most infrastructure deployment costs would be avoided.

For the final ECO-VAL, average industry CAPEX and OPEX costs regarding the deployment and operation of networks will be researched. Modelling and simulation results within the ANTENNAE project will determine what private, dedicated network deployment may be needed to meet ICNS service performance requirements within specific air traffic areas and what SIM-based service subscriptions may be needed to ensure broader regional ICNS service performance. This research will

consider significant CAPEX infrastructure costs such as average industry cost per xG base station and spectrum rights and significant OPEX costs such as average industry SIM-based service cost per Gigabyte of data. Cost variables will be used to analyse how scaling-up or down the variables such as ICNS coverage area affects the overall CBA. The table shown in Figure 6 provides a preliminary illustration of the Costs and Revenues the CBA will consider.

Applicable Cost Drivers from Table 8: identification of solution's cost drivers and deployment locations							
Stakeholder	Costs and Benefits (Revenues)		CBA period (years)	Assumptions	CBA Model Cost and Benefit (Revenue) Variables		CBA Outcome (Positive or Negative)
					Low Altitude Airspace (square kilometers)	Number of Stakeholders per "Low Altitude Airspace"	
ANSPs	CAPEX	Network infrastructure acquisition and deployment	1 to 10		1 to 100	1 to 10	To be estimated in the final version of Solution 0521 ECO-EVAL
		ATCO and technician initial training on new data source					
	OPEX	System maintenance and software licenses					
		ATCO and technician recurrent training and proficiency checks					
	REVENUE	xG "UAS" Surcharge funding					
Network Manager (NM)	CAPEX	Network infrastructure acquisition and deployment	1 to 10		1 to 100	1 to 10	To be estimated in the final version of Solution 0521 ECO-EVAL
		System software update to handle ICNS data via xG TN and NTN networks					
	OPEX	System maintenance and software licenses					
	REVENUE	xG "UAS" Surcharge funding					
Airspace users: Rotorcraft (VTOL)	CAPEX	Software and hardware upgrade to make aircraft compatible with xG for ICNS	1 to 10		1 to 100	1 to 100	To be estimated in the final version of Solution 0521 ECO-EVAL
		OPEX					
	REVENUE	Profits from more efficient air traffic synchronization (support of more efficient flight planning/authorization)					
U-space Stakeholder: UAS operators	CAPEX	UAS operator initial training on new data source	1 to 10		1 to 100	1 to 1,000	To be estimated in the final version of Solution 0521 ECO-EVAL
		Software and hardware upgrade to make the aircraft compatible with xG for ICNS (done by UAS manufacturers)					
	OPEX	Product design, operation, and safety certification cost (done by UAS manufacturers)					
	REVENUE	Ongoing training and proficiency checks					
		Profits from increased air traffic synchronization (support of higher density of aircraft within the low altitude airspace)					
U-space Stakeholder: Common information service provider (CISP)	CAPEX	U-space and ATM xG data integration	1 to 10		1 to 100	1 to 10	To be estimated in the final version of Solution 0521 ECO-EVAL
		Network infrastructure acquisition and deployment					
	OPEX	System software update to handle ICNS data via xG TN and NTN networks					
	REVENUE	Maintenance of integration software/hardware					
		xG "UAS" Surcharge funding					
U-space Stakeholder: U-space service provider (USSP)	CAPEX	Network infrastructure acquisition and deployment	1 to 10	USSPs will may use Telecommunications operators networks (MNO networks) or USSPs could deploy and operate a private dedicated xG network for ICNS services. CAPEX > OPEX for the deployment of a dedicated Private Network, as infrastructure investment would be very high yet SIM subscription costs would be very low. OPEX > CAPEX for the use of MNO networks, as SIM subscription costs would be higher yet infrastructure costs would be lower.	1 to 100	1 to 10	To be estimated in the final version of Solution 0521 ECO-EVAL
		Data processing and storage hardware					
		System software update to handle ICNS data via xG TN and NTN networks					
	OPEX	Maintenance of integration software/hardware					
		Maintaining the network infrastructure and software for ICNS as service provisioning which implies possible ANSP/USSP services and additionally ICNS services supporting UAS/VCA operations					
	REVENUE	Review and update of the regulations					
		Inspection and monitoring of the ICNS services					
		xG "UAS" Surcharge funding for USSP entity					
		SIM Subscription profits for Telecommunications operator					

Figure 6: Applicable cost drivers from Table 8 - identification of solution 0521 cost drivers and deployment locations based on CBA Model Cost and Benefit (Revenue) variables

7 CBA results

This chapter shall be completed in the CBA deliverable that is expected for solutions aiming at a higher maturity level than TRL2.

However, as agreed with SJU, these chapters will be included in the final version of Solution 0521 ECO-EVAL.

Not applicable for the initial version of the ECO-EVAL.

8 Sensitivity and risk analysis

This chapter shall be completed in the CBA deliverable that is expected for solutions aiming at a higher maturity level than TRL2.

However, as agreed with SJU, these chapters will be included in the final version of Solution 0521 ECO-EVAL.

Not applicable for the initial version of the ECO-EVAL.

9 Recommendations and next steps

9.1 Solution summary and evaluation of ECO-EVAL results

Current communication, navigation and surveillance technologies are facing the arrival of new users in ECAC airspace. The growing increase in legacy aviation traffic, coupled with the emergence of UASs, requires new resources to cope with the specific constraints of these new vehicles, while ensuring quality of service, efficiency and safety for LL and VLL altitude. The ANTENNAE project (SESAR Solution 0521) proposes to unify the three domains, thus speaking of ICNS, using terrestrial and non-terrestrial xG networks. This approach aims to ensure high data rate and low latency connectivity while providing continuity between the ATM and the U-space

The qualitative assessment of Solution 0521 shows a high degree of confidence that the deployment of ICNS through xG would allow the development of the airspace capacity at LL and VLL. More specifically, the deployment of the solution hopes to see the development of U-space, integrating with ATM while taking an increasingly important part in ECAC airspace. However, there will be costs associated with the use of xG. Firstly, in terms of changes in terms of equipment for UAS and aircraft, which will have to integrate the appropriate equipment. Secondly, in terms of ground infrastructure, in the event that the technology is not provided by telecommunications operators (for TN and NTN).

By reusing existing infrastructure, Solution 0521 hopes to increase the number of aircraft circulating in ECAC airspace, without having a strong environmental impact. The additional coverage provided by the use of TNs and NTNs, as well as the introduction of A-PNT and A-SUR, hopes to allow for new, more efficient and shorter flight routes.

The use of A-PNT and A-SUR is also expected to increase safety and security, in particular by thwarting vulnerabilities related to the use of GNSS. However, a more in-depth study of the security risks must be carried out.

Due to its cross-domain nature, Solution 0521 impacts several Stakeholders across ATM and U-space domains. To arrange the CNS data exchange and interface with ANSP, CISP, USSP, aviation authorities, and UAS operators, it may require the creation of network physical links between these entities and also the telecommunication operators, as well as the update of their internal network, data processing, and data storage infrastructure to channel in and process all the new data flowing from the 3GPP xG ICNS providers. Where human interaction is needed, the training and qualification of the staff is of paramount importance to keep all the procedures at high standards of safety and efficiency. Other Stakeholders are involved and will have indirect costs, such as aviation authorities and manufacturers, that will need to work together to design, assess, and certify the solution.

Information concerning the stakeholders and their involvement, the scenarios and their descriptions, as well as the impacts of the solution and its benefits, has been rigorously evaluated. These inputs form a solid basis for future quantitative analyses and the continuation towards a higher TRL.

9.2 Recommendations

Some recommendations can be made to take the solution even further and improve the study of its impact, both economically and in terms of performance:

- Human Performance assessment: Deployment of Solution 0521 will require training for control staff. For the time being, the content and duration of these future training courses are still unknown, making it difficult to estimate their impact in terms of Human Performance, which will therefore have to be assessed.
- Evaluation through simulation of all benefits: Not all estimated benefits will be evaluated during validation exercises. For a more thorough assessment of all benefits, particularly in terms of quantitative data, it is recommended to evaluate them through simulation if the opportunity arises.

9.3 Next steps

The next steps resulting from the analysis performed are listed below:

- Carry out the security assessment following the SecRAM 2.0 methodology,
- Carry out validation exercises and use the results to quantitatively assess the PIs that can be measured,
- Carry out a more in-depth study of the costs associated with solution deployment, while considering the expected benefits in terms of cost-efficiency,
- Consider and carry out a study on the impact and potential use of the solution by military stakeholders,
- Use quantitative data to strengthen the benefits analysis in the ECO-EVAL final version,
- Complete coverage of all TRL2 maturity criteria in the ECO-EVAL final version.

10 References

10.1 Applicable documents

This ECO-EVAL complies with the requirements set out in the following documents:

[SESAR solution pack](#)

- [1] ANTENNAE, Preliminary Concept of Operations (CONOPS) for Data Driven Cost Effective 5G Integrated CNS As a Service, 01.02, 11 June 2025.
- [2] ANTENNAE, Operational Services and Environment Description for Data Driven Cost Effective 5G Integrated CNS As a Service, 01.08, 2 June 2025.
- [3] ANTENNAE, Initial Functional Requirements for Data Driven Cost Effective 5G Integrated CNS As a Service, 01.00, 30 June 2025.
- [4] ANTENNAE, Exploratory Research Plan (ERP) for Data Driven Cost Effective 5G Integrated CNS As a Service, 01.00, 30 June 2025.

[Content integration](#)

[Content development](#)

- [5] DES Common Assumptions, 00.02.01, 29 June 2023.
- [6] DES SESAR solution ECO-EVAL quick start guide, 1.0, 2 February 2024.
- [7] DES SESAR Maturity Criteria and sub-Criteria, 01.01, 15 Février 2024.

[System and service development](#)

[Performance management](#)

- [8] DES performance framework – U-space companion document, 00.01.02, 3 April 2023.
- [9] DES Performance Framework, 00.01.04, 29 June 2023.

[Validation](#)

[System engineering](#)

Safety

Human performance

Environment assessment

Security

- [10] DES security risk assessment methodology (secRAM 2.0), 03.00.01, 16 April 2024

Programme management

- [11] 101167288 ANTENNAE Grant Agreement, 25 June 2024.
[12] SESAR 3 JU Project Handbook – Programme Execution Framework, 01.00, 11 April 2022.

10.2 Reference documents

- [13] [Integrated Communication, Navigation and Surveillance System Fact Sheet, DOI: 10.3030/874478.](https://doi.org/10.3030/874478)
- [14] SESAR Initial Economic Evaluation (ECO-EVAL) for Data Driven Cost Effective 5G Integrated CNS As a Service – SESAR Solution 0521, 7 October 2022.
- [15] SESAR PJ.14-W2-81b - TRL4 CBAT Alternative Position, Navigation and Timing - Enhanced DME, 25 October 2022.
- [16] SESAR PJ.14-W2-81c- A-PNT-LDACS Analysis: Cost Benefit Analysis (CBA) for TRL4, 24 April 2023.
- [17] [Future all Aviation CNS Technology \(FACT\) Fact Sheet, DOI: 10.3030/894616.](https://doi.org/10.3030/894616)
- [18] [Enabling sustainable AiR MObility in URrban contexts via emergency and medical services \(AiRMOUR\), DOI: 10.3030/101006601.](https://doi.org/10.3030/101006601)
- [19] AiRMOUR, Deliverable 5.3: Comparative CBA of manned and unmanned EMS UAM operations in comparison for traditional EMS transport, 14 August 2023.
- [20] [Enhanced Automation for U-Space/ATM integration \(EALU-AER\) Fact Sheet.](#)
- [21] [Future Connectivity and Digital Infrastructure \(FCDI\) Fact Sheet, DOI: 10.3030/101114729.](https://doi.org/10.3030/101114729)
- [22] [ETHER Project, About ETHER.](#)

- [23] [u-Space sePAraTIO management \(SPATIO\) Fact Sheet, DOI: 10.3030/101114674.](#)
- [24] ICAO, Doc 4444, Procedures for Air Navigation Services – Air Traffic Management.
- [25] [SESAR Joint Undertaking, European ATM Master Plan – Executive view, 2025.](#)
- [26] [ICAO, “Unmanned Aircraft Systems Traffic Management \(UTM\) – A Common Framework with Core Principles for Global Harmonization Edition 4”, September 2023.](#)
- [27] [Commission Delegated Regulation \(EU\) 2019/945 of 12 March 2019 on unmanned aircraft systems and on third-country operators of unmanned aircraft systems, European Commission, 2019, C/2019/1821.](#)
- [28] ICAO, Cir 328, Unmanned Aircraft Systems (UAS).
- [29] [Commission Implementing Regulation \(EU\) 2021/665 of 22 April 2021 on a regulatory framework for the U-space \(C/2021/2671\).](#)
- [30] [SESAR Joint Undertaking, SMART ATM U-space and urban air mobility.](#)
- [31] [EUROCONTROL, Guidelines for RNAV 1 Infrastructure Assessment, July 2021.](#)
- [32] [FAA, GBN-Distance Measuring Equipment \(DME\), March 2024.](#)
- [33] [Wikipedia, Distance Measuring Equipment.](#)
- [34] [SKYbrary, Geofencing Basics.](#)
- [35] [M. A. Ullah, V. Kramar, H. Alshaer, G. Geraci, 5G Integrated Communications, Navigation, and Surveillance: A Vision and Future Research Perspectives, February 2025.](#)
- [36] [ICAO, Integrated CNS Project.](#)

Appendix A Maturity criteria (self-assessment)

The self-assessment of maturity criteria as defined in the DES SESAR Maturity Criteria and sub-Criteria document [7] is presented in Table 9: Self-assessment of TRL2 maturity criteria for Solution 0521 Table 9. Criteria that are only partially covered in this initial version are intended to be fully covered in the final version of the ECO-EVAL expected at the end of the project.

Sub-Criteria (Criteria ID PER.TRL2.2)	Criteria/Sub-Criteria ID Is the criteria covered?	Where?	Explanation if not covered (or partially)
Scope of the solution and Enablers (if available)	Yes	Section 2.2, section 3.1, section 3.2	Covered
Interdependencies with other solutions	Yes	Section 3.2.1	Covered
Implementation/Deployment options	Partially	Section 3.5	As work is still in progress, this criterion will be fully covered in the final version.
Identification of the impacted stakeholders	Yes	Section 3.4	Covered
Qualitative description of the benefits including the most impacted KPAs and KPIs.	Yes	Chapter 4	Covered
Identification of cost drivers	Partially	Chapter 5	As work is still in progress, this criterion will be fully covered in the final version.

Table 9: Self-assessment of TRL2 maturity criteria for Solution 0521