Final Project Report

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Abstract

This project presented the outcomes of the CNS system of system project. This project was a CNS project which has coordinated with the Communication, Navigation and Surveillance SESAR projects as well as supported the transversal SESAR project in charge of the ATM Master plan update through the development of a Technical Architecture Document (TAD) and Roadmaps for CNS domains. In addition, it provided a framework for cross-domain CNS study and delivered four ad-hoc studies: a CNS Cross-Domain Spectrum Evolution report, a feasibility Study on the Monitoring of GNNS Constellation Degradation Using ADS-B, an evaluation on the future use of voice communication and a preliminary study on the use of a non-geostationary satellite for future CNS services. Finally, a preliminary study that identified the emerging security requirements at CNS level has been conducted.

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Acronyms

Acronym	Definition
A/G	Air/Ground
ABAS	Aircraft Based Augmentation System
ACARS	Aircraft Communications Addressing and Reporting System
ACAS	Airborne Collision Avoidance System
ADF	Automatic Direction Finder
ADS-B	Automatic Dependent Surveillance-Broadcast
ADS-C	Automatic Dependent Surveillance-Contract
AeroMACS	Aeronautical Mobile Airport Communications System
AFTN	Aeronautical Fixed Telecommunication Network
AIRM	Aeronautical Information Referece Model
AIS	Aeronautical Information Service
AMHS	Aeronautical Message Handling System
ANS	Air Navigation Services
ANSP	Air Navigation Service Provider
AOC	Airline Operational Communications
A-PNT	Alternative-Position, Navigation and Timing
APV	Approach Procedure with Vertical guidance
A-SMGCS	Advanced-Surface Movement Guidance and Control Systems
ATFCM	Air Traffic Flow and Capacity Management
ATM	Air Traffic Management
ATN	Aeronautical Telecommunication Network
CPDLC	Controller-Pilot Data Link Communications

DATIS	Digital Automatic Terminal Information Service
DFMC	Dual Frequency Multi Constellation
DME	Distance Measuring Equipment
EATMN	European Air Traffic Management Network
ECAC	European Civil Aviation Conference
EGNOS	European Geostationary Navigation Overlay Service
EU	European Union
EUROCAE	European Organisation for Civil Aviation Equipment
G/G	Ground/Ground
GBAS	Ground Based Augmentation System
GLONASS	GLObal NAvigation Satellite System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
ILS	Instrument Landing System
L-DACS	L-band Digital Aeronautical Communications System
LNAV	Lateral NAVigation
LORAN	Long Range Navigation
LPV	Localiser Performance with Vertical guidance
MLAT	Multilateration
MLS	Microwave Landing System
NAVAID	NAVigation AIDs
NDB	Non-Directional Beacon
PBN	Performance Based Navigation
POA	Plain Old ACARS
PRS	Public Regulated Service

PSR	Primary Surveillance Radar
RNAV	aRea NAVigation
RNP	Required Navigation Performance
RPAS	Remotely Piloted Aircraft Systems
SARPS	Standard and Recommended Practices
SATCOM	Satellite Communications
SBAS	Satellite Based Augmentation System
SESAR	Single European Sky ATM Research Programme
SJU	SESAR Joint Undertaking
SMR	Surface Movement Radar
SSR	Secondary Surveillance Radar
TAD	Technical Architecture Description
TCAS	Traffic alert and Collision Avoidance System
TIS-B	Traffic Information Services-Broadcast
TMA	Terminal Manoeuvring Area
VDL	VHF Data Link
VNAV	Vertical NAVigation
VoIP	Voice over IP
VOR	VHF Omnidirectional Radio Range
WAM	Wide Area Multilateration

1 Project Overview

SESAR CNS System of System project aimed at covering the development of a CNS Technological Architecture Document (TAD) and providing inputs into update cycles of the Master Plan, addressing a consolidated CNS Roadmap, providing a framework for CNS cross-domain technical study to improve the overall CNS robustness, and finally to address emerging CNS security requirements.

1.1 Project progress and contribution to the Master Plan

The project has coordinated with the Communication, Navigation and Surveillance SESAR projects as well as supported the transversal SESAR project in charge of the ATM Master plan update through the development of a Technical Architecture Document (TAD) and Roadmaps for CNS domains. The project has been directly involved in the different updates of the Master Plan, providing inputs for the planning and architecture.

The bases of the ATM Master plan (Enablers, Operation Improvements and Standards and deployment packages) have been reviewed and modified according to the developments resulting from the SESAR projects.

Update of the Master Plan for Communication, Navigation and Surveillance domain are usually driven by three main factors: changes in the operational services, increasing of system performances and environmental restrictions. The Operational improvements are not necessarily related exclusively to the effect of a change in technology, they can relate to procedures, working methods or routines and human factor aspects. An Operational Improvement is always associated to an operational benefit and is associated to one or more “strategic objectives”, forming part of one or more directions of change. In addition, the OI could also mean the “improvement of an existing capability” and/or the introduction of a new capability.

Operational services changes are reflected on the Master Plan in the concept of “Operational Improvements” (OI). This OI are created and introduced in the Master Plan by the Operational projects and they are linked to the necessary CNS Enablers involved in this operational change.

In addition, other OI have been generated due to the necessity of increasing performances, cost reductions or environmental restrictions. This OI have been introduced in the Master Plan and linked to Enablers by the CNS primary.

Different types of OI can be found, attending to the concept components defined in ICAO Doc 9854 Global Air Traffic Management Operational Concept that need to be integrated to form the ATM system. Each OI acronym attends to the following components:

AO: Aerodrome Operations
AOM: Airspace Organization and Management
AUO: Airspace Users Operations
CM: Conflict Management
CNS: Communications, Navigation and Surveillance
DCB: Demand and Capacity Balancing
IS: Information Services
SDM: ATM Service Delivery Management
TS: Traffic synchronization

Taking into account the explained above, the following tables summarizes the Operational Improvements affecting the CNS Infrastructure based on latest Master Plan version

Code	Name	Project contribution	Maturity at project start	Maturity at project end
CM-0102-A CM-0102-B	Dynamic Sectorisation based on complexity	More flexible sectorisation – not anymore based on national borders – may be supported by voice telephony based on Voice over IP.	N/A	N/A
CM-0105-A CM-0105-B	Enhanced ATC processes by the use of new CPDLC messages and related procedures, also for TBO	Data Link applications supported by ATN Baseline 1 data link can support the evolving ops concepts.	N/A	N/A
CNS-0001-A CNS-0001-B CNS-0001-C	Rationalisation of COM systems/infrastructure for Step1/2/3	Communication infrastructure evolution has been assessed within different SESAR work-packages dealing with the evolving operational concept..	N/A	N/A
IS-0303-A	Downlink of on-board 4D trajectory data to enhance ATM ground system performance: initial and time based implementation	Initial 4D trials were performed using ATN/OSI, technology intended for near and mid-term.	N/A	N/A
AO-0505-A	Improve Low Visibility Operation using GBAS Cat II/III based on GPS L1	Validation activities through flight tests have been performed on ground and airborne sytems.	N/A	N/A
AO-0505-B	Improve Low Visibility Operation using GBAS Cat II/III based on dual GNSS	Preliminary analysis of the evolution of the operations for CAT II/III using GBAS MC/MF has been performed.	N/A	N/A
AOM-0602	Enhanced terminal operations with APV using Barometric VNAV	The development of APV operations are supported by ICAO due to the increased safety level provided by the vertical guidance. Most of large airframe are Baro-VNAV capable.	N/A	N/A
AOM-0603 AOM-0605	Enhanced Terminal Airspace for RNP-based Operations Enhanced Terminal Operations with RNP transition to ILS/GLS/LPV	The combinaison of RNP and ILS/GLS/LVP can bring a high level of predictability during the approach while keeping low minimas in final approach. The different study on these transition and in particular the ones that include the use of RF leg support the overall improvement of terminal operations.	N/A	N/A
AOM-0604	Enhanced terminal operations with LPV using SBAS	Technical results from the performance assessment as well as recommendation on EGNOS v3 implementation have supported the	N/A	N/A

		implementation of these approach.		
CNS-0002-A CNS-0002-B CNS-0002-C	Rationalisation of NAV systems/infrastructure for Step1 Rationalisation of NAV systems/infrastructure for Step2 Rationalisation of NAV systems/infrastructure for Step3	Navigation infrastructure rationalisation has been widely assessed and studies within different SESAR work-packages.	N/A	N/A
AO-0202	Detection of FOD (Foreign Object Debris) on the Airport Surface	The primary sensors provide more safety detecting FOD on the movement area and informing the controller.	N/A	N/A
AO-0204	Airport Vehicle Driver's Traffic Situational Awareness	Increase of safety and efficiency for airport vehicles movements.	N/A	N/A
AO-0206	Enhanced Guidance Assistance to Airport Vehicle Driver Combined with Routing	The guidance assistance to vehicle drivers has been enhanced, displaying dynamic traffic information and status of the environment.	N/A	N/A
AO-0309	Minimum-Pair separations based on RSP	Improvement of runway capacity due to a more efficient non-wake turbulence pair wise separation based on Required Surveillance Performance.	N/A	N/A
AUO-0605	Traffic Alerts for Pilots during Runway Operations	Improvement of safety for pilots in runway operations, providing to flight crew alerts on potential risks of collision.	N/A	N/A
CM-0203 CM-0207-A CM-0210	Automated Flight Conformance Monitoring Advanced Automated Ground Based Flight Conformance Monitoring in En-Route Ground Based Flight Conformance Monitoring in En-Route using aircraft Data	Assistance to the controller in tasks subject to automatization, as trajectory re-calculation for deviated aircraft from its clearance, plan or flight intent.	N/A	N/A
CM-0801	Ground Based Safety Nets (TMA, En-Route)	Provision of alerts to air traffic controllers when separation minima may be infringed or potential threats.	N/A	N/A
CM-0802	Display and use of ACAS resolution advisory downlink on the controller working position	Increase of controller's situational awareness in critical situations.	N/A	N/A
CNS-0003-A CNS-0003-B CNS-0003-C	Rationalisation of SUR functionalities and/or technologies for CNS systems supporting cost efficiency, spectrum efficiency,	Surveillance infrastructure rationalisation has been widely assessed and studies within different SESAR work-packages.	N/A	N/A

	etc. for Step 1 Rationalisation of SUR systems/infrastructure for Step2 Rationalisation of SUR systems/infrastructure for Step3			
SDM-0201 SDM-0205	Remotely Provided Air Traffic Service for Single Aerodrome Remotely Provided Air Traffic Services for Two Low-density Aerodromes	ACS or AFIS provided from a remote location, removing the need of sending this information from the control towers in aerodromes.	N/A	N/A

1.2 Project achievements

The first and main objective of this project was to support the transversal SESAR project in charge of the ATM Master Plan update [2]. This objective has been fully achieved by the development of a CNS Technical Architecture Document. This document that details a first level of CNS System decomposition supports the identification of individual and common element of communication, navigation and surveillance domain. In addition, the development of the integrated CNS roadmap complemented the ATM Master Plan by providing a detailed roadmap and strategy for the CNS infrastructure that covers the short, mid and long term evolution.

The second objective of this project was to provide a framework to support the development of ad-hoc CNS cross-domain studies. This objective has been fully achieved and five cross-domain CNS studies have been carried out: a CNS Cross-Domain Spectrum Evolution report, a feasibility Study on the Monitoring of GNNS Constellation Degradation Using ADS-B, an evaluation on the future use of voice communication, a preliminary study on the use of a non-geostationary satellite for future CNS services, and a security risk assessment for the current and future CNS systems. These fives activities have demonstrated the need for projects where communication, navigation and surveillance expertise are bring together to address cross-domain matters.

Finally, it should be noted that the project has been internally coordinated through the organisation of four face-to-face progress meeting during which all members where represented. The external coordination has been ensured by the participation to two infrastructure plenary meetings. The technical outcomes of the first and last task (Technical Architecture Document, integrated CNS roadmap and the emerging security requirements) have been presented and reviewed during two airspace user workshops.

1.3 Project Deliverables

The following table presents the relevant deliverables that have been produced by the project.

Reference	Title	Description
D01-01	CNS Technical Architecture Document	The CNS Technological Architecture Document presented a first level of decomposition of CNS System of Systems as established in co-ordination with the transversal SESAR project in charge of the

		ATM Master plan update. It provides a high level description of each Communication, Navigation or Surveillance System and a list of their in/out data flows. A dynamic analysis is also presented in the form of sequence diagrams. It also includes a series of traceability tables that aim at identifying the expected mid-term evolution (2013 - 2024) and the longer-term evolutions (2024 - 2030) changes within CNS Systems, the enablers that supports the changes and the involved SESAR projects. Some civil-military CNS interoperability aspects are highlighted in the document for consistency with the Roadmap
D02-02	Integrated CNS roadmap	The integrated CNS roadmap presented a strategic CNS view that detailed the drivers for change in CNS and described the current trend to integrate CNS systems and operations together. In addition, for each Communication, Navigation and Surveillance domain, a description of the short, mid and long term available and foreseen technology is provided, the interoperability and standardisation are addressed and a roadmap for the next decades is given. This roadmap has been drawn by concatenating together the existing SESAR roadmap and strategy [2], [17-23]. The civil/military interoperability has also been addressed based on civil and military existing roadmap [9-11]. An integrated CNS roadmap presenting the evolution of the main system and technology for each domain has also been provided.
D04	CNS Technology Assessment	Part 1: CNS Cross-Domain Spectrum Evolution Report Based on the SESAR Spectrum Strategy and Vision, the first part provides an overview of current systems and associated issues per frequency band and second per CNS-domain. Building on this inventory, the two bands subject to the most potential CNS-cross-domain evolution were further analysed: the VHF band and the L band (960 to 1215 MHz). Some interesting ideas have been proposed for the VHF band that should be further pursued. Due to the pairing of ILS/VOR and DME channels, the VHF and L bands are intricately linked. The main frequency shortage in navigation concerns ILS/DME, which leads to a need to maintain marker beacons to support the ILS in some cases. Progressive implementation of RNP approaches could lead to some removal of ILS Cat I approaches and thus reduce this congestion to some extent. The coordinated development of a more equalized DME/DME network could also contribute. De-pairing of navigation frequency channels has been suggested again and will deserve further study to better evaluate the benefits in light of the effort that would be required to implement this. The same is true for the potential making available of the upper part of the VOR spectrum to VHF voice COM, following the

		rationalization of the VOR network. Part 2: Feasibility Study on the Monitoring of GNNS Constellation Degradation Using ADS-B The second part is a feasibility study on the use of ADS-B data to detect GNSS degradation. GNSS outages may be monitored based on data coming either from a ground monitoring network or from airborne measurements, for example by using position messages broadcast by aircraft. Several ground and airborne data collection options are presented, giving a description of their properties and a synthesis with the pros and cons. Architectural issues have been discussed, proposing a high-level architecture and suitable data processing and display solutions for the monitoring system. Finally, a prototype algorithm has been tested and validated through many simulation sessions based on real ADS-B data collected from a ground station located in southern Italy. Part 3: Use of voice communications in a future 4D based environment The third part addresses the A/G and G/G voice Communication solutions in a future 4D based environment. A description of the current and future operational, functional and performance voice requirements coming from EUROCAE ED-136 standard, SESAR communication project and Iris Phase 2.1 has been provided. Then, an analysis of the voice communication demands for Flexible Airspace Management has been performed, taking in particular the sector delegation concept into account. In addition, the sector-less ATM concept focusing on the impact to voice communication system and its A/G and G/G communication solutions have been addressed. Sector-less ATM is an alternative concept for air traffic management in the upper airspace which envisions en-route air traffic control without conventional sectors. Instead, a controller will be assigned several aircraft regardless of their geographic position. He will be responsible for these aircraft during their entire flight in the upper airspace. This document defined a first set of requirements and assumptions for a sector-less ATM voice communication system. It analysed the problems, like Media access control, Routing of the voice for A/G and G/G communication, etc. and compared the proposed solutions. Specific use cases were developed and the workflow for aircraft assignment, aircraft delegation, etc. was proposed. In addition, an A/G and G/G voice communication demonstrator for sector-less ATM have been developed and has been described in the document. Finally, a number of areas that could not lead to a definitive conclusion in the project timeline, and for which future investigation is required have been

		highlighted. Part 4: Study of DataLink/SBAS-ARAIM/Satellite-based ADS-B The fourth and last part of this task initiated a study of a common non-GEO SATCOM solution that can cover the need for air-ground information exchange within ANS as a whole. The purpose of this common solution is to obtain true global service (ANS), including service (ANS) in areas and environments where the properties of satellite-based solutions are superior – typically in remote, oceanic or low-traffic areas. Methods used are data survey for identification of possible rationalization of A/G transmissions and joint use of datalinks across services, operational benefit analysis, display of possible technical solutions and identification of need for further work.
D05	Emerging security requirements at CNS level Report	The first section of this deliverable presents an overview of the security risk assessment methodology and how it has been applied to assess the security of Communication, Navigation and Surveillance systems. Then, a section is dedicated for each separated risk assessment for Communication, Navigation and Surveillance system respectively. In addition to the individual risk assessment, a risk assessment for an integrated CNS system recognising the growing interdependencies between the three systems has also been performed and is describes in the document. Finally, the summary of the risk assessment is presented and some mitigation is discussed.

1.4 Contribution to Standardisation

SESAR CNS System of System Project addressed the mid-term to long-term CNS architecture and evolution which is beyond standardisation activities. As such, the project's members did not contribute or participate to standardisation activities. However, the D02 CNS Roadmap listed the current standardisation and regulatory status for each of the Communication, Navigation and Surveillance domain based on existing and future European regulations [3-8].

1.5 Project Conclusion and Recommendations

Conclusions

The development of a Communication, Navigation and Surveillance Technical Architecture Document fully supported the SESAR transversal projects in charge of the European ATM Master Plan. The decomposition of the CNS system of systems allowed the identification of common system between

the different Communication, Navigation and Surveillance domain. Such decomposition also supported the development of the integrated CNS roadmap.

The integrated CNS roadmap detailed for each of the Communication, Navigation and Surveillance domain the short, mid, and long term technologies, the target operational environment and a roadmap that draw the evolution of these technologies to support the operational improvement. Based on the individual roadmap, an integrated roadmap per flight phase has been developed. Although this document does not fully provide a holistic CNS strategy view, it is a good basis for a further development of such a strategy.

The spectrum analysis performed within that project concluded that the main band that requires coordinated CNS action from aviation spectrum planning remains the L-band where the most significant compatibility and evolution challenges come from LDACS and external threats. A first overview based on the available results of the compatibility tests and simulations performed so far has been provided. LDACS standardization and deployment scenarios will need to be carefully analysed to permit the right system choices such that all CNS services can evolve in line with operational needs and maintain a high level of safety performance.

The implementation of a GNSS status monitoring service based on ADS-B has been assessed as possible even if with some limitations have been identified. Several improvements of ADS-B standard have been proposed to properly identify GNSS failures and, in view of future implementation of multi-constellation airborne receivers, which specific GNSS system or constellation is available or not. Such considerations have been summarised in the form of requirements that may need to be considered during the development of future ADS-B standard.

The voice communication solutions for flexible airspace management concepts like sector delegation and sector-less ATM have been analysed and future operational, functional and performance voice requirements have been considered. For allowing sector delegation between ATSUs the required main features are parallel access to frequencies from multiple ATSUs, as well as a dynamic radio and phone routing via the inter-ATSU network. For the tactical handover process access to information about which part of the airspace is being managed by which air traffic controller is essential, which leads to an acknowledged workflow process between the VCS preventing gaps in the airspace management. For sector-less ATM the impact to voice communication system and its radio and phone communication were performed. It seems that sector-less ATM would increase the throughput of an area by utilizing more flexibility airplane assignment and by improving the communication between controllers and pilots. The study highlighted that the removal of the geographical sector borders decreases the communication intensity. However the new concept reveals new problems that have to be solved, such as media access control i.e. keeping radio communication discipline, addressing i.e. routing of the voice for A/G and G/G communication, decentralized aircraft conflict management and role addressing…. Some mitigations have been identified that can address these new difficulties.

The evaluation of the use of non-geostationary satellite for Communication, Navigation and / or Surveillance in northern latitude was a preliminary study and initial results have been obtained. The methodology used was based on a data survey for identification of possible rationalization of A/G transmissions and on the assumption of a possible joint use of datalinks across CNS services. The main results were an initial description of the current status of air-ground data transmission within an air navigation service provider (ANSP) and the uncovering of the operational need and technological possibilities for a common non-geostationary SATCOM solution. Finally, motivations to prepare for further study of this issue within the aviation community have been summarized.

This CNS security risk assessment performed under this project illustrated that the current CNS system is mainly robust against unlawful interference due to the different technologies and techniques which provide the services and the bespoke nature of the system – making it difficult to successfully implement an attack. The future CNS systems will remain robust to unlawful interference but measure should be taken to continue to protect the systems – in particular the communication infrastructure as it moves to support the SWIM concept.

Recommendations

The project recommends continuing this activity within SESAR 2020 framework in order to better identify potential technological and functional synergies across the Communication, Navigation and Surveillance domain and to optimize the potential benefit from common infrastructure and/or system capabilities for both airborne and ground segment. In particular, the following point should be addressed: analysing the Communication, Navigation and Surveillance current infrastructure, requirements and vulnerabilities as an integrated domain; identifying the foreseen evolution of these infrastructure and defining the future integrated ATM architecture, identifying a spectrum strategy across CNS; ensuring the civil-military interoperability for current and future CNS infrastructure.

2 References

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[2] European ATM Master Plan

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[20] SESAR WP15.01.06 D04-01 SESAR Aeronautical Spectrum Strategy and Vision, Edition 1.02, 08/10/2015

[21] SESAR WP15.01.06 D04-02 Spectrum Strategy Band-by-Band, Edition 1.01, 08/10/2015

[22] SESAR WP15.01.06 D05 Implementation of the SESAR Aeronautical Spectrum Strategy & Vision, Edition 1.01.01, 07/10/2016

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