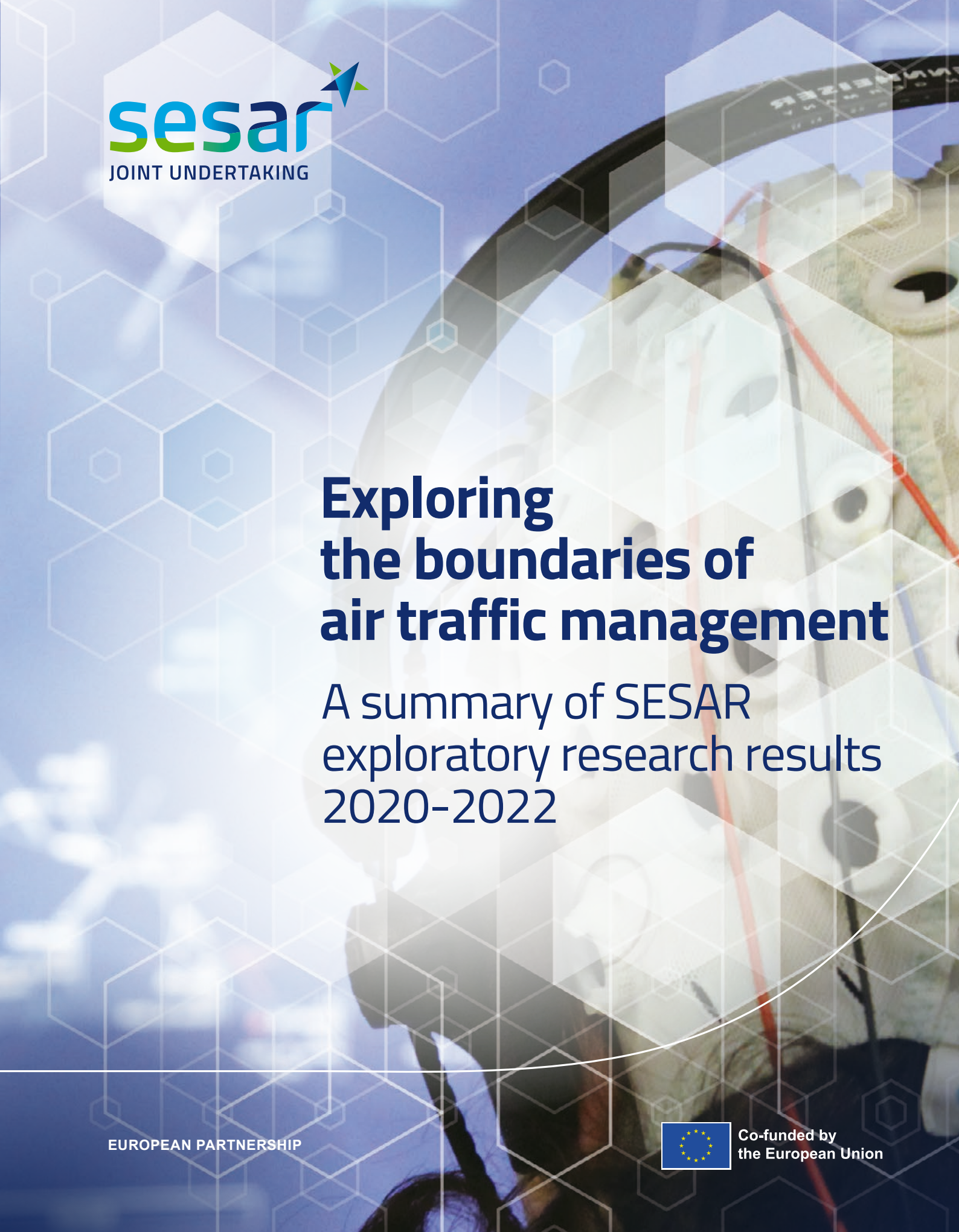

sesar
JOINT UNDERTAKING

# Exploring the boundaries of air traffic management

## A summary of SESAR exploratory research results 2020-2022

EUROPEAN PARTNERSHIP

Co-funded by the European Union

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# Contents

# ABOUT SESAR 3 JOINT UNDERTAKING

The SESAR 3 Joint Undertaking is an institutionalised European private and public partnership set up to accelerate through research and innovation the delivery of the Digital European Sky. It is developing and accelerating the market take-up of the most cutting-edge technological solutions to manage conventional aircraft, drones, air taxis as well as vehicles flying at higher altitudes.

The SESAR 3 JU partnership brings together the EU, Eurocontrol, and more than 50 organisations covering the entire aviation value chain, from airports, airspace users of all categories, air navigation service providers, drone operators and service providers, the manufacturing industry and scientific community.

The partnership also works closely with the regulatory and standardisation bodies, notably EASA and Eurocae, as well as key stakeholders, such as professional staff organisations, the space and military communities and global partners.

# FOREWORD

"*The lightning spark of thought, generated in the solitary mind, awakens its express likeness in another mind, in a thousand other minds, and all blaze-up together in combined fire; reverberated from mind to mind, fed also with fresh fuel in each, it acquires incalculable new heat as converted into action.*" This beautifully expressed observation was made by Thomas Carlyle, a renowned 19th century essayist, historian and philosopher, about collaboration and its power to transform individually held knowledge into joint ventures and innovative actions.

As a collaborative platform for innovation, the SESAR 3 Joint Undertaking facilitates this meeting of minds in the domains of aviation and air traffic management, providing the right conditions to yield fresh ideas that push the boundaries of our research and development. However, this is not a pursuit of knowledge for the sake of it; but rather a harnessing of the latest advances in technology to support aviation's sustainable transition, deliver much-needed efficiency gains, while enabling the continued growth and diversification of air travel, as new types of vehicles such as drones take to the sky.

Unlocking innovation to tackle the opportunities and challenges that lie ahead is very much in line with the SESAR vision to deliver the Digital European Sky as set out in the European ATM Master Plan, and matches the ambitions of the EU's 'Sustainable and Smart Mobility Strategy', the 'European Green Deal' and the 'Europe fit for the digital age' initiative. At the SESAR 3 Joint Undertaking, we support long-term exploratory research and have created a pipeline that transforms ideas into solutions to increase the performance of European aviation, in terms of safety, efficiency and the environment.

This publication captures the results from some 41 completed exploratory research projects and the SESAR knowledge transfer network, Engage. Active between 2020 and 2022, the projects brought together just under 200 academic and industry partners, such as universities, SMEs, research centres, airlines, manufacturers, and air navigation service providers from across the European Union and EU Associated Countries. The projects explored concepts and technologies coming from not just aviation and ATM, but also other sectors, such as automotive, robotics or system engineering, as well as other safety-critical industries.

The most promising and mature technologies will now be considered for inclusion in the industrial research strand of the Digital European Sky research and innovation programme, with the ultimate goal of delivering smart, sustainable and safe air travel for Europe and its citizens.

**Andreas Boschen**

*Executive Director*
*SESAR 3 Joint Undertaking*

# INTRODUCTION

## The SESAR Innovation Pipeline

The Digital European Sky leverages the latest digital technologies ("SESAR Solutions") to increase the levels of automation, cyber-secure data sharing and connectivity in air traffic management, as well as to enable the virtualisation of its infrastructure and air traffic service provision in all types of airspace, including for very-low and high-altitude operations. In doing so, these technologies enable the system to become more scalable and agile, while building resilience to disruptions, changes in traffic demand and diversity of air vehicles. These attributes are all key to future-proofing the system in a smart and sustainable way.

To deliver the Digital European Sky, the SESAR research and innovation programme is designed as an innovation pipeline, made up of exploratory research, industrial research and validation and very large-scale demonstrators, where ideas are transformed into tangible solutions. The research takes place in over 50 test beds across Europe (simulation platforms, on-board commercial flights, dedicated airport testbeds and air traffic control centres), which validate concepts and candidate solutions.


## Exploring what is beyond the horizon

Through its exploratory research, the SESAR 3 JU looks beyond the current research and development and what is already identified in the 2020 European ATM Master Plan. The aim is to investigate new ideas, concepts, and technologies, but also challenge pre-conceived notions about air traffic management and the aviation value chain. By advancing promising research ideas and embedding them in a broader programme of work, the SESAR 3 JU is helping to make Europe's aviation industry fit for the digital age and to maintain its global competitive edge.

The key principles guiding SESAR exploratory research activities are:

- Bringing together the brightest of minds in Europe to undertake curiosity-driven research in order to find "out of the "box" unconventional ideas, concepts, methods and technologies to current and future ATM challenges;
- Considering innovations and technologies coming from non-ATM sectors, such as automotive, robotics or system engineering, as well as in other safety-critical industries;
- Maturing new concepts for ATM that extend or go beyond those identified in the Master Plan, as well as advancing technologies to the level of maturity required to feed into SESAR's industrial research strand of activities.

## What is in this publication?

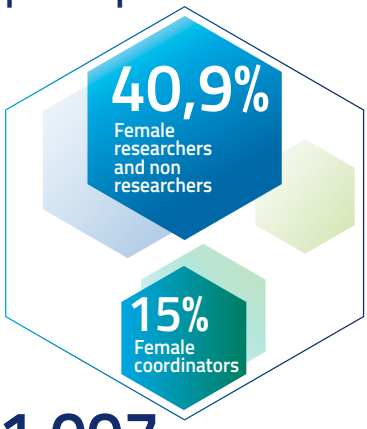
Building on previous exploratory research projects (see Annex 1) and following a call for proposals (ER4) in 2020 the SESAR JU selected and launched 41 projects with a total of EUR 58 million in funding, as well as one knowledge transfer network (2017 – 2022) within the framework the EU's Horizon 2020 research and innovation programme.

The projects brought together a total of 182 organisations, including private companies, research organisation, small and medium enterprises and public bodies. In total, over 1 000 experts from across Europe participated in the projects. of which over 40 % were women.

### Total funding


**41** projects & Engage

### Total participation




**1,007** people

### Breakdown of participation


**182** organisations

### Participating countries

AT, BE, CH, CZ, DE, DK, EL, ES, FI, FR, HR, HU, IS, IT, NL, NO, PL, PT, RS, SE, TR, UK

## Key themes

The projects addressed a wide variety of aspects of air traffic management, reflecting new trends and developments coming from within and outside the aviation industry. The following provides a snapshot of the key themes covered by the projects.[1]

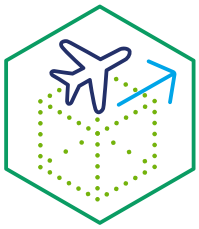
### AUTOMATION AND DIGITALISATION

Automation has revolutionised many industries; think self-driving cars, medical diagnosis and speech recognition. Now it's the turn of air traffic management (ATM)! Automation based on artificial intelligence including machine learning, is capable of learning from new data, detecting patterns that a human cannot and considering thousands of variables at the same time to reach a solution. Projects looked at automation and the use of AI-enabled solutions from many facets. For instance, the AISA project assessed the feasibility of integrating an artificial situational awareness system into team situation awareness for en-route operations. While the HAAWAII project developed a new speech recognition architecture, based on machine learning for supporting air traffic controllers. Many of the projects addressed the challenge of ensuring that AI-driven solutions are explainable, transparent and trustworthy, such as MAHALO, TAPAS and ARTIMATION, and at the same time protecting private datasets used in machine learning applications to encourage the sharing of data (AICHAIN). See page 12 for more details.

### ECONOMICS

Improving the economic sustainability of air traffic management is a core focus of SESAR innovation. In this latest wave of research, projects looked at the economics of the business, particularly with regard to flight exchanges and prioritisation. For instance, flight exchanges between different airlines are currently limited due to the confidentiality surrounding flight cost structures, which may vary for any number of reasons, from the provisioning of connecting flights for passengers or work-time restrictions for crew members. By using blockchain technology and a secure multi-party computation, the SlotMachine project looked at extending the existing user-driven prioritisation process (UDPP) SESAR solution to allow for more flexible flight sequences without the need to disclose any confidential information. Meanwhile, the BEACON project explored different approaches to assessing flight prioritisation solutions and their potential cost reductions. Ultimately, the goal of SESAR is to accelerate the uptake of innovative technologies: in this respect, the ITACA project developed a new set of methodologies and tools enabling a rigorous and comprehensive assessment of policies and regulations aimed at amplifying the uptake of new technologies within ATM. See page 19 for more details.

[1] It should be noted that the themes listed below do not necessarily correspond to the categorisation of the projects in the call documentation.



## FUTURE ATM ARCHITECTURE

The vision of the Digital European Sky is to accommodate all types of air vehicles in Europe's airspace, including for very low and high altitude operations. In support of this vision, the ECHO project developed a concept of operations for the higher airspace (above approximately 60,000 ft), a portion of airspace that is hosting an expanding range of vehicles, including long-endurance balloons, high altitude platform stations (HAPS), supersonic and hypersonic aircraft. See page 22 for more details.

Medium and low-level airspace have also been the focus of a wide number of projects (See U-space and remotely piloted aircraft systems for more details).

## ENVIRONMENT AND METEOROLOGY

The digital transformation of air traffic management is just one of multiple pathways that is required to reduce the environmental impact of aviation. The environment was the focus of a large number of projects in this publication. Part of FlyATME4E's research assessed how small flight detours can help avoid the formation of persistent contrail cirrus and NOx-induced effects. Some of the projects focused on reducing the environmental footprint of aviation at specific phases of flight. This was the case of the AEON project, which developed a concept of operations for the integration of green taxiing techniques, taxibots, wheeltugs, e-taxi and single-engine taxis. Meanwhile the DYNCAT project demonstrated how to take into account environmental factors when optimising 4D trajectories, enabling safer, more cost-efficient and more environmentally sustainable operations in the terminal manoeuvring area (TMA). ATM deals with disruptive weather on a regular basis, but such events are likely to become more frequent and extreme as the climate changes. In turn, unpredictable weather patterns are exacerbating further the situation as aircraft are unable to fly their most environmentally optimal trajectory. This challenge was the focus of several projects, including START, ISOBAR, FMP-Met, SINOPTICA and CREATE, which investigated different solutions to address meteorological uncertainty and predictability. See page 25 for more details.

## PERFORMANCE AND NETWORK MANAGEMENT

Improving all areas of ATM performance is at the heart of the Digital European Sky research and innovation programme. This priority was also the focus of the NOSTROMO project, which developed a new active learning metamodeling approach for assessing the potential performance benefits of SESAR Solutions. Meanwhile, the SIMBAD project developed and evaluated a set of machine learning approaches aimed at enhancing the capabilities of large-scale ATM microsimulation models to support performance evaluation at network level.

Performance can be hampered when the available airspace capacity does not match air traffic demand. Capacity must be planned months in advance and there are limited options to adjust it at short notice to demand which is inherently variable. The Network Manager has a role to coordinate this demand-capacity balancing (DCB) process, but has only limited options to enhance the performance of the entire system. The CADENZA project analysed different conceptual options for improving the current Network Manager DCB process by making it more network-centric. See page 34 for more details.

## AIRPORT OPERATIONS

Every flight begins and ends at airports, which make them essential nodes in the aviation network. It is for this reason that SESAR 3 JU makes use of advances in technologies to help fully integrate airport operations into the network and to increase the performance of airports' airside operations. In this latest portfolio of exploratory research, two projects focussed specifically on airport operations: the ASPRID project defined an operational concept and system architecture to protect airport operations from drone intrusions. The project identified technologies, procedures, regulations and standards that can help better safeguard against drone incursions and recover from any disruptions as quickly and as efficiently as possible. Meanwhile, the AEON project developed a concept of operations for the integration of green taxiing techniques, taxibots, wheeltugs, e-taxi and single-engine taxis. This includes the development of an algorithm for inclusion into the airport collaborative decision making (A-CDM) to evaluate the taxiing technique most appropriate for each flight. See page 38 for more details.

## COMMUNICATION, NAVIGATION AND SURVEILLANCE

European air traffic management makes use of a patchwork of CNS infrastructures with different technologies and networks, which is costly and inefficient. SESAR researchers are working on a more integrated and spectrum efficient CNS concept that takes advantage of ground and satellite-based systems, and advances in digital technology. This is the case of the FACT project, which investigated the potential use of cellular networks, such as 4G and 5G, as a complement to the existing CNS technologies in the air traffic management (ATM) and U-space environment. Meanwhile, the NewSense project assessed innovative low-cost sensors, widely used outside of ATMS, for use in airport surface surveillance. These sensors consist of a 5G-signal-based surveillance solution and a millimetre wave (mmWave) radar augmented with artificial intelligence (AI). Communication was the focus of the SINAPSE project, which designed AI applications to detect and address transmission errors and cyber security threats. See page 41 for more details.

## MULTIMODALITY

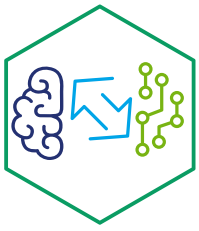
Travellers have never had so many mobility options to choose from for getting from A to B. But what combination of these offers the quickest, most affordable, reliable and greenest travel options, especially for journeys that involve air travel? The Modus, TRANSIT, X-TEAM D2D and SYN+AIR projects looked at different aspects, including future drivers, data sharing and performance indicators, of facilitating seamless door-to-door multimodal travel. Anticipating the role of airports, the IMHOTEP project developed a concept of operations and a set of data analysis methods, predictive models and decision support tools to enable information sharing, common situational awareness and real-time collaborative decision-making between airports and ground transport stakeholders. See page 45 for more details.

## SAFETY AND RESILIENCE

Safety science has advanced in recent years, recognising that 'systems' today, such as ATM, are characterised as being 'socio-technical' and inherently complex with often reconciling competing and changing system goals, and performance variables. The FARO project looked at the adaptive capacity of a system in response to unforeseen events and challenges, with a view to modelling the system that emerges. It designed a framework to quantify safety levels and identify resilience strategies, using natural language processing (NLP) and taking into account interdependencies between competing ATM goals. Machine learning technologies have the ability to analyse vast amounts of diverse data (usually coming from different sources) to extract patterns. This hidden knowledge can be used to identify safety risks or performance inefficiencies and, in doing so, offer support to controllers in their decision-making. SafeOPS investigated how AI solutions can enable safety applications that create a proactive, data-driven approach to safety, capable of predicting potential hazards in real-time. More precisely, SafeOPS developed an AI solution to warn air traffic controllers about the occurrence of go-arounds. See page 51 for more details.

## U-SPACE AND REMOTELY-PILOTED AIRCRAFT SYSTEMS (RPAS)

U-space is Europe's enabling framework for drones and unmanned air vehicles to access the airspace, and was the focus of research by several projects, addressing important matters such as safe separation (USEPE, BUBBLES) deconfliction and dynamic capacity management (Metropolis II), balancing demand and capacity (DACUS) and a common altimeter reference for all airspace users (ICARUS). Other projects looked at larger remotely-piloted aircraft designing a remain-well-clear (RWC) function for vehicles flying airspace classes D to G (URClearED), as well as a concept of operation for the full integration of RPAS within terminal manoeuvring areas (TMAs) and airport environments under instrument flight rules (IFR) (INVIRCAT). The portfolio also featured SAFELAND, a project dedicated to assessing the feasibility of moving to single-pilot operations. See page 54 for more details.



## KNOWLEDGE TRANSFER NETWORK

The Engage knowledge transfer network (KTN) was set up to share the resources and findings of the SESAR research and innovation programme with a view to informing future fundamental research as well as transferring results towards application-oriented work. Running for 4.5 years, the network initiated and supported multiple activities for SESAR and the European ATM community. Around two-thirds of the financing was invested back into the community, for example through catalyst fund projects and PhDs.

See page 64 for more details.

# AUTOMATION AND DIGITALISATION

PROJECT SUMMARIES

# AISA - AI Situational Awareness Foundation for Advancing Automation

## A safe way to share common awareness between humans and artificial intelligence

While we accept automation as part of our daily lives, increasing its role in air traffic control requires automated data to be verified and specific in its application before it can be safely integrated into operations.

In a domain-specific application, this SESAR exploratory research project explored the effects of human-machine distributed situational awareness, and opportunities to automate monitoring tasks, in en-route operations. It identified the data needed by the air traffic controller and developed a method to provide that data. It also investigated how to adapt the automated system to accommodate changes and ensure business continuity and safety.

The artificial situational awareness system developed by the project collected high-integrity information (using aeronautical information exchange models) to create a knowledge graph describing the traffic situation at sector level. The knowledge-based system managed and executed factual knowledge and added rule-based knowledge on top via reasoning engine. The knowledge-graph was integrated with multiple machine-learning modules which enabled the assessment of probabilistic events (e.g. aircraft trajectory prediction or conflict detection). By combining the reasoning engine with machine-learning, the system could assess complex interactions between objects, draw and explain conclusions, and predict future system states.

**Sharing the same team situational awareness among air traffic control team members and AI will enable the automated system to reach the same conclusions as controllers when confronted with the same problem.**

Air traffic controllers at Skyguide's facilities in Zurich conducted human-in-the-loop simulations with two main goals: First, to compare human and artificial situational awareness; second, to assess the feasibility of integrating artificial situational awareness system into team situation awareness. The experiments showed that the artificial situational awareness system is comparable to human situational awareness, however a lot of work remains to be done to successfully integrate the two.

The project laid the foundation for further research into human-machine shared situational awareness and integration of machine learning-based automation with knowledge graph systems. Longer term, it supports safety enhancements by bringing high reliability to repetitive monitoring tasks.

### Project Partners

Faculty of Transport and Traffic Sciences at University of Zagreb (Coordinator)

Johannes Kepler University Linz / Institute of Business Informatics

Skyguide Swiss Air Navigation Services Ltd

Slot Consulting Ltd.

Technische Universität Braunschweig, Institute of Flight Guidance

Universidad Politécnica de Madrid

Zurich University of Applied Sciences (ZHAW), School of Engineering

### Benefits

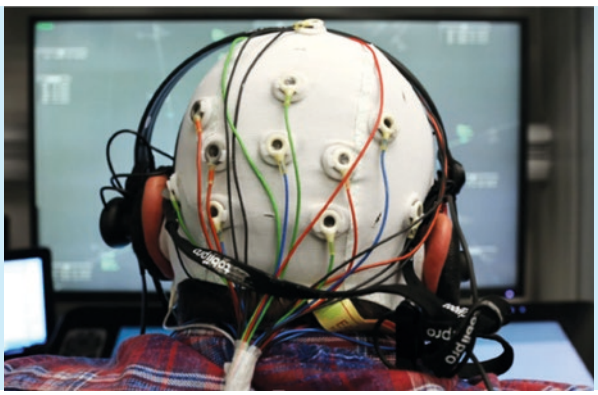
- Efficient human-machine collaboration
- Automation of monitoring tasks
- Enables machine learning

### Website

https://aisa-project.eu/

# ARTIMATION - Transparent Artificial Intelligence and Automation to Air Traffic Management Systems

## Transparent visual and data-driven tools build confidence in machine learning



### Project Partners

Mälardalen University (MDU) (Coordinator)

Deep Blue

École National de l'Aviation Civile (ENAC)

Sapienza University (UNISAP)

### Benefits

- Transparent AI models
- Increased trust in AI
- Human-centred design

### Website

https://www.artimation.eu/

Society is becoming increasingly dependent on artificial intelligence (AI) which raises the importance of installing trust and security in its use. This becomes easier once humans understand how AI systems think and operate.

The aim of ARTIMATION was to address challenges related to transparency of automated systems in air traffic management using explainable AI (XAI).The research was limited to two main use cases: Conflict detection and resolution; and delay prediction and propagation. It proposed tools aim to improve explainability through AI algorithms based on data-driven storytelling and immersive analytics with the purpose of assessing the effectiveness of different visualisation techniques.

Both conflict detection and resolution and delay prediction and propagation concepts are useful applications that support controllers' everyday tasks and help air navigation service providers to improve performance in air traffic management, including the human having full control of the AI decision support. By introducing data-driven and user-driven storytelling for each use case, researchers were able to help explore how the machine learning could be applied to support controllers, air navigation service providers and generic end users in their activities.

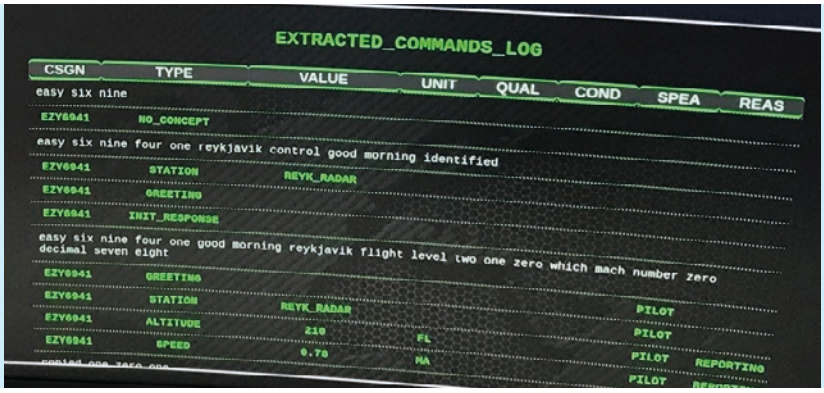
**AI Explainability (XAI) in ATM should deliver understandable outcomes through an understandable process, this will be a key enabler to human-centred AI tools.**

The project also explored how to integrate different levels of explanation in an adaptive passive brain-computer interface. This would enable the AI development to fit controllers' contextual explainability needs and accommodate changes in mental and emotional states (e.g., workload, stress) measured by neurophysiological measures.

ARTIMATION represents a small step along the path to building trust and dependency on AI systems. It demonstrated the importance of effective and immersive data visualisation towards increasing end-users' acceptance, using examples of machine learning. The main outcome of this effort was improved understanding of how machine learning should be developed, and identification of measures aimed at keeping the human in-the-loop through transparent AI models provided by novel data visualisation.

# HAAWAII - Highly Automated Air Traffic Controller Workstations with Artificial Intelligence Integration

## Taking inspiration from Alexa and Siri to reduce workload for air traffic controllers




As Alan Turing pointed out in 1952, speech recognition is not speech understanding. However, SESAR machine learning technology shows improved understanding rates in pilot-controller voice exchanges while reducing controller workload.

The HAAWAAI project developed new speech recognition architecture based on machine learning for two complex airspace regions: The congested London area; and Iceland's airspace stretching over 5,000,000 square kilometres. Some 20 hours of voice utterances were transcribed manually and machine learning techniques used to adapt the basic recogniser to the local challenges. Just one hour of training data reduced the word error rate from 50% to 25%, while further training of the HAAWAII system in understanding pilots' voices led to a word error rate below 10%. Air traffic controllers' recognition rates were twice as good.

However, more important than incorrect word recognition is extracting call signs or waypoint names. Combining voice with radar data brought significant improvements at semantic level: Aircraft call signs from controllers, for example, had recognition rates of 97%.

Machine learning was also used to create a readback error detection assistant (REDA). Readback errors are where, for example, a controller gives clearance for a pilot to climb to 7,000 feet, but the pilot repeats this as 8,000 feet, risking a collision if undetected. The REDA will, however, generate an alert. When evaluated during offline exercises using real-live data, and by five air traffic controllers, the number of detected readback errors during REDA tests was over 66%, with a false alarm rate below 50 %.

**Digitisation of controller and pilot voice utterances can be used for a wider variety of safety and performance related benefits.**

Speech recognition is already integrated in our daily life with the likes of Alexa or Siri. HAAWAII made the technology usable in airspace management with very good extraction rates at both word and semantic levels, and reduced air traffic controllers' workload. Manual repeated input of spoken commands via mouse or keyboard was no longer needed and automatic call sign highlighting became possible when the pilot was still speaking. Last but not least, air traffic safety is increased by automatic readback error detection.

### Project Partners

German Aerospace Center DLR, Germany, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Coordinator)

Austro Control

Brno University of Technology (BUT)

Croatia Control

Idiap Research Institute, IDIAP

Isavia ANS

NATS

### Benefits

- Automatic error detection
- Reduced controller workload
- Enhanced safety

### Website

www.haawaii.de

# MAHALO - Modern ATM via Human/Automation Learning Optimisation

## Artificial intelligence agents win trust and acceptance as part of a team

### Project Partners

Deep Blue (DBL) (Coordinator)

Center for Human Performance Research (CHPR)

Linkopings Universitet

Luftfartsverket (LFV)

Technische Universiteit Delft


### Benefits

- Reduction in perceived workload
- Maintains the human-in-the-loop
- Guidance for future research

### Website

http://mahaloproject.eu/

Automation is a valuable part of complex and labour-intensive industries like air traffic control, but how personalised and transparent should digital information be for air traffic controllers? What trade-offs exist, in terms of controller trust, acceptance and performance?

To answer these questions, MAHALO developed a hybrid machine learning (ML) system composed of layered deep learning and reinforcement learning models, trained on controller performance, strategies and physiological data. It learned to solve ATC conflicts and, coupled with an enhanced en-route traffic conflict detection and resolution (CD&R) prototype display, it presented machine rationales for the ML output. The ML system was then tested with Italian and Swedish air traffic controllers to evaluate in real-time simulations the relative impact of ML conformance, transparency, and traffic complexity on controller understanding, trust, acceptance, workload and performance, to guide the design of future AI systems.

**MAHALO results show how context and individual differences drive the benefit of ML systems.**

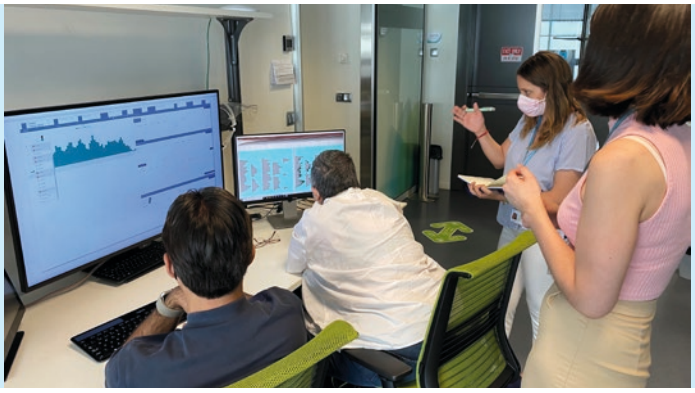
MAHALO sought to make the AI agents fully cooperative with the human controller rather than just a "black box" that outputs solutions when necessary. It used both a novel approach to interfaces in ATM (such as solution space diagram metrics as input to a ML agent) and a mixture of conformal and optimal automation to test the best combination and acceptance uptake among controllers. In that way, MAHALO considered both accuracy of the automation and controller acceptance.

**Developing adaptive systems that automate the tuning between humans and AI allows adjustments in step with learning performances.**

The research found a statistically significant effect of conformance agreement, and also on reduced controller workload ratings. Moreover, even if there was no statistical significance, data trends suggested an interaction between conformance and transparency. It provided clear guidance on how ML should be developed to keep the human "in-the-loop", and for artificial intelligence agents to act as team players that understand the user's needs, not to be just a machine giving out outputs when asked.

# TAPAS Towards an Automated and ExPlainable ATM System

## Identifying the principal elements behind trust in artificial intelligence



Effective automation as an enabler to increase capacity is one of the pillars of future airspace management. However, adopting digital technologies also brings new challenges. In particular, our need as humans to be able to understand how decisions are made so that we can trust these artificial intelligence (AI) systems. The lack of explainability behind AI systems hampers our ability to rely on them fully, together with social acceptance and regulatory approval.

The TAPAS project carried out a series of tests showing how applications built using explainable AI can improve trust in human operating automation-enhanced air traffic management. The project explored highly automated scenarios (including unprecedented fully automated action decisions by the AI system) through explainable AI (XAI) prototypes together with visual analytics (VA) techniques, in order to identify needs and strategies to address transparency and explainability in two operational cases. Not all use cases present similar requirements: an air traffic controller needs a deeper understanding of solutions provided by an AI-based functionality that an operator in a non-safety-critical scenario. Prototype applications were applied to both pre-tactical air traffic flow and capacity management and to tactical conflict detection and resolution using human-in-the-loop simulations with the goal to overcome the transparency barrier.

**TAPAS explored explainable AI in techniques in higher levels of automation, including full AI action decision and implementation.**

**TAPAS produced a general framework of principles for explainability of AI/ML applications in ATM has been produced, to facilitate widespread uptake.**

With testing and validation of these prototypes, TAPAS produced a general framework of explainability principles for AI/ML applications in airspace management and developed a set of principles and criteria, which pave the way for their successful general deployment in the airspace management domain. This outcome is expected to contribute to facilitate the effective uptake of AI/ML techniques in ATM.

### Project Partners

Centro de Referencia de Investigación, desarrollo e Innovación en ATM (CRIDA A.I.E.) (Coordinator)

Boeing, Fraunhofer

Indra Sistemas S. A.

ISA Software and University of Piraeus

### Benefits

- Adding capacity in a resilient way
- Enhanced situational awareness and safety
- improved cost efficiency

### Website

https://www.sesarju.eu/projects/tapas

https://tapas-atm.eu/

# AICHAIN – A Platform for Privacy-preserving Federated Machine Learning using Blockchain to enable Operational Improvements in ATM

## Blockchain and federated machine learning protects data in a digital age

### Project Partners

SITA EWAS Application Services (Coordinator)

EUROCONTROL

Nommon Solutions and Technologies

SCALEOUT SYSTEMS

Swiss International Airlines

### Benefits

- Enhanced predictability, safety, capacity, and efficiency
- Enhanced cyber-security and privacy
- AI trustworthiness

### Website

https://www.aichain-h2020.eu/

The aviation industry includes many actors ranging from airspace users, air traffic control and airports to support service delivery. Operational safety, efficiency and capacity are enhanced greatly through data sharing, however this also comes with privacy concerns. Digital technologies, in particular machine learning software, benefit from access to high-quality datasets, prompting research into privacy-preserving data-driven models.

The AICHAIN solution enables the privacy-preserving exploitation of large private datasets from different stakeholders to enrich operational machine learning applications. This is achieved through privacy-preserving federated machine learning, where the training and serving of the federated models can be done at the data owners' facilities in a cyber-secured and trustworthy manner without sharing any data. In this way, private data owners can remain in full control of their dataset's privacy. A novel blockchain-based mechanism enhances the federated learning platform with two key features: 1) an audit trail to support model trustworthiness, as required for operational AI applications in airspace management; and 2) a system of tokens to implement direct incentives for the participants and fairness policies.

**The collaborative training and serving of the models occur at the data owners' facilities with full privacy.**

AICHAIN research began by proving the technical feasibility of the concept and its value to airspace management, along with consideration of governance and incentive mechanisms. Prototype architecture was used to demonstrate the solution through federated learning experiments and cyber-security assessments of the platform before two air traffic management use-cases were enhanced private data from a federated airline. A framework of customisable tokens to implement rewarding policies was created, aimed at encouraging the effective collaboration of the private data owners in the federated processes.

**Air traffic management can be improved through machine learning collaboration on private data sets.**

These results could now be used to implement large-scale experiments with more airlines in the federation and under more realistic operational conditions.

# ECONOMICS

PROJECT SUMMARIES

# BEACON - Behavioural economics for ATM concepts

## Exploiting behavioural economics to improve ATM decision making

### Project Partners

University of Westminster (Coordinator)

EUROCONTROL

Nommon Solutions and Technologies

Salient

Swiss International Air Lines

Università degli Studi di Trieste

### Benefits

- Reduced delay costs
- Equitable delay management
- Reduced passenger delays.

Airspace users have the option to reorder their flights to optimise resources, such as aircraft, pilots and crew in instances of air traffic flow management (ATFM) disruptions. Applying behavioural economics to these complex decisions expands the concept beyond individual prioritisation to consider also wider network performance. The BEACON project researched new methods and tools for airspace users that take account of requirements such as equity, bounded rationality and hyperbolic discounting.

The project addressed this on two levels. At the methodological level, new approaches were developed for the assessment of flight prioritisation mechanisms based on behavioural economics; while at an applied level, new flight prioritisations were formulated and assessed. The research considered long term planning capabilities by flight planning agents as well as tactical decision making.

Three semi-automated flight prioritisation mechanisms were designed and tested using two agent-based simulators, one strategic and one tactical. Two mechanisms were used in the human-in-the-loop simulations in order to collect the data to be used to calibrate the parameters of behavioural economics models chosen to describe the biases and the deviations from rationality that one can expect from the airlines. The parameters were then included in the tactical simulator to assess the impact of the mechanisms that considered behavioural economics biases at the network level.

**BEACON developed new approaches for the assessment of flight prioritisation mechanisms based on behavioural economics. The proposed mechanisms provided remarkable cost reductions.**

The proposed mechanisms were able to provide remarkable cost reductions even when some of the actors involved made decisions in a sub-optimal and non-rational manner. It resulted in better understanding of how behavioural economics can improve airspace management methodologies and deepened and broadened the concepts of prioritisation beyond user driven prioritisation process (UDPP) and their potential impacts on network performance.

# ITACA Incentivising Technology Adoption for Accelerating Change in ATM

## Future proofing air traffic control with accelerated technology take-up

**The ITACA assessment framework enables the evaluation of policies (e.g., innovative ATM pricing schemes) and regulations to amplify the uptake of new technologies within ATM.**

Air traffic control's strong safety record brings with it a cautious approach to the deployment of new technology. Yet leveraging the latest digital technologies to increase the level of automation, cyber-secure data sharing and connectivity can enable the industry to become more scalable and agile, while maintaining today's safety levels.

In response to this need, ITACA set out to accelerate the development, adoption, and deployment of new technologies in airspace management. The research considered barriers and levels of technology adoption as well as potential policy measures to accelerate the process. This led to the development of a new set of methodologies and tools that enable the rigorous and comprehensive assessment of policies and regulations aimed at amplifying the uptake of new technologies.

ITACA identified the main levers and barriers for airspace management technology adoption based on a combination of literature review, interviews and economic models. The research combined industrial organisation theories with behavioural economics to develop an agent-based model that simulates the behaviour of the European air traffic management system. It used gaming experiments and participatory simulations to establish a methodology for the calibration and validation of the ITACA agent-based model and assessed a set of policies aimed at fostering the adoption of new technologies.

The policies were benchmarked in three different case studies, which found that policies such as cost-plus pricing can deliver considerable benefit. However, no individual policy outperformed the others across all the areas included in the performance assessment, while the combination of economic incentives (e.g., cost-plus pricing, subsidies) and enforcement through mandates provided the best results on the economic and operational sides.

ITACA developed a new policy assessment framework that provides evidence-based recommendations on policy approaches to facilitate technology uptake in ATM, hence contributing to all SESAR key performance areas in a transversal manner and ultimately to the achievement of the European ATM Master Plan performance ambitions.

### Project Partners

Nommon Solutions and Technologies (Coordinator)

CRIDA A.I.E.

Kungliga Tekniska Högskolan

Transport and Mobility Leuven

### Benefits

- better understanding of the mechanisms to accelerate change in ATM
- evidence-based advice on the most adequate policy approaches to facilitate technology uptake
- accelerate the development and deployment of new technologies better fitting stakeholder needs

### Website

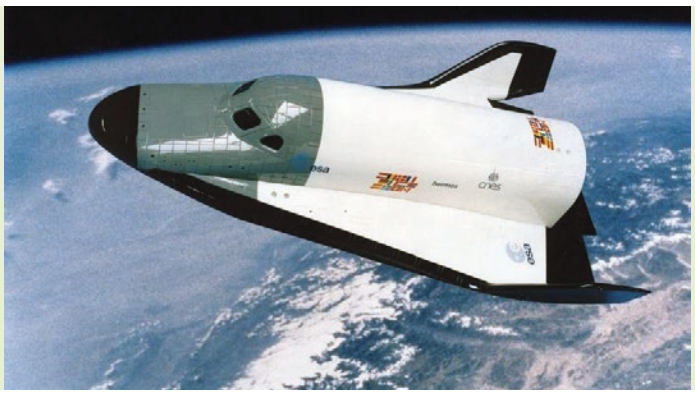
https://www.itaca-h2020.eu/

# FUTURE ATM ARCHITECTURE

PROJECT SUMMARIES

# ECHO - European Concept of operations for Higher airspace Operations

## Space for higher airspace platforms to grow



A growing number of vehicles use higher airspace – the region between the airspace normally used by aircraft and the beginning of space – to deliver a range of commercial services including surveillance, broadband connectivity, supersonic and hypersonic travel, trans-atmospheric and suborbital vehicles, and military users. The mix of uncrewed, piloted, fast and slow-movers requires a robust operational framework to ensure safe operations.

**The ECHO project is instrumental in developing a Global performance-based framework for higher airspace, and unleashing the great potential of this new frontier for flight.**

The ECHO project carried out a comprehensive demand analysis and developed a basic concept of operations (ConOps) for higher airspace to enable safe, efficient and scalable operations above the flight levels where conventional air traffic operates. The ConOps helps to identify future infrastructure needs and will allow business values in the order of billions per year to take shape. Particular attention must be given to scarce resources already managed in a cooperative manner (e.g. frequencies, transponder codes), as well as elements that are necessary for safety reasons (e.g. capabilities to monitor and mishap debris) and necessary capabilities for communications, navigation and surveillance. As demand is expected to evolve over time, the ConOps addresses short-, medium- and long-term time frames; importantly addressing today's operations as well as of vehicles and activities still to be developed. The project also paves the way for the economic development of innovative and commercial concepts using the higher airspace environment including system wide information management and trajectory-based operations.

The ConOps provides the foundation for the development of a higher airspace regulatory framework by the European Union Aviation Safety Agency (EASA) and continued research into industry requirements. It represents a significant step forward towards achieving international approvals and opening up a burgeoning sector across Europe.

### Project Partners

EUROCONTROL (Coordinator)

Airbus UTM (Airbus Operations SL)

CIRA

Dassault Aviation

DLR

DSNA

ENAC (Italian CAA)

ENAC (French University)

ENAV

ONERA

Thales Alenia Space

### Benefits

- Safe higher airspace operations
- Informs global performance-based regulation
- Supports innovative and commercial concepts

### Website

https://higherairspace.eu/

# SlotMachine - A Privacy-Preserving Marketplace for Slot Management

## Blockchain technology improves flight sequencing and safeguards data

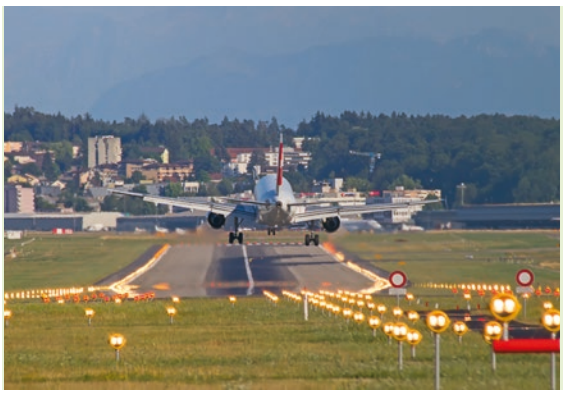
### Project Partners

Frequentis AG (Coordinator)

AIT Austrian Institute of Technology

EUROCONTROL

Swiss International Air Lines



### Benefits

- Trustworthy ATFM slot marketplace
- Improved airline efficiency
- Lower emissions and shorter delays

### Website

http://slotmachine.frequentis.com/

Air traffic flow management (ATFM) slots are allocated times of departure, arrival, or passage through a sector, which are issued by Eurocontrol's Network Manager to regulate traffic in congested areas of airspace. Typically, simple swaps between flights take place. Such exchanges are helpful for airlines to prioritise expensive flights in order to minimise costs and passenger delays, providing much needed flexibility.

Slot swapping is currently restricted to two flights. Flight cost structures, which tend to drive prioritisation, vary for any number of reasons from the provisioning of connecting flights for passengers to work-time restrictions for crew members, are confidential information for the airlines. This is where the SlotMachine project plays a role in optimising the allocation of flights according to airline priorities based on the cost structure of the different airlines. By using blockchain technology and secure multi-party computation, the project allows flexible prioritisation without the need to disclose confidential information. The research builds on the existing user-driven prioritisation process (UDPP)[2] solution, which allows airspace users to reschedule their flights to keep their business-driven priorities on track.

**The SlotMachine solution enables slot swapping between different airlines without disclosing highly confidential information about flight cost structures they do not necessarily want to share with others**

SlotMachine successfully deployed multi-party computation (MPC) and hyper-ledger techniques to determine the optimal flight sequence based on airline costs without disclosing sensitive information to competitors and without the need of a trusted arbiter. The project employed evolutionary optimisation algorithms, e.g., genetic algorithm, that seeks solutions to the flight list prioritisation problem in an iterative manner. The advantage of such algorithms is that they can be parallelised easily and aborted at any point while still returning a solution.

SlotMachine showed the feasibility of a privacy-preserving platform, recognising an essential element in the future aviation industry. The next step is to update the technology stack and involve more airlines and air navigation system providers in real swaps between multiple airlines.

[2] SESAR PJ07S02 UDPP

# ENVIRONMENT AND METEOROLOGY

PROJECT SUMMARIES

# ALARM: Multi-hAzard monitoring and earLy wArning systeM

## Anticipating severe hazards

### Project Partners

Universidad Carlos III de Madrid (Coordinator)

DLR

Royal Belgian Institute for Space Aeronomy (BIRA-IASB)

SATAVIA

SYMOPT S.R.L (SYstems and Modelling OPTimization Co. Ltd)

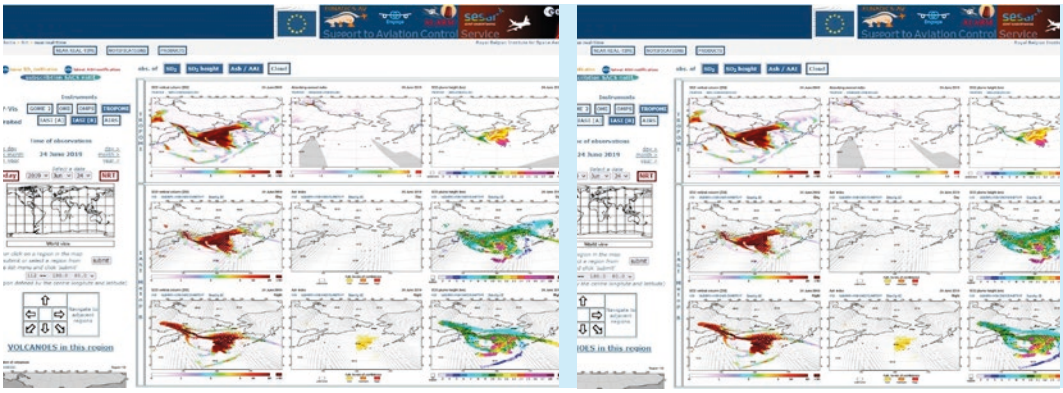
Università degli Studi di Padova

### Benefits

- Enhanced alerts include satellite data
- Improved natural hazard observations
- Nowcasts of sulphur dioxide dispersion and thunderstorms near airports
- Climatic hotspot forecasts

### Website

https://alarm-project.eu/



**The ALARM prototype anticipates severe hazards and facilitates situational awareness to foster better decision-making in air traffic management.**

Volcanic eruptions, forest fires, electrical storms, electromagnetic radiation, sandstorms and more extreme events have become more frequent and intense as a result of global warming. Aviation safety can be jeopardised by these natural hazards, whose effects can be extremely disruptive. Engine ingestion of dust, smoke, and sea salt aerosols contributes to erosion, corrosion, pitot-static tube blockage, and engine flameout in flight; while volcanic ash and sulphur dioxide gases cause windscreen abrasions, reduction of visibility, damage to aircraft instrumentation and can result in engine stalling. Space weather is also damaging, disrupting radio and satellite communications and degrading navigation systems.

The ALARM project developed an early warning system hosting platform for natural hazards, designed to assimilate a wide range of data collected by terrestrial and satellite observation systems. This is used to create multi-hazard models for early warning and nowcasting that can be shared via aeronautical communication channels in the form of alerts. ALARM research has also developed a demonstration artificial intelligence tool to improve on currently available forecasts and to carry out additional information analysis in support of airspace management planning.

The ALARM prototype global multi-hazard monitoring and early warning system (EWS) generates prompt alerts of natural hazards based on continuous global multi-hazard monitoring in near-real time. Among deliverables, it provides nowcasting up to two hours in advance, and short-term forecasting up to six hours in advance, of sulphur dioxide plumes at regional scale, and of severe thunderstorms at local scale (for example, an airport). It also provides medium-term forecasting (up to 48 hours) of climatic hotspots at a European scale and is compliant with the system-wide information management yellow profile for aeronautical data exchange.

# CREATE - Innovative operations and climate and weather models to improve ATM resilience and reduce impacts

## New tools to mitigate the climate impact of aviation

Aviation has a responsibility to mitigate its climate impact as part of global efforts to reduce anthropogenic climate changes. Air traffic operations have significant impacts on air quality, for example in areas adjacent to airports, where optimised trajectories can help to reduce emissions and help to protect human health and the environment.

Disruptive weather events are becoming more frequent and extreme as the climate changes. To become more resilient to weather phenomena, CREATE developed a climate and weather-aware concept of operations (CONOPS) encompassing a multi-aircraft four-dimensional (in space and time) trajectory optimisation framework. It also built an environmental scoring module (ESM) to evaluate the "greenness" of aircraft trajectories. This considers $CO_2$, non-$CO_2$ emissions and contrail probability formation during the en-route phase of flight, in addition to NOx and particulate matter emissions (related to the impact on air quality) during the approach and departure phase. The algorithmic approach is fast enough to be easily implemented at different stages of the trajectory lifecycle; for example helping to resolve hotspots in the network due to weather hazards, or air quality sensitive regions, within the context of an evolving traffic picture.

**Assessing environmental impact during flight planning and execution is a key part of minimising aviation emissions.**

The models were tested using fast-time simulation for the North Atlantic region extending into European airspace, and a terminal manoeuvring area (TMA) use-case for a typical medium-size airport (Capodichino) close to dense population in the Mediterranean.

The scoring, based on environmental performance dashboards common to airlines and air navigation service providers, showed it was possible to exploit detailed and accurate weather predictions to update aircraft trajectories to avoid contrail-sensitive areas, adverse weather conditions, and minimise the climate impact.

**Environmental issues can help to solve network hotspots as part of a network optimisation framework**

### Project Partners

Università degli Studi di Napoli "Parthenope", Italy (UNIPARTH) (Coordinator)

ARIANET srl, Italy

CIRA

Finnish Meteorological Institute, Finland (FMI)

Institute for Sustainable Society and Innovation, (ISSNOVA, UNIPARTH third party)

Netherlands Aerospace Center, Netherlands (NLR)

Universitat Politecnica de Catalunya, Spain (UPC)

### Benefits

- Reduced climate impact
- Improved environmental performance
- increased resilience to weather hazards

### Website

https://create-project.eu/

# DYNCAT – Dynamic Configuration Adjustment in the TMA

## Reducing the environmental footprint of arrival flights

### Project Partners

Deutsches Zentrum für Luft- und Raumfahrt e.V. (Coordinator)

Eidgenössische Materialprüfungs- und Forschungsanstalt

Swiss SkyLab Foundation

Swiss International Air Lines AG

Thales AVS France SAS

### Benefits

- Reduced fuel consumption, noise and $CO_2$ emissions
- Improved predictability, increased pilot awareness
- Highlights regulatory changes needed

### Website

www.dyncat.eu

As pilots prepare for descent, they need to configure the aircraft for landing (extending flaps, slats and landing gear) depending on many parameters, including aircraft performance, configuration and weather, and reduce speed prior to touchdown. Flying an energy-efficient approach and descent profile relies on better flow of information between the pilot and ground controller, and improved sharing of predictive capabilities on-board the aircraft.

DYNCAT identified the potential to improve the current situation based on integrated real-world data from all relevant sources. The project developed an operational concept that addresses both ground and airside by introducing novel pilot support functions and supportive tools that reduce pollution and noise in the terminal manoeuvring area (TMA). DYNCAT's new flight management system (FMS) functionality - supporting the flight crew in energy and configuration management - was evaluated in piloted real-time simulations on an industrial test bench. It shows promising operational and environmental improvements, including reduced $CO_2$ emission and noise footprint, with the only requirement on air traffic control to transmit a distance-to-go or indicated time of arrival.

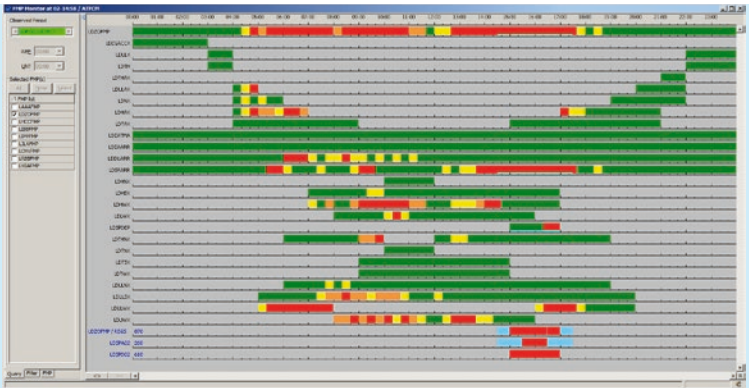
**Analysis of ATC communications, aircraft flight data, noise measurements, weather data and radar data identified opportunities to reduce environmental impact.**

**More economical and ecological approaches are possible with a pilot assistance system.**

DYNCAT also recommended adjustments to the overall ecosystem that sets the course for more environmentally friendly and more predictable flight profiles, the latter benefitting reliability of ATM planning and thus supporting a virtuous circle. The solution provides the capability to make individual trade-offs between fuel consumption and noise footprint, for example for certain arrival routes or time windows, and applies to any FMS-equipped fixed-wing aircraft. Further development and industrialisation of the solution could provide more cost-efficient operations for airlines and at the same time noise mitigation for residents in the surrounding airport area.

# FMP-Met - Meteorological Uncertainty Management for Flow Management Positions

## More accurate weather predictions for air traffic controllers



Weather is difficult to predict even with the help of the latest in forecasting technology, but an accurate weather outlook is crucial for air traffic management. Timely information about the likelihood of weather-induced delays from a trustworthy source enables a traffic flow manager to keep delay to a minimum using tactical measures.

FMP-Met set out to integrate meteorological forecast uncertainty into the flow management position (FMP), an operational position that monitors the level of traffic in airspace sectors and coordinates flow measures when an excess of demand over capacity is detected. Weather events such as unexpected or prolonged storms make sector demand hard to predict, increasing complexity that in turn leads to reduced capacity. The research focused on the development of an intuitive and interpretable probabilistic assessment of the impact of convective weather on operations based on the combination of the probabilistic sector demand, complexity and capacity reduction.

Project partners analysed the challenge facing the flow manager and researched different probabilistic weather forecast products, with different lead times and coverage areas, and concluded the provision of probabilistic traffic and capacity reduction forecasts under convective weather for a forecasting horizon of eight hours leads to better-informed decision making.

**FMP-Met generated traffic and capacity reduction predictions under adverse weather with an extended lead time of eight "hours".**

The main outcome of the project was the development of a probabilistic methodology to forecast traffic congestion and traffic complexity to be used in conjunction with the tools currently employed by FMPs.

**The FMP-Met concept to integrate weather uncertainty information into FMP tools was assessed positively by expert FMPs.**

The next steps in this research should lead to the development of a prototype tool, in close collaboration with FMPs, implementing the FMP-Met concept. This will support the FMP in taking anticipated, appropriate and timely tactical flow measures.

### Project Partners

Universidad de Sevilla (Coordinator)

Agencia Estatal de Meteorología - AEMET

Austro Control

Croatia Control

Linköpings universitet (LiU)

MeteoSolutions GmbH

Paris Lodron University Salzburg

Universidad Carlos III de Madrid

Sveučilište u Zagrebu, Fakultet prometnih znanosti

### Benefits

- Timely tactical flow measures
- Preliminary evaluation of measures
- Enhanced efficiency

### Website

https://fmp-met.com

FlyATM4E

# FlyATM4E: Flying Air Traffic Management for the benefit of environment and climate

## Optimising aircraft trajectories to mitigate climate effects

### Project Partners

Deutsches Zentrum für Luft- und Raumfahrt (DLR) (Coordinator)

Technische Universiteit Delft (TUD)

Technische Universität Hamburg (TUHH)

Universidad Carlos III de Madrid (UC3M)

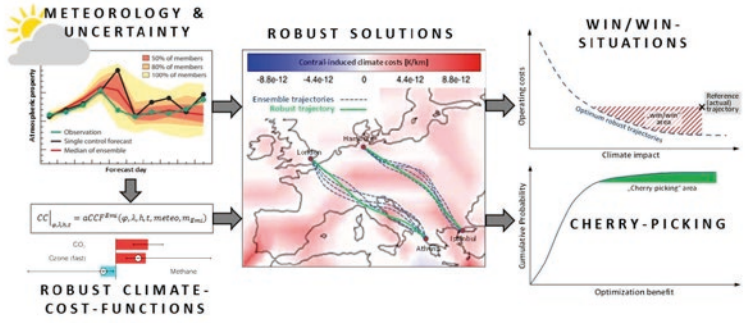



**Figure 3.2:** Schematic illustration of FlyATM4E concept.

### Benefits

- Identifies weather situations with high mitigation potential
- Identifies climate-optimised aircraft trajectories
- Demonstrates mitigation potential non-$CO_2$ effects

### Website

https://flyatm4e.eu/

Analysis shows that controlling both $CO_2$ emissions and non-$CO_2$ effects has the potential to double the benefits available from reducing carbon emissions alone. Non-$CO_2$ effects such as contrail cirrus clouds (ice crystals that form behind aircraft) and nitrogen oxide (NOx)-induced changes of ozone and methane upset the radiative balance of the atmosphere. They are strongly dependent on the weather and vary considerably according to atmospheric conditions such as air temperature and altitude.

**The FlyATM4E solution enables ATM to identify climate-optimised aircraft trajectories which provide a robust and economically efficient reduction in aviation's climate impact.**

Every aircraft has access to weather information, and it is the expansion of this interface with meteorological data that provides the opportunity to develop climate-optimised trajectories in collaboration with air traffic control and supported by advanced meteorological data products.

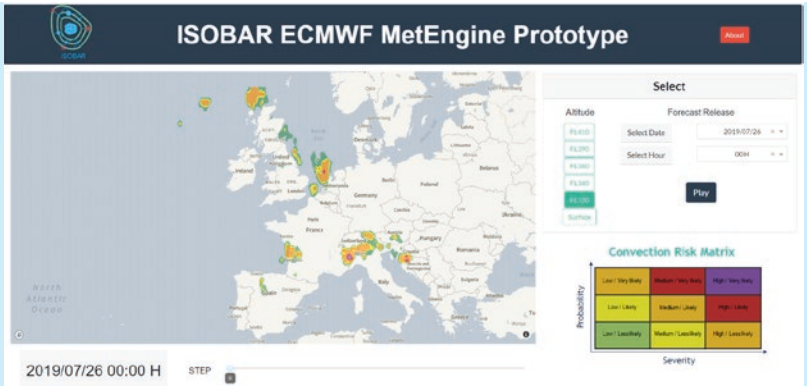
**The overall modelling concept explores climatic optimisation of aircraft trajectories and estimates benefits.**

FlyATM4E identified those weather situations and aircraft trajectories that lead to a robust climate impact reduction despite uncertainties in atmospheric science, which can be characterised by ensemble probabilistic forecasts. Planning of these climate-optimised aircraft trajectories requires air traffic management to use spatially and temporally resolved information on the magnitude of the climate effects associated to aviation emissions during the trajectory planning process. The FlyATM4E solution relies on prototypic algorithmic climate change functions (aCCFs) to derive such climate impact information for flight planning directly from operational meteorological weather forecast data. By combining the individual aCCFs of water vapour, NOx and contrail-cirrus, i.e. merged non-$CO_2$, it becomes possible to generate aCCFs that describe the overall climate impact of non-CO2 aviation emissions and identify weather situations with high mitigation potential, including an uncertainty assessment. The analysis of sample flights showed different changes in average temperature response with respect to cost or climate optimum and trade-off trajectories within the set of pareto-optimal solutions.

These results suggest that applying these enabling solutions have the potential to reduce the aviation climate footprint by low or no additional costs.

# ISOBAR -Artificial Intelligence Solutions to Meteo-Based DCB Imbalances for Network Operations Planning

## More precise weather data for network flow and capacity management




Weather is one of the principal causes of flight delays, which come at a significant cost not just for the passenger but also airports and airlines. Predicting the weather is an important part of network forecasting and performance, however forecast uncertainty leads to a high dependency on the expertise of human operators.

To change this situation and contribute to a more efficient management of traffic demand and airspace capacity balance, the ISOBAR project created a network operations plan based on artificial intelligence (AI). This involved integrating dynamic weather cells in collaborative air traffic flow and capacity management (ATFCM) processes at pre-tactical and tactical phases, and at local and network level. It also introduced more precise characterisation of demand and capacity imbalances at pre-tactical level with the help of probabilistic weather products through the integration of weather data and airspace management functions.

ISOBAR prototyped a user-driven mitigation plan that takes into account airspace user priorities, weather-related changes in demand, ATFCM regulations, flow constraints and network effects. Finally, it developed an operational and technical roadmap for the integration of ancillaries into the Network Manager platform by defining interfaces, and functional and performance requirements. This includes a neural network that integrates convective prediction into a structured airspace map, together with a set of AI modules, such as AI-based hotspot detection and adaptive mitigation measures, to support the human operator decision-making.

The main application of this dashboard is to provide traffic managers with information about the sectors that will be affected by convective weather, helping to create a more efficient air transport system and promoting a better quality of life for European citizens.

**ISOBAR connects the dots between improved spatial and temporal meteorological forecasting and air traffic control flow management positions.**

**AI helped to build machine-learning methods, essentially neural networks, to detect hotspots and share the analysis, enriched with historical data, using a new support tool.**

### Project Partners

- CRIDA A.I.E. (Coordinator)
- AEMET
- Cranfield University
- DGAC DSNA
- Earth Networks
- ENAC
- EUROCONTROL
- METEO FRANCE
- Sopra Steria
- Swiss International Air Lines
- Universidad Carlos III de Madrid

### Benefits

- AI-enhanced thunderstorm prediction
- More predictable flow coordination
- Predictive re-routings and demand mitigations
- Reduced network delay

### Website

https://isobar-project.eu/

# SINOPTICA -Satellite-borne and IN-situ Observations to Predict The Initiation of Convection for ATM

## More precise, integrated weather data moderates extreme weather effects

### Project Partners

CIMA Research Foundation (Coordinator)

Austro Control

Geomatics Research and Development srl (GrED)

Deutsches Zentrum für Luft- und Raumfahrt (DLR)

Università degli Studi di Padova

Universitat de Barcelona

### Benefits

- Improved short term extreme weather forecasting
- Optimised approach trajectories
- Improved knowledge of extreme weather measurement

### Website

http://sinoptica-project.eu/

More frequent extreme weather events, such as intense thunderstorms, have led to an increase in weather-related flight cancellations and this trend is set to continue as a result of climate change. Rapidly developing thunderstorms are challenging to predict but affect flight safety and trigger flight re-routing, delays or cancellations. The consequences of these events can include inconvenience for passengers, fuselage damage, delays, cargo damage, increase in pollution and economic losses for airlines.

**High accuracy in extreme weather prediction gives air traffic managers and controllers confidence in their actions.**

SESAR research shows that more reliable arrival manager performance is possible by integrating highly accurate predictions of adverse weather into air traffic control decision-support tools. The SINOPTICA project exploits the untapped potential of assimilating remote sensing (derived from electro-optical and ground-based radar), as well GNSS-derived datasets and in-situ weather stations data into very high-resolution, very short-range numerical weather forecasts to provide improved prediction of extreme weather events. The project developed a short-term forecasting system of severe thunderstorms affecting airports and, together with the air traffic managers, deployed new strategies to adjust flight trajectories and avoid the adverse weather areas.

**Precise weather forecasting enables air traffic control to react to meteorological disturbances at an early stage. Integration into controller support systems leads to significantly reduced delays and flight cancellations.**

The research included four case studies with locally extreme weather, along with development and modeling of possible flights solutions. The results showed that continuously updating the database with variables from GNSS-derived and in-situ weather stations succeeded in monitoring atmospheric variables at high spatial resolution and high accuracy in extreme weather, nowcasting with up to 30 minutes lead time. Future steps will be dedicated to reach the same performances for longer lead times.

# START: A stable and resilient ATM by integrating robust airline operations into the network

## Optimising air traffic in disturbed scenarios

Trajectory-based operations (TBO) share a common plan for a flight's trajectory in a four-dimensional context (latitude, longitude, altitude and time). One of the key enablers of TBO is the automated updating of trajectories in reaction to developing uncertainties, including disruptive weather events such as storms. However, a high frequency of updates and modifications leads to degradation of system stability.

In order to achieve stable and resilient ATM performance even in disturbed scenarios, the START project set out to develop, implement and validate optimisation algorithms for robust and predictable airline operations. It used a combination of applied mathematics, artificial intelligence (AI), data science, and algorithm design to create more certain and reliable outcomes.

START began by modelling uncertainties at the micro (trajectory) level and used radar/automatic dependent surveillance broadcast (ADS-B) to assimilate observations every 15 minutes. The trajectory uncertainties were propagated using assimilated models and a stochastic trajectory predictor. It also modelled uncertainties at the macro (ATM network) level, and again assimilated observations every 15 minutes, relying on satellite data to provide storm and network status, and used the assimilated models to propagate ATM network uncertainties.

**The START project focuses on optimising conventional traffic situations while considering disruptive weather events such as storms.**

START then developed an AI algorithm capable of generating a set of pan-European robust trajectories covering the entirety of traffic over Europe, designed to make the European ATM system more resilient when faced with uncertainties. The algorithm was demonstrated by modelling its implementation as an advanced flight dispatch functionality for airspace users to obtain robust trajectories.

The concepts were validated using system-wide simulation procedures in order to evaluate their stability and enable the simulations to provide insight into uncertainties that impact TBO systems.

### Project Partners

Universidad Carlos III de Madrid (Coordinator)

Boeing Deutschland GmbH

Deutsches Zentrum für Luft und Raumfahrt eV

Ecole Nationale de l Aviation Civile

Flightkeys GmbH

Istanbul Teknik Universitesi

Universitat Politecnica de Catalunya

### Benefits

- Increased airspace resilience and stability
- Fewer flight cancellations, lower airline costs
- Fewer conflicts, less weather encounters

### More information

https://start-atm.com/

# PERFORMANCE AND NETWORK MANAGEMENT

PROJECT SUMMARIES

# CADENZA - Advanced Capacity and Demand Management for European Network Performance Optimization

## A network-centric demand-capacity balancing solution to improve performance

Providing adequate airspace capacity for air traffic demand is one of the biggest challenges in European air traffic management. Capacity must be planned months in advance and there are limited options to adjust it at a short notice to demand which is inherently variable. Insufficient capacity leads to delays and re-routings (with additional greenhouse gas emissions) and excess capacity means underutilised resources – both resulting in higher cost for airspace users. Currently, capacity decisions are decentralised with the air navigation service providers (ANSP) and airspace users making individual choices as to how to navigate through the congested network. The Network Manager has a role to coordinate this demand-capacity balancing (DCB) process, but has only limited options to improve performance of the European network.

**Network-centric capacity planning reduces delays, re-routings and emissions and a new charging scheme could effectively address and overcome inefficiencies of the current system.**

The CADENZA project analysed different conceptual options for improving the current DCB process by making it more network-centric. The aim was to optimise network performance by balancing the cost of capacity provision and associated negative effects of a lack in capacity, i.e., delays, re-routings, and additional greenhouse gas emissions. Several case-studies provided quantitative results from different scenarios accounting for real world uncertainties.

**Network-centric capacity management combined with innovative demand management optimises network performance.**

CADENZA showed that – while requiring less sector-hours to handle the same traffic volume – network-centric DCB leads to lower delays, fewer re-routings, and greenhouse gas emissions, and thus lower costs for airspace users. The results also showed that sharing available capacities between ANSPs could further reduce costs for airspace users, serving as a hedge against demand variability. Moreover, the CADENZA project developed an innovative charging concept, called 'trajectory products'. It minimises both the incentives for airspace users to plan longer than necessary routes when capacity is sufficient and the negative effects of lacking capacity by giving them the option to decide how to navigate through portions of congested airspace, which is not the case today.

### Project Partners

Univerzitet u Beogradu - Saobracajni fakultet (Coordinator)

EUROCONTROL

Hochschule Worms

Universitat Politècnica de Catalunya

WHU – Otto Beisheim School of Management

### Benefits

- Better use of capacity
- Lower delays and re-routings
- Reduced greenhouse gas emissions

### Website

www.cadenza-project.eu

# NOSTROMO - Next-generation Open-Source Tools for ATM performance Modelling and Optimisation

## A versatile metamodel to assess performance of airspace management solutions

### Project Partners

CRIDA A.I.E. (Coordinator)

Danmarks Tekniske Universitet (DTU)

ISA Software

Nommon Solutions and Technologies

Universitat Politècnica de Catalunya (UPC)

University of Westminster

### Benefits

- Simulation-based analyses without full simulation runs
- Visual exploration of assessment variables in real-time
- Potential to save significant computational time

### Website

nostromo-h2020.eu

Airspace management is intrinsically difficult to model due to the interaction of multiple different elements in an ever-changing environment. One of the most challenging modelling problems is the assessment of the performance impact of new solutions at a system-wide level, which has been a long-time objective of the airspace research community.

The NOSTROMO project set out to develop a new methodology that could be applied to measure performance of SESAR solutions. It copied the construction of metamodels, which approximate the behaviour of simulation models, and additionally deliver model transparency, computational tractability and ease of use. NOSTROMO's approach essentially integrated two well-established techniques: Active learning (to achieve greater performance with fewer data points); and simulation metamodels (functional approximators of the input-output relationships of a simulator).

**NOSTROMO built a metamodel that, given one or more Solutions, is able to run multiple input values and predict their corresponding output values in real-time.**

**The NOSTROMO metamodeling approach is theoretically generalisable to any ATM simulator.**

The active learning metamodeling approach was then applied to two air traffic management simulators, Mercury and FLITAN, each modelling up to two SESAR solutions, assessed at the network level. The training of the metamodels required several hours (eight for Mercury, five for FLITAN), after which their prediction performance was more than 1 000 times faster, with an error lower than 11%, compared with the output values generated by the simulators.

To extend NOSTROMO's architecture to enable it to be used to assess other airspace management solutions, an online application programming interface (API) was developed to allow the training and creation of a new metamodel in a simulator-agnostic context; the possibility to explore the entire metamodel space; and to measure confidence in the metamodel predictions.

A NOSTROMO simulator-agnostic dashboard was developed to facilitate performance assessment, allowing real-time dynamic communication with the API, visual exploration of the variables of interest (inputs and KPIs), and user-exportable reports.

# SIMBAD - Combining Simulation Models and Big Data Analytics for ATM Performance Analysis

## Machine learning enhances assessment of key performance indicators

Assessing the performance of air transport management and the impact of new concepts aiming to improve the network performance requires a detail simulation of airspace use. The development of performance modelling methodologies able to simulate the impact of new technologies at a system wide level has been a long-time objective of the industry. Microsimulation models are often the only feasible approach to address this problem in a reliable manner. However, the practical application of large-scale simulation models to strategic ATM performance assessment is often hindered by their computational complexity.

**Through the combination of machine learning, visual analytics, and state-of-the-art microsimulation techniques, SIMBAD provides new insights into ATM performance.**

**The SIMBAD performance modelling framework has been successfully evaluated in the RNEST and DYNAMO ATM simulation tools.**

The SIMBAD project developed and evaluated a set of machine learning approaches aimed at enhancing the capabilities of start-of-the-art large-scale airspace management microsimulation models to effectively support performance evaluation at network level. The solution includes: machine learning algorithms for trajectory modelling and for the estimation of hidden variables related to airspace users' behaviour; machine learning algorithms for multi-scale traffic pattern classification that allow the identification of demand patterns to assess new SESAR solutions; and active learning based meta-models for a more efficient, hence faster, exploration of the simulation space. The developed models and techniques were demonstrated for two microsimulation models: R-Nest and DYNAMO.

The SIMBAD innovative airspace management performance modelling framework comprises three parts: 1) a model for the estimation of hidden variables related to airspace user behaviour that are necessary inputs for air traffic microsimulation models (e.g., cost index and mass payload); 2) a methodology to identify representative traffic patterns at different scales (Europe-wide, country-wide, control centre and airport level) for each particular problem under study; and 3) a meta-modelling framework that enables the approximation of the results of a microsimulation model to facilitate a more efficient exploration of its input-output space.

The solution delivers a more comprehensive, accurate, and efficient assessment of the performance impact of new airspace management solutions and concepts, and has a positive impact across all the SESAR key performance areas and ultimately on European ATM Master Plan performance ambitions.

### Project Partners

Nommon Solutions and Technologies) (Coordinator)

CRIDA A.I.E.

Fraunhofer Gesellschaft zur Förderung der Angewandten Forschung E.V. (Fraunhofer)

Universitat Politecnica de Catalunya (UPC)

University of Piraeus Research Center (UPRC)

### Benefits

- Comprehensive performance assessment
- Efficient assessment of new ATM solutions

### Website

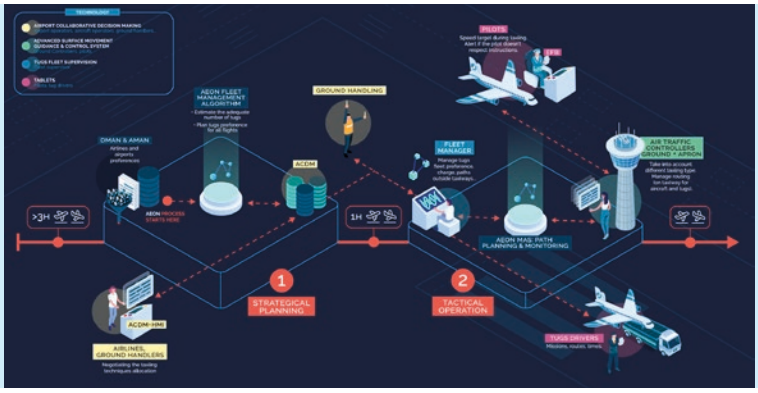
www.simbad-h2020.eu

# AIRPORT OPERATIONS


PROJECT SUMMARIES

# AEON – Advanced Engine-Off Navigation

## More sustainable taxiing operations




A new concept of engine-off taxiing operations promises to halve fuel consumption and reduce emissions at the airport. The more sustainable techniques require the collaboration of different actors from air traffic control to ground handling and set of dedicated tools including fleet management algorithms and supervision interfaces to support the operators.

**AEON defined an innovative concept of operations for green taxiing techniques.**

**The new taxiing concept brings the European aviation sector a step closer to net-zero carbon emissions.**

AEON defined a new concept of operations to make best use of green taxiing techniques; specifically TaxiBots, WheelTugs, e-Taxi and single-engine taxiing were investigated to address airport ground operations at a long to medium-planning and execution phases. In the long to medium-planning phase, AEON integrates a supporting algorithm into the airport-collaborative decision making (A-CDM) platform to evaluate the taxiing technique most appropriate for each flight. Then, in the execution phase, an algorithm for tug allocation and path planning is integrated into the advanced surface movement guidance and control system (A-SMGCS). The tools help ground controllers and pilots carry out taxiing operations more efficiently.

The project also proposed a new role of tug fleet manager and designed its working position. The operator will assist the ground controllers by preparing the missions for each tug according to the initial plan computed by the algorithm and adapted to the actual operational situation. The tug fleet manager tools support operators in the implementation of the best tug (re)allocation.

The AEON solution includes additional functions, for example computing routing and speed profiles for all aircraft and tugs and optimised engine start up times, to maximise the engines-off time on the ground.

### Project Partners

Ecole Nationale de l'Aviation Civile (ENAC) (Coordinator)

Deep Blue s.r.l. (DBL)

Technical University of Delft (TUD)

SCHIPHOL NEDERLAND BV

### Benefits

- 50-85 % less fuel consumption
- 11 % reduction in $CO_2$ emissions
- Precursor to automated taxiing operations

### Website

https://aeon-project.eu/

# ASPRID - Airport System PRotection from Intruding Drones

## Reducing risks caused by non-authorised drones at airports

### Project Partners

Instituto Nacional de Técnica Aeroespacial (INTA) (Coordinator)

Aeropuertos Españoles y Navegación Aérea (AENA)

Aeroespace Laboratory for Innovative components S.c.a r.l. (ALI S.c.a r.l.)

CIRA

ENAIRE

Office National d'Etudes et de Recherches Aérospatiales (ONERA)

Soul Software SRL

### Benefits

- Increased operational situational awareness
- Autonomous system for non-collaborative drones
- Mitigation of drone incursions effects.

### Website

www.asprid.eu


Drone flights over non-authorised areas pose a growing threat to airport operations, stopping departures, diverting flying aircraft to other airports, and incurring extra cost. At the same time, response measures need to be appropriate in a populated airport environment and can only be used with a high degree of caution.

**ASPRID concepts were evaluated using a prototype human man interface (HMI).**

A broad range of systems are available to detect and neutralise rogue-drones, drawn largely from the defence sector. By means of an integrated and holistic approach, ASPRID researchers defined an operational concept and system architecture that is more appropriate for the protection of airports. By examining historical data and carrying out a vulnerability assessment, ASPRID defined a methodological framework and pinpointed risk scenarios that can be used to inform a decision support system to help manage the selection of operational mitigation actions. The architecture is used to establish the adequate level of alert, response, and, if needed, neutralisation.

**ASPRID modelled drone incursions in the airport environment and tested stakeholder interactions in a gaming exercise.**

The project identified technologies, procedures, regulations and standards that can help better safeguard us against drone incursions and recover from any disruptions as quickly and as efficiently as possible.

To validate the operational concept, the solution was simulated using a prototype human machine interface (HMI) in combination with a gaming exercise that enabled the main stakeholders participating in the exercise to interact with each other during a series of modelled drone incursions in the airport environment. In addition to feedback from air traffic controllers and airport personnel, input was provided by drone operators, IT and security experts.

The solution was evaluated and consolidated using the qualitative and quantitative data collected. The results were used to identify needs and draw up recommendations on how to implement efficient airport operations against intruding drones.

# COMMUNICATIONS, NAVIGATION AND SURVEILLANCE

PROJECT SUMMARIES

# FACT- Future All aviation CNS Technology

## Safe communications for existing and new airspace users

### Project Partners

Honeywell International (Coordinator)

AOPA

Eskisehir Technical University

Eurocontrol

Istanbul Technical University

Nokia Solutions & Networks

Sarp Air


### Benefits

- Easier integration of new technologies
- Supports existing and new airspace users
- Performance-based requirements

### Website

https://fact.itu.edu.tr

New entrants in the skies above us will stretch the capabilities of existing infrastructure to maintain safety levels given the density and diversity of new vehicle types. One of the key enablers of operational safety is the wide deployment of affordable and interoperable communication, navigation and surveillance (CNS) capabilities across all types of airspace users. By introducing performance-based integrated communication, navigation, and surveillance (iCNS), it becomes easier to add new technologies while existing technologies become more efficient.

The primary goal of FACT was to evaluate and demonstrate performance-based iCNS using cellular networks such as 4G and 5G as a complement to existing CNS technologies to support airspace management and U-space services. Cellular technology meets many of the critical needs of airspace users operating at low altitudes by offering light weight, high bandwidth, low power consumption compared to analogue transmitters/receivers, and low prices. Addressing both existing and new airspace users such as drones, the project aimed to build a bridge between conventional airspace management systems and the future automated, digital U-space environment.

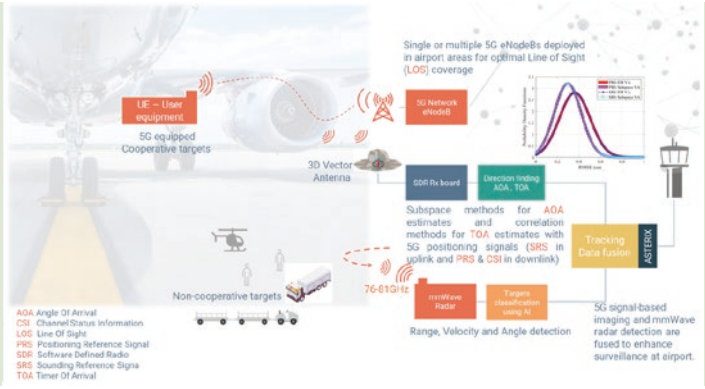
**Performance-based integrated communications, navigation and surveillance (iCNS) supports existing and new technologies.**

The project examined how new wireless technologies can be safely integrated into air-ground datalinks in the context of low altitude mixed air traffic. The operational evaluation considered 4G/5G in terms of datalink performance and positioning in the context of selected CNS functions; and went on to explore CNS safety enhancements for individual stakeholders including general aviation pilots, remote pilots of drones and air traffic control. Project partners completed an operational demonstration in Eskisehir in Turkey which focused on a coexistence of drones and general aviation including rotorcrafts with other airspace users within the controlled and uncontrolled airspace.

The project results indicate both opportunities and performance limitations of public cellular networks when used for airborne operations with recommendations on where their use within the iCNS concept is beneficial. Such evaluation is essential as cellular technology seems to meet the critical needs of many airspace users operating at low altitudes such as drones, UAM, and GA aircraft: light weight, low electric power consumption (compared to the existing analog transmitters/receivers), and low prices due to mass production.

# NewSense - Evaluation of 5G Network and mmWave Radar Sensors to Enhance Surveillance of The Airport Surface

## Affordable safety enhancements at secondary airports using innovative technologies




New technologies like cellular networks and low-level radar can benefit secondary airports by lowering costs compared with traditional infrastructure. Introducing innovative products widely used outside of air traffic management offers an opportunity to improve industry performance.

**The mmWave radar provides cost-effective surface surveillance up to few hundred meters with ±65° field of view.**

The NewSense project focused on safety and capacity benefits provided by advanced surface movement guidance and control systems (A-SMGCS), typically limited to the world's largest airports with sufficient resources to purchase surface movement radar and multilateration infrastructure. The project assessed low-cost sensors including a 5G-signal-based surveillance solution and a millimeter wave (mmWave) radar augmented with artificial intelligence (AI).

By applying deep learning algorithms to the radar data, NewSense was able to explore the potential of radiofrequency (RF) signals in measuring an object's position and velocity in a seamless process.

The research included designing a 5G-signal-based surveillance solution for the airport surface adding a 3-dimensional vector antenna and a 5G positioning function to measure the position of cooperative targets using their transmitted 5G RF signals. It also included designing a radar-like system relying on 5G signals to calculate the position of non-cooperative target positions from reflected 5G base station RF signals. The low-cost mmWave radar provided non-cooperative surveillance that positioned and classified targets using reflected mmWave radar signals and deep learning methods.

System performance was tested through simulations, in-lab measurements and at Muret aerodrome, general aviation airfield near Toulouse. Assessed against equivalent A-SMGCS industry standards, the mmWave radar provided cost-effective surveillance up to few hundred meters with ±65° field of view, and the 5G-signal-based surveillance solution provided a super-resolution at 360° and an estimated maximum range up to 2 km.

**The 5G-signal-based surveillance solution provides a super-resolution at 360° and an estimated maximum range up to 2 km.**

### Project Partners

Altys Technologies (Coordinator)

ENAC

Eurocontrol

Tampere University

### Benefits

- Detects cooperative and non-cooperative targets
- Enhanced controller situational awareness in all weather

### Website

www.newsense-s2020.eu

# SINAPSE

## Advanced technology to support safer, more efficient airspace

### Project Partners

ALTYS Technologies (Coordinator)

Enaire

Frequentis

University Of Bradford (UOB)


### Benefits

- Connectivity
- Rapid, automatic adjustment of services
- Robust IP network for network aircraft

### Website

https://sinapse-s2020.eu/

Safe air traffic control and capacity management rely on careful planning of complex airways and user preferences. Artificial intelligence (AI) and machine learning (ML) can assist human decision making and help to optimise airspace configuration, tactical planning and post-operation analysis.

**SINAPSE predicts controller pilot datalink communications disruption events ten minutes before they happen.**

SINAPSE research focussed on the aeronautical communications network (ATN), the global infrastructure used for safety communications between aircraft and air traffic controllers (ATC), airlines or manufacturers. The ATN comprises all systems that assist aircraft from departure to landing. To enhance this resource, the project developed an intelligent and secure ATN network architecture design based on a software defined networking (SDN) architecture model augmented with artificial intelligence. This was used to train federated AI models for the benefit of the whole ATN community and enabled data to be shared widely — while respecting data privacy.

**ML analyses network traffic for signatures known to match cyberattacks.**

The intelligent internet protocol (IP) network improved air traffic control awareness by predicting safety services outages: For example, the trained ML model was able to predict events that disrupt ATN controller pilot datalink communications (CPDLC), such as provider abort issues, occurring today in Europe on the current ATN network. As the proposed methodology is agnostic from the underlying network technology, the AI-driven monitoring techniques are future-proofed to support upgrades.

The network also employed ML to predict the probability of transmission errors in satellite links used for voice and data telecommunication services with air traffic control. Additionally, the ML uses deep neural network (DNN) algorithms and federated learning, and strengthens cybersecurity by the use of intelligent intrusion detection and prevention (IDPS) applications. The collaborative cyber security model results in collective learning and the data footprint is shared among all the users. Data privacy is ensured as only the AI footprint is shared, thanks to the federated learning architecture.

# MULTIMODALITY

PROJECT SUMMARIES

# IMHOTEP - Integrated Multimodal Airport Operations for Efficient Passenger Flow Management

## Passenger flow, efficiency and sustainability all benefit from sharing data

### Project Partners

Nommon Solutions and Technologies (Coordinator)

AENA

Aimsun SLU

Amsterdam University of Applied Sciences (HvA)

Cranfield University (CU)

Empresa Municipal de Transportes de Palma (EMT)

Ingeniería de Sistemas para la Defensa de España S.A. (ISDEFE)

London City airport

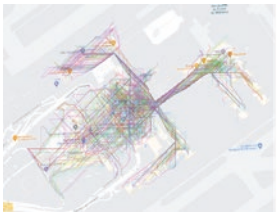
Technische Universität Dresden (TUD)

### Benefits

- Improves passenger experience
- Improves environmental sustainability
- Increases stakeholders cost efficiency and capacity

### Website

www.imhotep-h2020.eu



Integrated transport systems are central to the European Commission's vision for safer, more efficient and sustainable transport. Sharing information between different actors helps to create common situational awareness and supports real-time collaboration, which leads to more efficient resource management and less congestion.

The IMHOTEP project researched data sharing between airports and ground transport stakeholders and developed a decision support tool designed to enhance multi-stakeholder decision-making. The research began with an initial concept of operations that extended the airport-collaborative decision-making (A-CDM) process to terminal access and egress legs through the inclusion of ground transport stakeholders. Introducing a new set of data analysis and fusion methods, IMHOTEP provided a comprehensive view of the door-to-door passenger trajectory through coherent integration of different types of high-resolution passenger movement data. This enabled the development and integration of predictive models capable of anticipating the evolution of the passenger flows within the terminal and the ground transport system.

**IMHOTEP supports multi-stakeholder decision-making by providing a continuously updated and comprehensive picture of the passenger flows during a day of operations.**

The new concept and methodology was validated through a set of case studies involving airports and ground transport operators at Palma de Mallorca and London City airports. The IMHOTEP decision support tool allowed the user to simulate different what-if scenarios to better understand the impact of several management decisions and choose the best course of action.

**IMHOTEP foresees a passenger-centric vision of the multimodal European transport system where the different modes are seamlessly integrated.**

The insights extracted from IMHOTEP demonstrate the benefits brought by the inclusion of ground transport stakeholders in the A-CDM process and will be used to assess the readiness of the proposed technologies for future industrial deployment. Implementation of the proposed concept would bring significant benefits to the stakeholders involved, due to more predictability in the incoming passenger flows, and to the end users, as the enhanced integration between modes increases the efficiency, reliability and resilience of the passenger journey.

# Modus – Modelling and assessing the role of air transport in an integrated, intermodal transport system

## Modelling air-rail mobility options guide future policy


Seamless passenger journeys call for the optimisation and alignment of different transport systems whether by air, rail, road or sea. Improved multimodality across the European transport network will help passengers make the best choices in the future.

**Close cooperation between air and rail mobility providers is required to ensure a seamless door-to-door journey for travellers.**

The Modus project modelled a seamless door-to-door multimodality and passenger experience to evaluate the impact of an improved joint air-rail transport system for a variety of different passenger types. By deploying passengers' modal choice decisions based on a combination of airport and railway station connectivities, city archetypes and respective catchment areas, the model was adjusted to individual passenger itineraries in the air-rail network. As a further contribution, the model considered various future scenarios that depict different potential development pathways of air-rail mobility, including a significant short-haul shift from air to rail, traffic growth with strong technological support, or a move towards a more decentralised, remote and digital mobility. It sought to identify future drivers for passenger demand, and supply of, future mobility and how these impact passengers' modal choices.

The Modus solution assessed the impact of passenger choice on capacity, predictability, and the environment, across different scenarios and for multimodal journeys. It enabled the development of multiple scenarios of future mobility pathways, taking into account new regulatory frameworks and environmental standard, or new business models, and covering a time horizon of 2030 and beyond. This can provide useful support for policy makers as well as transport service providers in shaping future multimodal mobility. In particular, it brings better understanding of the impact of air and rail as substitutes and provides insights into possible development pathways for European mobility.

**Multimodal mobility requires legislation and a regulatory framework that fosters cooperation across modes and across national borders.**

### Project Partners

Bauhaus Luftfahrt (Coordinator)
Ecole Nationale de l'Aviation Civile
EUROCONTROL
Innaxis
International Union of Railways
Skymantics
University of Westminster

### Benefits

- Models the impact of multimodality
- Models door-to-door journey requirements
- Models future mobility pathways

### Website

https://modus-project.eu/

# SYN+AIR - Synergies between transport modes and air transportation

## Seamless travel benefits from contractual agreements between service providers

### Project Partners

UPC (Coordinator)

AETHON Engineering

Franck Dumortier

Politechnico di Bari

Sparsity Technologies (SPA) (affiliated company of UPC)

University of Belgrade - Faculty of Transport and Traffic Engineering

### Benefits

- Standardised multimodal collaboration
- Single ticketing including air transport
- Faster and easier trip booking

### Website

http://syn-air.eu/

A seamless door-to-door journey of multimodal trips relies on collaboration and data sharing among transport service providers (TSPs) across transport modes. However, collaboration is a generic concept that is hard to define. To overcome this challenge, the SYN+AIR project designed a smart contracts framework (SCF) aimed at facilitating the generation of contractual agreements among TSPs. This framework is an alloy of different architectures (i.e., business, information, technical and application) hosted by a cloud platform.

**SYN+AIR smart contracts framework enables transport service providers to generate standardised contractual agreements, managed centrally, using shared data.**

**The smart contracts framework is compatible with existing platforms and third parties including transport data clouds and travel companion applications.**

TSPs can register on the SYN+AIR platform and create, modify, or cancel a contract. A contract is an agreement between two TSPs that defines the data sharing criteria and uses a data flow model match mechanism and a graph knowledge base that sets out the scope, dataset attributes and specifications, parties' obligations, revenue, responsibility sharing, contract time span and fulfilment criteria, etc. Moreover, the platform is designed to facilitate collaboration between transport service providers of different modes, and to perform the management of their contracts in a centralised manner. Its design envisions connections with third party services and software solutions such as transport clouds, data spaces transport, open data repositories and data transformation platforms to obtain the necessary inputs to run the SYN+AIR platform.

The platform supports connections with mobility-as-a-service providers and travel companion apps. On the one hand, those apps allow the verification of a signed contract on the SYN+AIR platform. On the other hand, the travellers benefit from data sharing and coordination of transport services which can lead to less waiting time, single ticketing and single check in.

The SYN+AIR web-based platform that hosts the SCF is ready to be implemented by TSPs and travel companion applications and offers European citizens and travellers the opportunity to enjoy the benefits of multimodal door-to-door seamless transport.

# TRANSIT - Travel Information Management for Seamless Intermodal Transport

## Simpler, more sustainable single ticket long-distance travel

### Project Partners

Nommon Solutions and Technologies (Coordinator)

AENA

ENAC

Eidgenössische Technische Hochschule Zürich (ETH Zürich)

EUROCONTROL

Fulfilling the European Commission's vision of multimodal door-to-door mobility requires a shift towards a fully integrated, multimodal and sustainable transport sector. Achieving this goal depends upon creating and monitoring the digital solutions that will deliver favourable conditions for transport users.

TRANSIT developed a set of multimodal key performance indicators (KPIs), mobility data analysis methods and transport simulation tools designed to evaluate the impact of innovative intermodal transport solutions on the quality, efficiency and resilience of the door-to-door passenger journey. In practical terms, this means the purchase of tickets in one transaction enables passengers to travel using different transport modes provided by numerous operators.

**TRANSIT used advanced mobility data analytics and multimodal travel modelling to develop a methodological framework and a set of software tools to evaluate of new intermodal concepts and solutions.**

The project delivered three main outcomes: Firstly, TRANSIT developed an intermodality assessment framework consisting of (1) a set of multimodal passenger-centric performance indicators encompassing, among other aspects, travel time, travel time reliability, affordability, environmental impact and resilience; (2) a set of data analytics techniques for the detailed reconstruction of long-distance multimodal trips through the analysis of new big data sources (e.g., mobile network data); (3) an open-source simulation framework that integrates a long distance travel demand model with a simulation model of airport access and egress; and (4) a methodology to combine these tools for the assessment of multimodal solutions.

**TRANSIT foresees a passenger-centric vision of the multimodal European transport system where the different modes are seamlessly integrated.**

Secondly, the TRANSIT intermodal timetable synchronisation solution enabled the design of synchronised timetables between air and ground public transport modes; and thirdly, the TRANSIT intermodal disruption management tool, provided a mechanism for information sharing and coordination between airspace management and ground transportation suppliers for the tactical management of unplanned disruptions to airport access.

### Benefits

- Enhanced passenger experience
- Improved efficiency, predictability, environment and resilience
- Better integration and coordination between transport modes.

### Website

https://www.transit-h2020.eu/

# X-TEAM D2D - eXTEnded AtM for Door2Door travel

## Putting the passenger at the centre of the transport journey

### Project Partners

CIRA (Coordinator);

Amsterdam University of Applied Science

D-Flight (D-flight)

DLR

Łukasiewicz Institute of Aviation (ILOT)

ISSNOVA

### Benefits

- More efficient door-to-door travel
- Identified enablers and barriers
- Centralises passenger needs

### Website

www.xteamd2d.eu

To achieve the European goal of seamless door-to-door (D2D) travel, air transport needs to be part of an intermodal network that includes other available transportation means such as rail, road and sea. Such a network would address connections between a big metropolis and the surrounding area up to country-wide level.

X-TEAM D2D addressed seamless integration of air traffic management and air transport in urban and suburban environments and identified enabling technologies applicable in the short term and longer term. Taking multimodal transport use cases, the research highlighted barriers to the implementation of the envisaged scenarios and provided detailed outcomes related to baseline (2025), intermediate (2035) and final (2050) target time horizons.

**X-TEAM integrates air transport into an overall network of air, ground and water transport while optimising the capacity of each.**

The project designed a concept of operations (ConOps) for the definition of an integrated multimodal transport network, implementing a total traffic management (TTM) approach, including a high-level description of the system architecture and related main components. It also identified the associated system requirements, as well as expected user requirements over the next decades, and designed a dedicated service blueprint to model the interaction of the passengers with the infrastructure throughout the whole D2D journey. This identified the main organisational needs and policy steps for the transition from the current situation towards the integrated X-TEAM D2D defined infrastructure.

**Increased intermodal transportation efficiency accounts for passenger needs and expectations.**

Moving from the current situation where each leg of the journey has its own service, to an integrated transport service that is unique to each passenger for the whole D2D journey, led to the formulation of the X-TEAM D2D ConOps, paving the way to total traffic management for all modes of transport where travellers' preferences have a high priority.

To validate the X-TEAM D2D ConOps, two performance areas were assessed: Journey efficiency – measured in terms of total distance travelled, total travel time, and average travel speed per passenger); and quality of travelling for passengers, based on the waiting time at interconnections.

# SAFETY AND RESILIENCE

PROJECT SUMMARIES

FARO

# FARO – saFety And Resilience guidelines for aviatiOn

## Quantifying safety brings added confidence in new technology

### Project Partners

CRIDA A.I.E. (Coordinator)

ENAIRE

EUROCONTROL

Lund University

UPM

University of Belgrate - Faculty of Transport and Traffic Engineering – UB-FTTE

Zenabyte S.L.R.

### Benefits

- Safety performance functions
- Resilient performance indicators
- Identifies hidden safety precursors

### Website

https://faro-h2020.eu

Increased automation promises scalable, more resilient air traffic services in line with the strategic objectives of the Digital European Sky. Ensuring new technology improves performance while maintaining safety calls for design guidelines to manage its impact on organisational, human and procedural actions.

FARO addressed this objective by developing a conceptual framework for safety and resilience, underpinned by the exploitation of natural language processing techniques to expand it based on reports of past incidents. The project then advanced in three different streams: The development of safety performance functions; resilience engineering and quantitative methods based on data exploitation; and the integration between these views.

**FARO accurately models predicted safety levels, and, for the first time, captured operators' strategies as they respond to changing traffic scenarios.**

The research used Bayesian belief networks to provide a non-linear methodology for quantifying safety levels and undertook activities to develop safety performance functions that were sufficiently flexible to accommodate different features. It demonstrated that resilience engineering can adopt quantitative methods to complement existing qualitative ones. In addition, by integrating safety and resilience engineering methods, the project demonstrated it could facilitate a deeper understanding of the interdependencies between competing goals in the air traffic management system.

FARO validated its approach in three real-world use cases in Spain. The two operational changes included the deployment of direct route airspace around Santiago, and re-organisation of the airspace above Barcelona feeding the Balearic Islands. The third use case concerned automation, with approach controllers at Barcelona airport receiving information directly downlinked from aircraft. FARO compared the situation before and after the changes in each use case by analysing data going back to 2013.

The key outcomes of the project are presented in a single document *Safety and Resilience Guidelines.* FARO's techniques could prove a milestone in helping stakeholders quantify safety levels and identify resilience strategies, key to keeping European citizens flying confidently.

# SafeOPS

## Data-driven controller support tools improve decision-making


### Project Partners

Technical University of Munich

Deep Blue S.r.l.

DFS Deutsche Flugsicherung GmbH

Iberia

Innaxis

Pegasus Airlines

The high levels of safety and resilience in air traffic management need to be maintained and optimally improved. As the next generation of air traffic management systems are pushed more and more towards digitalisation, combing these two goals remains a priority for air traffic service providers.

SafeOPS investigated how artificial intelligence (AI) solutions can enable safety applications that create a proactive, data-driven approach to safety, capable of predicting potential hazards in real-time. The project focussed specifically on developing an AI-solution decision support tool to warn air traffic controllers about the occurrence of go-arounds. A go-around prediction tool provides air traffic controllers with greater situational awareness, alerts others, and enables coordination when necessary. Thus, AI supports controllers in making more informed decisions when handling go-arounds, avoiding knock-on effects like radar or wake separation challenges, thereby making aviation safer and more resilient.

**SafeOPS developed an AI-based decision support tool to warn air traffic controllers about the occurrence of go-arounds.**

Alongside the possible positive impacts, the provision of non-deterministic information can also introduce risks, like false predictions or overconfidence. Therefore, SafeOPS developed a risk framework to investigate the challenges of how probabilistic information could best be integrated into existing processes in air traffic management, along with associated risks, arising through the use (and possibly misuse) of uncertain information in air traffic control, with special focus on human factors.

SafeOPS produced a data-pipeline that allows the processing of freely available data to investigate the landing phase of aircraft. The SafeOPS prototypic tool for go-around predictions shows promising results with further research underway to determine whether the achieved levels of accuracy are enough to impact safety and resilience in a positive manner. The project concluded by publishing guidance on AI-driven decision support tools, based on the project's learnings.

### Benefits

- Increased aviation safety and resilience
- Analysis of AI tools in a high reliability environment
- Increased digitalisation of air traffic management

### Website

https://safeops.eu/

# U-SPACE AND REMOTELY PILOTED AIRCRAFT SYSTEMS

PROJECT SUMMARIES

# BUBBLES - Defining the BUilding Basic BLocks for a U-Space SEparation Management Service

## A safe and efficient concept of operations for new entrants


Keeping aircraft safely separated is one of, if not the core function of air traffic management today. As larger numbers of unmanned aerial systems (UAS) take to the skies, separation management become more important to avoid mid-air collisions.

Defining a risk-based, operation-centric concept of operations (ConOps) for the provision of U-space separation management enables the remotely piloted sector to grow in a safe and efficient way. The ConOps developed by BUBBLES comprises the definition of conflict horizons, separation modes, and the applicable separation minima, which are dynamically updated using artificial intelligence (AI)-based algorithms to adapt them to the actual performance of communication, navigation and surveillance (CNS) systems.

**BUBBLES defined a set of safety events of increasing severity and mitigation barriers aimed at preventing them from ending up in a mid-air collision.**

Manned aircraft benefit from BUBBLES ConOps as they have better situational awareness and can be assisted to manoeuvre in the event of loss of separation. At the same time, UAS operators can safely exploit the airspace capacity given the UAS capabilities and the available U-space services, as well as the actual CNS performance.

**CNS performance metrics were defined and evaluated to determine the thresholds that trigger the update of the separation minima to keep the required levels of safety.**

The ConOps was validated by using simulators developed by the project, as well as by means of a test flight campaign where several UAS flew simultaneously using a mock-up developed based on Indras's UTM platform, U-TraC. U-TraC monitored the CNS performance and provided dynamic separation management, traffic information and alerts of increasing severity when the separation minima were compromised.

BUBBLES defined the separation management as a new SESAR solution in the European air traffic management architecture (EATMA), which will be considered in future research activities aimed at developing U-space level 3 (U3) services mature enough to be deployed. In the short-term, the results will be used to improve some U2 services such as traffic information and strategic conflict resolution.

### Project Partners

Universitat Politècnica de València (Coordinator)

EUROCONTROL

Indra Sistemas S. A.

Universidade de Coimbra

Università degli Studi di Roma La Sapienza

### Benefits

- Improved airspace capacity and safety
- Better awareness of separation loss events
- Early resolution of separation issues

### Website

https://bubbles-project.eu/

DACUS

# DACUS - Demand and Capacity Optimisation in U-space

## Tools to balance airspace capacity and demand over population

### Project Partners

CRIDA A.I.E. (Coordinator)

Aha.is

Boeing Research & Technology Europe

ENAIRE

EUROCONTROL

Ingenieria y Economia del Transporte (INECO)

ISA Software Limited

Jeppesen GmbH

Sopra Steria Group

Toulouse Métropole

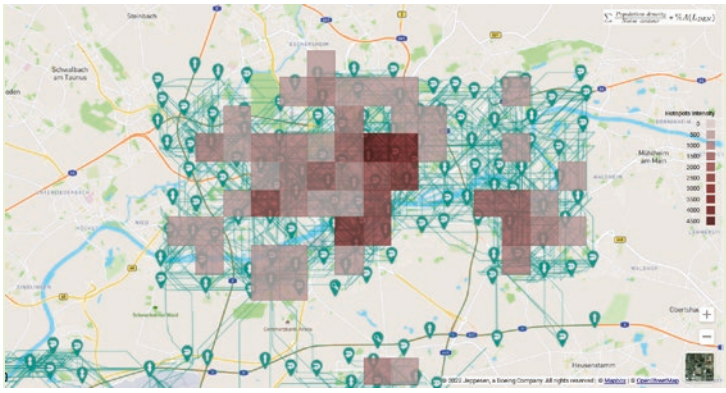
Technische Universität Darmstadt (TUDA)

### Benefits

- Mitigates impact noise and visual annoyance
- Prioritises free-route operations whenever possible
- Effective decision-making based on stable predictions

### Website

https://dacus-research.eu/



As drone operations become more common over populated areas, managing the number and type of unmanned aerial vehicles (UAV) becomes increasingly important. Influential factors including noise effects, visual impact, collision risk, separation processes, drone flight planning and U-space services all play a part in efficiently balancing demand and supply.

DACUS developed a demand and capacity balancing (DCB) decision-making process and designed a DCB concept of operations (ConOps) for U-space that takes account of key limiting factors for drone operations over the population. The project developed prototypes of the proposed solutions: A collision risk prototype quantified the air and ground risks as a limiting factor to determine the maximum number of drones in an urban area; a social impact prototype measured the visual and noise effects over the population as another limiting factor; and a route planning prototype took into account the uncertainty of demand as part of the process. Because drone mission trajectories tend to be more dynamic than manned aviation, the system needs to deal with diverse and multiple changes that affect flight plans that can be received at short notice.

DACUS tested the prototypes in several simulations at different stages of the drone operations lifecycle (strategic, pre-tactical and tactical phases), and in representative European cities: Toulouse, Frankfurt, Madrid, and Toledo. The project demonstrated that it is possible to monitor the demand and capacity imbalances based on safety and social criteria, and then to implement DCB measures in U-space airspace in response.

**The DACUS solution supports the development of a U-space system that incorporates safety and social criteria.**

DACUS helps to facilitate the social acceptance of future drone operations in urban environments. The solution is capable of monitoring both noise and visual impact over the population, while ensuring that risk levels do not increase.

# ICARUS: Integrated Common Altitude Reference System for U-space

## A common altimeter reference for all airspace users

Unmanned aerial systems (UAS) share very low-level (VLL) airspace with conventional aircraft. To maintain separation among all users of this airspace, the altitudes of all aircraft must be known unambiguously through a common datum. However, while manned aviation uses pressure altitude obtained from barometric readings, UAS may use other systems such as GNSS-based altitudes.

**ICARUS enables traditional and new airspace users to use their preferred altitude reference system.**

New methods and procedures are needed for the expected large numbers of drones that will operate in the VLL airspace, especially over cities where the existing altitude references cannot always address the challenges arising from flying near, or sometimes even below, ground obstacles. ICARUS carried out a thorough analysis of the challenges involved in drone operations conducted in VLL airspace, including a public survey, and gap analysis. With this information, the project defined a system architecture and prototype to validate the ICARUS concept of operations (ConOps).

The research proposed an innovative solution for a common altitude reference in VLL airspace by defining new U-space services and validated the findings in real operational environments. The solution enables both traditional and new unmanned airspace users to continue to use their preferred altitude reference system while ensuring safety and interoperability. Additionally, those embracing the full range of ICARUS services will benefit the most from added functionalities regarding obstacle detection and avoidance, and the added accuracy of height measurements.

**ICARUS contributes to the U-space with three new services: real-time geospatial information service (RGIS), vertical conversion service (VCS), and the vertical alert service (VAL)**

The ICARUS concept is based on six U-space services: three existing, and three defined by the ICARUS project New services include real-time geospatial information service (RGIS), vertical conversion service (VCS), and the vertical alert service (VALS). All six services are referenced in the draft ISO DIS 23629-12, UAS Traffic Management – Requirements for UTM service providers, ensuring that the results of the project will be used by the community.

### Project Partners

e-Geos (Coordinator)
DiCEA –Sapienza
Droneradar
EUROCONTROL
EuroUSC España
EuroUSC Italia
Politecnico di Milano
Telespazio
TopView

### Benefits

- Common altimeter reference for all airspace users
- Enhanced capacity management in congested airspace
- Ground obstacle alert service in VLL airspace

### Website

www.u-spaceicarus.eu

# INVIRCAT - IFR RPAS Control in Airports and TMA

## Unleashing the full potential of remotely piloted aircraft systems

### Project Partners

DLR (Coordinator)

CIRA

Deep Blue

EUROC

ISDEFE

Institute for Sustainable Society and Innovation (ISSNOVA)

NLR

### Benefits

- Efficient RPAS operations
- New business and job opportunities

### Website

www.invircat.eu

Remotely piloted aircraft systems (RPAS) are among a growing number of new airspace users fulfilling commercial and military roles. As they are currently largely confined to segregated airspace, solutions need to be established that allow full integration of RPAS into non-segregated airspace.

INVIRCAT focused on the integration of RPAS into the existing air traffic control (ATC) procedures and infrastructures within terminal manoeuvring areas (TMA) and airport environments under instrument flight rules (IFR).

**INVIRCAT showed that it was possible to integrate different types of RPAS in different types of airspace and at different airports under appropriate conditions considering the local traffic and environment without entailing a significant impact on the current users of the airspace.**

The project designed a harmonised concept of operations (ConOps) for full integration of RPAS in TMA environments, complete with air traffic control procedures, flight planning processes, separation requirements, and necessary technological enablers for the new processes. The ConOps takes past and on-going results of relevant activities into account. The project tested and validated the ConOps by means of three real-time simulations involving air traffic controllers and remote pilots, and then used the results of the study to consolidate the ConOps and identify the technical and operational requirements. An impact and effects analysis considered safety, operational efficiency, human performance, equity and capacity. It also took into account key enablers such as the command and control (C2) link, automatic take-off and landing (ATOL), RPAS on-board technologies, voice communication infrastructure (ground-ground), taxi systems, and handover procedures.

**The analysis focussed on safety, operational efficiency, human performance, equity and capacity and took into account key enablers.**

The project produced a set of conclusions and recommendations to inform regulators and standards organisations, facilitating the generation of a harmonised approach for the integration of RPAS in the TMA. The stable ConOps, high-level requirements and a reference architecture definition enables seamless RPAS integration, unlocking the potential for global and efficient RPAS operations.

INVIRCAT shows it is possible to integrate different types of RPAS in different types of airspace and at different airports under appropriate conditions considering the local traffic and environment without significant impact on current airspace users.

# Metropolis II - A unified approach to airspace design and separation management for U-space

## Appropriate U-space services for high-capacity urban airspace

Integrating manned and unmanned aerial systems (UAS) in urban and high-density airspace requires a degree of autonomy that does not yet exist in current-day air traffic management. This vision of shared airspace depends on the provision of U-space services capable of managing safe separation, dynamic flight re-routing and demand/capacity balancing. The operational capabilities of these advanced U-space services are foundational elements of the future Digital European Sky.

Metropolis 2 was one of few exploratory research projects working with the most advanced (U4) U-space services. It consolidated results from U1/U2 services to provide a unified approach to airspace design, demand/capacity balancing, flight planning and separation management. The project explored the future of urban air traffic mobility (UAM) by investigating different combinations of strategic deconfliction, tactical deconfliction, and dynamic capacity management. It sought to find the right balance between long-term (pre-departure) and short-term separation management.

**Metropolis 2 took the first steps towards the introduction of new forms of urban mobility, such as drone delivery and personal aerial mobility - services considered as enablers for large improvements in quality of life and economic activity.**

The main focus was given to developing solutions to support safe and efficient operations of large numbers of drones without adversely affecting manned aviation.

It explored the benefits and drawbacks of separation management paradigms with different approaches to who acts as separator: the drone, the U-space service, or a combination of both, and extended the segmentation and alignment principles of geo-vectoring to an operational concept applicable to high-capacity urban airspace. It also specifically addressed safe U-space operations within the urban scope with better social acceptance.

The project used large-scale fast-time simulations, in combination with an extensive set of metrics relating to properties such as efficiency, safety, capacity, and equity, to evaluate and compare different separation management concepts. The project developed a unified approach to airspace rules, flight planning and separation management approaches to support safe and efficient U-space operations in urban environments.

### Project Partners

Delft University of Technology

ENAC

Linkoping university

NTT DATA Spain S.L.U. (NTTDES)

NLR

Unifly

Laboratory of Applied Mechanics and Vibrations Dept. of Mechanical Engineering & Aeronautics, Univ. of Patras (AML/UoP)

### Benefits

- Consolidated U1/U2 U-space results
- Metrics to determine safety and efficiency
- Realistic foundation for urban air mobility

### Website

https://metropolis2.eu/

# SAFELAND – SAFE LANDing through enhanced ground support

## Safe ground-based support for single-pilot operations

### Project Partners

Deep Blue (Coordinator)

Airholding

Deutsches Zentrum für Luft und Raumfahrt (DLR)

Easn Technology Innovation Services (EASN-TIS)

Eurocontrol

European University Institute

Eurousc Italia

Luftfartsverket (LFV)

Swiss International Air Lines

### Benefits

- Advances SPO research
- Single-pilot incapacitation management
- Maintained levels of safety

### Website

https://safeland-project.eu/

Advances in automation technology could mean that one day only one pilot is needed in the cockpit of commercial aircraft. Key requirements for the implementation of single-pilot operations (SPO) will be preserving the safety levels as in current multi-pilot operations and addressing risks such as in-flight pilot incapacitation.

These safety requirements were at the core of the operational concept developed by SAFELAND, which aimed at supporting a single-piloted aircraft during the flight and landing in case the single pilot on board becomes incapacitated. The concept was predicated on the interaction of a ground-based operator working from a remote ground station position with on-board automation and air traffic controllers.

**A key requirement for the implementation of SPO will be preserving the safety levels as in current multi-pilot operations.**

**SAFELAND aimed at supporting a single-piloted aircraft in the event of in-flight pilot incapacitation.**

The SAFELAND concept assumed that the single-piloted aircraft is equipped with more sophisticated automation than the current CS-25 certified aircraft (e.g., onboard pilot health monitoring system, reliable and sufficient command and control (C2) datalink, and an advanced system capable of autonomously landing the aircraft). In addition, the concept envisaged remote pilots operating from the ground to monitor single-piloted aircraft, to support the single pilots upon request and, if necessary, to intervene and take over control of the aircraft. On the other hand, no significant changes to the tasks and responsibilities of air traffic control and the airline operations control centre (AOCC) were foreseen since the incapacitated aircraft would be handled by following standard emergency procedures.

SAFELAND validation activities endorsed the envisioned operational procedures, the roles and distribution of responsibilities, and the dynamic of the interactions between the involved actors. The project results support future rulemaking relating to the rules of the air, operations, aircrew and ground crew competencies, and the functions and responsibilities of people involved (i.e., pilot in command, air traffic controllers, remote operators on the ground). The results, complemented by regulatory and legal analyses as well as safety and cyber-security assessments, are expected to significantly advance SPO research.

# URClearED Project - A Unified Integrated Remain Well Clear Concept in Airspace D-G Class

## A reliable remain-well-clear function for RPAS airspace users

As more certified remotely piloted aircraft systems (RPAS) take to the skies to serve as vehicles for civil and military purposes, ensuring they carry out their business safely and securely becomes ever more important.

The URClearED project addressed a key technological issue that will allow certified RPAS to carry out services, such as monitoring, surveillance and cargo delivery, while sharing airspace with other users. URClearED investigated the concept of a remain-well-clear (RWC) function of a detect and avoid system for certified unmanned air vehicles flying instrument flight rules (IFR) in airspace classes D to G. Well below the typical cruise altitudes of commercial airlines, the airspace is used by small and medium-sized aircraft like helicopters, general aviation and unmanned systems.

**URClearED analysed remain-well-clear (RWC) functions to support the safe integration of unmanned vehicles in manned airspace.**

**URClearED defined and validated a remain-well-clear concept for remotely piloted aerial systems operating in European airspace classes D to G.**

The project considered existing standards relating to RWC concepts and parameters, and analysed operational scenarios to propose a concept of RWC. To assess its functional and operational acceptability to both remote pilots and air traffic controllers, operational stakeholders participated in a series of fast time and real-time validation exercises to test the impact of the RWC on human performance.

URClearED project results were useful to specify the requirements of the RWC module for drones and the associated concept of operations in airspace classes D to G. In addition to helping to define some of the features required within a European RWC system, the validation tests provided preliminary estimates of workloads and acceptability by remote pilots and air traffic controllers. Finally, the project identified the gaps and next relevant steps for the full development and assessment of such a system, paving the way to future industrial-level activities.

### Project Partners

CIRA (Coordinator)

Deep Blue

EUROCONTROL

DLR

General Atomics Europe

SAAB Aeronautics

UPC

### Benefits

- Safe integration of drones
- More efficient airspace usage
- Facilitates growth of new services

### Website

https://www.urcleared.eu

# USEPE - U-Space Separation in Europe

## Ensuring safe separation in complex urban airspace

### Project Partners

ISDEFE) (Coordinator)

DLR

Indra Navia AS

Leibniz Universität Hannover (LUH)

Nommon Solutions and Technologies

POLIS Cities and Regions for Transport Innovation

University of South-Eastern Norway (USN)

### Benefits

- New opportunities and applications for drones
- Feedback to support policy makers
- Introduces automated separation management

### Website

https://usepe.eu

In the future, the number of drones flying simultaneously in the same geographical area will increase and will need to be safely separated from each other and other airspace users. The separation problem becomes more complex in an urban environment where buildings and turbulence add to airspace complexity.

**USEPE developed a new separation method addressing strategic and tactical U-Space services.**

The USEPE project explored potential separation methods throughout the strategic and tactical flight planning phases, including defining the actors responsible for making decisions. The research considered which actor should be the predetermined separator (the drones themselves or the U-space system) throughout the strategic and tactical planning phases before defining a set of concepts to provide safe separation for different kinds of drones.

USEPE analysed concepts including density-based separation and geo-vectoring by assigning speed limitations, and applied machine learning algorithms, namely a recurrent neural network, in order to improve the separation management outcome. This resulted in the development of a new separation method called D2-C2 dynamic density corridor concept, which combines the density-based method with high-speed corridors and geo-vectoring syntax to separate drones in a high-density environment.

**USEPE validated three applications: Last mile delivery, emergency services and urban surveillance.**

To simulate the different concepts and assess the impact of the key performance areas of safety, capacity and efficiency, USEPE developed and made available new modules in Bluesky, an open access simulator. These included a city module, a path planning module, a strategic deconfliction module and an airspace segmentation module. The simulations included real wind data. The findings from the USEPE research project will be shared with relevant stakeholders as a first step in creating an initial concept of operations for an urban airspace separation management system.

# KNOWLEDGE TRANSFER NETWORK

PROJECT SUMMARIES

# Engage – the SESAR 2020 Knowledge Transfer Network

## A one-stop, go-to source for air traffic management research and knowledge

### Project Partners

University of Westminster (Coordinator)

EUROCONTROL

European Aviation Safety Agency

Frequentis

Innaxis

Technical University of Delft

University of Belgrade - FTTE

University of Trieste.

### Benefits

- Stimulates the innovation pipeline
- Over 230 research outputs
- Laid foundations for the SESAR Digital Academy

### Website

https://engagektn.com

https://wikiengagektn.com


The Engage knowledge transfer network (KTN) was set up to share the resources and findings of the SESAR research and innovation programme with a view to informing future fundamental research as well as transferring results towards application-oriented work. The EngageWiki is a knowledge hub, which provides a one-stop, go-to source for air traffic management research and knowledge in Europe, featuring highly innovative content. This includes an integrated and interactive research map that places SESAR exploratory and industrial research projects in one location for the first time. The wiki also includes a consolidated and searchable research repository that catalogues research for easy access. This repository describes over 350 projects and includes more than 1 400 deliverables/ reports and over 650 conference papers.

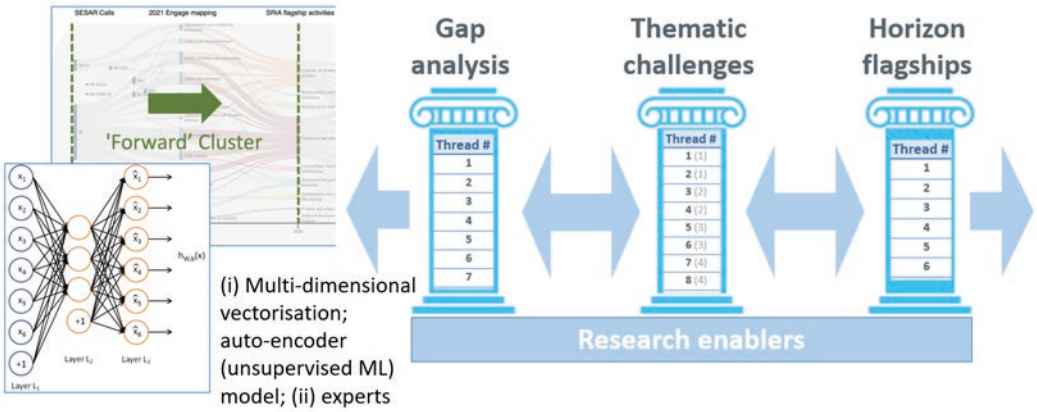
The wiki features an interactive roadmap of (future) air traffic management concepts, a database of over 110 undergraduate and postgraduate teaching programmes, and hosts training courses on air traffic management, airline planning and operations, airport planning and operations.

In addition, the EngageWiki hosts various discussion fora, and advertises (free of charge) jobs, internships and PhD opportunities. User accounts are free and the wiki hosts briefing videos to explain key features to new users.

**The Engage knowledge hub enhances the visibility of all SESAR research.**

The KTN supported four SESAR Innovation Days where consortium members collaborated with the SESAR Joint Undertaking, co-hosting thematic challenge workshops, supporting sessions, and republishing SESAR Innovation Days conference papers (2011-2020) on the EngageWiki.

Notable among the approximately 60 deliverables, was D3.10 (Research and innovation insights), which is viewed as a legacy deliverable from the KTN. The basic framework was structured around three research pillars. SESAR's Strategic Research and Innovation Agenda was a focal point of comparison. Detailed proposals for future research, plus research enablers and platforms, were suggested for the Digital European Sky research and innovation programme.




## Achievements

The Engage network ran for 4.5 years, initiating and supporting multiple activities for SESAR and the European ATM community. Around two-thirds of the financing was invested back into the community, for example through catalyst fund projects and PhDs.

Key throughout was integrating exploratory and industrial research, thus expediting the innovation pipeline and bringing researchers together. Permeating all features of the network was the pronounced and active engagement of industry. At the core of the network were four thematic challenges, supported by 14 dedicated workshops with exploratory and industrial researchers, in addition to further specialist/technical workshops. Catalyst funding, linked to these challenges, supported 18 projects, stimulating the transfer of exploratory research results towards ATM application-oriented research, returning very high value for money. Engage here worked with 31 unique institutions, and these projects produced over 130 research outputs.

10 PhDs were supported through financing and co-mentoring, producing approximately 100 research outputs with the KTN assisting with travel bursaries, publication grants and funded training places. Central to the educational and training provision of Engage were three summer schools (one physical, two virtual). The pedagogical approach evolved across the series of summer schools, from teaching the PhD candidates the fundamentals of ATM and wider research practice in 2019 (these materials forming the basis of the lecture courses published in the EngageWiki), to tailored industry presentations and methodological tutorials in 2020, through to extended panel discussions with domain experts from industry in 2021, also exploring how the PhDs could be taken forward in operational settings. Almost 100 participants, from 20 countries, participated in the 2021 summer school. These activities laid valuable foundations for the SESAR Digital Academy.

# ON THE HORIZON

Our pursuit of knowledge and applying it to deliver a smarter and more sustainable aviation does not end with the closure of the 41 projects and 1 knowledge transfer network that make up this publication. With the launch of the SESAR 3 JU, new opportunities are available to push the boundaries of air traffic management and feed the innovation pipeline with fresh concepts and advances.

In April 2022, the JU launched the first call for exploratory research projects under the new partnership, with the following provisions:

**Work area 1 fundamental science and outreach (EUR 10 million budget)**: comprises the exploratory research necessary to develop new concepts for ATM beyond those identified in the European ATM Master Plan, and will help to develop emerging technologies and methods to the level of maturity required to feed the applied research conducted by the SESAR 3 JU. This part of the research is structured around the same flagships identified in the rest of the programme to ensure that there is a flow of ideas and results in a structured manner across the whole programme.

**Work area 2 ATM application-oriented research (EUR 10 million):** comprises exploratory research aiming to bridge the results of ATM excellent science and outreach and the higher maturity ATM research performed with the wider research community, as part of SESAR 3 JU industrial research activities. It also aims to provide the necessary scientific support to ATM change.

**Work area 3 knowledge transfer network (EUR 3.75 million):** provides support for the SESAR 3 JU to continue maintaining the overarching view across ATM exploratory research, provides a coordinated exchange of research knowledge across a wide range of relevant themes and, within the context of this networking, helps to further stimulate the future ATM skilled workforce. The challenge is to support and encourage collaborative research on future and emerging innovative ideas, expertise and knowledge for the benefit of the future evolution of the European ATM system and its people.

Stay tuned for more results!

# ANNEXES

# ANNEX 1

## Overview of SESAR exploratory research projects (2016 - 2022)

**Co-funded by the European Union**

The projects in this publication were funded by the SESAR Joint Undertaking, within the framework of the EU's Horizon research and innovation programme.

| Acronym | Project name | Grant no. |
|---|---|---|
| **ADAPT** | Advanced prediction models for flexible trajectory-based operations | 783264 |
| **AGENT** | Adaptive self-Governed aerial Ecosystem by Negotiated Traffic | 699313 |
| **AIRPASS** | Advanced Integrated RPAS Avionics Safety Suite | 763658 |
| **AICHAIN** | A Platform for Privacy-preserving Federated Machine Learning using Blockchain to enable Operational Improvements in ATM | 894162 |
| **AISA** | AI Situational Awareness Foundation for Advancing Automation | 892618 |
| **AEON** | Advanced Engine Off Navigation | 892869 |
| **ALARM** | multi-hAzard monitoring and earLy wARning systeM | 891467 |
| **APACHE** | Assessment of Performance in current ATM operations and of new Concepts of operations for its Holistic Enhancement | 699338 |
| **ARTIMATION** | Transparent Artificial Intelligence and Automation to Air Traffic Management Systems | 894238 |
| **ASPRID** | Airport System PRotection from Intruding Drones | 892036 |
| **ATM4E** | Air Traffic Management for environment | 699395 |
| **AURORA** | Advanced User-centric efficiency metRics for air traffic perfORmance Analytics | 699340 |
| **AUTOPACE** | AUTOMATION PACE | 699238 |
| **BEACON** | Behavioural Economics for ATM Concepts | 893100 |
| **BEST** | Achieving the BEnefits of SWIM by making smart use of Semantic Technologies | 699298 |
| **BigData4ATM** | Passenger-centric Big Data Sources for Socio-economic and Behavioural Research in ATM | 699260 |
| **BUBBLES** | Defining the BUilding Basic BLocks for a U-Space SEparation Management Service | 893206 |
| **CADENZA** | Advanced Capacity and Demand Management for European Network Performance Optimization | 893380 |
| **CLASS** | CLear Air Situation for uaS CLASS | 763719 |
| **COCTA** | Coordinated capacity ordering and trajectory pricing for better-performing ATM | 699326 |
| **COMPAIR** | COMPetition for AIR traffic management | 699249 |
| **COPTRA** | COmbining Probable TRAjectories | 699274 |
| **CORUS** | Concept of Operations for EuROpean UTM Systems | 763551 |
| **COTTON** | Capacity Optimisation in TrajecTory-based OperatioNs | 783222 |

| Acronym | Project name | Grant no. |
|---|---|---|
| **CREATE** | Innovative operations and climate and weather models to improve ATM resilience and reduce impacts | 890898 |
| **DACUS** | Demand and Capacity Optimisation in U-space | 893864 |
| **DART** | Data-driven AiRcraft Trajectory prediction research | 699299 |
| **Domino** | Novel tools to evaluate ATM systems coupling under future deployment scenarios | 783206 |
| **DREAMS** | DRone European AIM Study | 763671 |
| **DroC2om** | Drone Critical Communications | 763601 |
| **DYNCAT** | Dynamic Configuration Adjustment in the TMA | 893568 |
| **ECHO** | European Concept of operations for Higher airspace Operations | 890417 |
| **EMPHASIS** | EMPowering Heterogeneous Aviation through cellular SIgnalS | 783198 |
| **Engage** | Knowledge Transfer Network | 783287 |
| **ENVISION** | Enhanced Situational Awareness through Video Integration with ADS-B Surveillance Infrastructure on Airports | 783270 |
| **EvoATM** | Evolutionary ATM. A modelling framework to assess the impact of ATM evolutions | 783189 |
| **FACT** | Future All aviation CNS Technology | 894616 |
| **FARO** | saFety And Resilience guidelines for aviatiOn | 892542 |
| **FlyATM4E** | Flying Air Traffic Management for the benefit of environment and climate | 891317 |
| **FMP-Met** | Meteorological uncertainty management for Flow Management Positions | 885919 |
| **GATEMAN** | GNSS navigation threats management | 783183 |
| **HAAWAII** | Highly Automated Air Traffic Controller Workstations with Artificial Intelligence Integration | 884287 |
| **ICARUS** | Integrated Common Altitude Reference System for U-space | 894593 |
| **IMHOTEP** | Integrated Multimodal Airport Operations for Efficient Passenger Flow Management | 891287 |
| **IMPETUS** | Information Management Portal to Enable the inTegration of Unmanned Systems | 763807 |
| **INTUIT** | Interactive Toolset for Understanding Trade-offs in ATM Performance | 699303 |
| **INVIRCAT** | IFR RPAS Control in Airports and TMA | 893375 |
| **ISOBAR** | Artificial Intelligence Solutions to Meteo-Based DCB Imbalances for Network Operations Planning | 891965 |
| **ITACA** | Incentivising Technology Adoption for Accelerating Change in ATM | 893443 |
| **MAHALO** | Modern ATM via Human/Automation Learning Optimisation | 892970 |
| **MALORCA** | Machine Learning of Speech Recognition Models for Controller Assistance | 698824 |
| **MINIMA** | MItigating Negative Impacts of Monitoring high levels of Automation | 699282 |
| **Metropolis 2** | A unified approach to airspace design and separation management for U-space | 892928 |
| **Modus** | Modelling and assessing the role of air transport in an integrated, intermodal transport system | 891166 |
| **MOTO** | the embodied reMOte Tower | 699379 |
| **NAVISAS** | Navigation of Airborne Vehicle with Integrated Space and Atomic Signals | 699387 |
| **NewSense** | Evaluation of 5G Network and mmWave Radar Sensors to Enhance Surveillance of the Airport Surface | 893917 |
| **NOSTROMO** | Next-Generation Open-Source Tools for ATM Performance Modelling and Optimisation | 892517 |

| Acronym | Project name | Grant no. |
|---|---|---|
| **OptiFrame** | An Optimization Framework for Trajectory Based Operations | 699275 |
| **PACAS** | Participatory Architectural Change Management in ATM Systems | 699306 |
| **PARTAKE** | cooPerative depArtuRes for a compeTitive ATM networK sErvice. | 699307 |
| **PercEvite** | PercEvite - Sense and avoid technology for small drones | 763702 |
| **PNOWWA** | Probabilistic Nowcasting of Winter Weather for Airports | 699221 |
| **RETINA** | Resilient Synthetic Vision for Advanced Control Tower Air Navigation Service Provision | 699370 |
| **R-WAKE** | Wake Vortex simulation and analysis to enhance en-route separation management in Europe | 699247 |
| **SAFELAND** | SAFE LANDing through enhanced ground support | 890599 |
| **SafeOPS** | From Prediction to Decision Support - Strengthening Safe and Scalable ATM Services through Automated Risk Analytics based on Operational Data from Aviation Stakeholders | 892919 |
| **SALSA** | SATELLITE-BASED ADS-B FOR LOWER SEPARATION-MINIMA APPLICATION (SALSA) | 699337 |
| **SAPIENT** | Satcom and terrestrial architectures improving performance, security and safety in ATM | 699328 |
| **SECOPS** | An Integrated Security Concept for Drone Operations | 763599 |
| **SIMBAD** | Combining Simulation Models and Big Data Analytics for ATM Performance Analysis | 894241 |
| **SINAPSE** | Software defined networking architecture augmented with Artificial Intelligence to improve aeronautical communications performance, security and efficiency | 892002 |
| **SINOPTICA** | Satellite-borne and IN-situ Observations to Predict The Initiation of Convection for ATM | 892362 |
| **SlotMachine** | A Privacy-Preserving Marketplace for Slot Management | 890456 |
| **START** | a Stable and resilient ATM by integrating Robust airline operations into the network | 893204 |
| **STRESS** | Human Performance neurometricS Toolbox foR highly automatEd Systems deSign | 699381 |
| **SYN+AIR** | Synergies between transport modes and Air transportation | 894116 |
| **TaCo** | Take Control | 699382 |
| **TAPAS** | Towards an Automated and exPlainable ATM System | 892358 |
| **TBO-Met** | Meteorological Uncertainty Management for Trajectory Based Operations | 699294 |
| **TERRA** | Technological European Research for RPAS in ATM | 763831 |
| **TRANSIT** | Travel Information Management for Seamless Intermodal Transport | 892358. |
| **URClearED** | A Unified Integrated Remain Well Clear Concept in Airspace D-G Class | 892440 |
| **USEPE** | U-space Separation in Europe | 890378 |
| **Vista** | Market forces trade-offs impacting European ATM performance | 699390 |
| **X-TEAM D2D** | eXTEnded AtM for Door2Door travel | 891061 |

# ANNEX 2

## Abbreviations

| | |
|---|---|
| aCCFs | algorithmic climate change functions |
| A-CDM | Airport collaborative decision making |
| ADS-B | Automatic dependent surveillance-broadcast |
| AI | Artificial intelligence |
| ANSPs | Air navigation service providers |
| AOCC | Airline operations control centre |
| API | Application programming interface |
| A-SMGCS | Advanced surface movement guidance and control system |
| ATC | Air traffic control |
| ATFCM | Air traffic flow and capacity management |
| ATM | Air traffic management |
| ATN | Aeronautical communications network |
| ATOL | Automatic take-off and landing |
| C2 | Command and control |
| CD&R | Conflict detection and resolution |
| CNS | Communication, navigation and surveillance |
| CONOPS | Concept of operations |
| CPDLC | Controller pilot datalink communications |
| DCB | Demand and capacity balancing |
| D2D | Door-to-door |
| DNN | Deep neural network |
| ER4 | Fourth SESAR exploratory research call for proposals – ER4 |
| EWS | Early warning system |
| EU | European Union |
| FMP | Flow management position |
| FMS | Flight management system |
| GA | General aviation |
| GA/R | General aviation & rotorcraft |
| GNSS | Global navigation satellite system |
| HAPS | High altitude platform stations |
| HMI | Human machine interface |
| IDPS | Intelligent intrusion detection and prevention |
| IFR | Instrument flight rules |
| IP | Internet protocol |
| JU | Joint Undertaking |
| KPAs | Key performance areas |
| KPI | Key performance indicator |
| KTN | Knowledge transfer network |
| ML | Machine learning |
| mmWave | Millimeter wave |
| MPC | Multi-party computation |
| NM | Network Manager |
| NLP | Natural language processing |
| REDA | Readback error detection assistant |
| RFI | Radio frequency interference |
| RGIS | Real-time geospatial information service |
| RPAS | Remotely piloted aircraft system |
| RWC | Remain-well-clear |
| SCF | Smart contracts framework |
| SDN | Software defined networking |
| SES | Single European Sky |
| SESAR | Single European Sky ATM Research |
| SPO | Single-pilot operations |
| TBO | Trajectory-based operations |
| TMA | Terminal manoeuvring area |
| TSP | Transport service providers |
| TTM | Total traffic management |
| UAM | Urban air traffic mobility |
| UAS | Unmanned aerial systems |
| UAV | Unmanned aerial vehicles |
| UDPP | User-driven prioritisation process |
| VALS | Vertical alert service |
| VCS | Vertical conversion service |
| VFR | Visual flight rules |
| VLL | Very low-level |
| WVE | Wake vortex encounter |
| XAI | Explainable AI |

## NOTES

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