

# Exploring the boundaries of air traffic management

A summary of SESAR  
exploratory research results

2016–2018



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## About SESAR

SESAR is the technological pillar of the Single European Sky and a key enabler of the EU Aviation Strategy. The project pools the knowledge and resources of the entire aviation community to transform ATM into a more modular, scalable, automated, interoperable system that takes advantage of advances in digital and virtualisation technologies.

The SESAR Joint Undertaking (SESAR JU) is the public-private partnership set up to define and deliver technological solutions to make this transformation a reality. It works with all actors in the aviation value chain to agree on the research and development priorities, as well as technology roll-out plans, which are documented in the European ATM Master Plan.

Founded by the European Union and Eurocontrol, the SESAR JU has 19 members, who together with their partners and affiliate associations represent over 100 companies working in Europe and beyond. The SESAR JU also works closely with staff associations, regulators, airport operators, airspace users, the military and the scientific community.



## Message from the founding members



**Henrik Hololei**, Director-General for Mobility and Transport at the European Commission, and Chair of the Administrative Board of the SESAR Joint Undertaking

**A**s recognised in the EU Aviation Strategy, innovation is a key enabler for addressing the challenges facing aviation and ensuring its sustainable growth in the decades to come. We have no time to waste in delivering new solutions, especially given the lack of capacity we are facing in the skies today. We must also be forward looking as outlined in FlightPath 2050 and the Strategic Research and Innovation Agenda from the Advisory Council for Aviation Research and Innovation in Europe (ACARE). The results summarised in this SESAR publication show the value of doing just that. It is my hope that this excellent body of work will prompt disruptive change and bring long term valuable returns to aviation sector as well as to people and business in Europe and beyond.



**Eamonn Brennan**, Director General, Eurocontrol, and Vice-Chairman of the SESAR JU Administrative Board

**T**echnological development in any field is typically a combination of improving the existing paradigm and also, occasionally, developing something radically new. In aviation, we have seen this with the move from propeller-driven aircraft to jets; this totally changed how we travel around the world.

It doesn't always work out (there are no supersonic passenger aircraft at present) but an essential part of moving forward is being willing to consider – and fund! – radical new ideas, even those that have no immediate practical application. We need to close the gap between our aviation experts and researchers/academics so that we can find out of the box solutions to the challenges we face now and also those we can see on the horizon.

I am a strong believer in pushing the boundaries and I welcome this snapshot of some of the results of current exploratory research – research that needs to continue if we are to cope with the quantity and diverse nature of tomorrow's air traffic.

# Foreword



**Florian Guillermet,**  
Executive Director,  
SESAR Joint Undertaking

**O**ur fascination with flying is as old as humankind itself. The pursuit of understanding how birds fly eventually led us to master the principles of flight, and design and manage the complex machines that we see in our skies today. Flying continues to fascinate us and push the boundaries of scientific exploration in the domain of aviation and air traffic management.

“

*Flying continues to fascinate us and push the boundaries of scientific exploration in the domain of aviation and air traffic management*

This appetite to look beyond what's on horizon is critical to aviation in order to respond to the growing demand for air travel and the increasing number of air vehicles, such as drones, taking to the skies. Harnessing innovation to tackle the opportunities and challenges that lie ahead is also very much in line with the vision set out in FlightPath 2050, the 2015 Aviation Strategy and the European ATM Master Plan.

”

At the SESAR Joint Undertaking we support long-term exploratory research and have created an innovation pipeline in our research programme that transforms innovative ideas into solutions to increase the performance of European aviation. This publication captures the results from some 28 completed exploratory projects. Taking place between 2016–2018, the selected projects have brought together 80 academic and industry partners, such as universities, SMEs, research centres, airlines, manufacturers, air navigation service providers from across the European Union and EU Associated Countries.

The projects explored innovations and technologies coming not just from aviation and ATM, but also other sectors, such as automotive, robotics or system engineering, as well as in other safety critical industries, such as nuclear, space, etc. The most promising and mature technologies will now be considered for inclusion in the industrial research strand of the SESAR programme, with the ultimate goal of delivering smart, seamless and safe air travel for Europe and its citizens.

# The people behind the research

SESAR Scientific Committee



SESAR Innovation Days

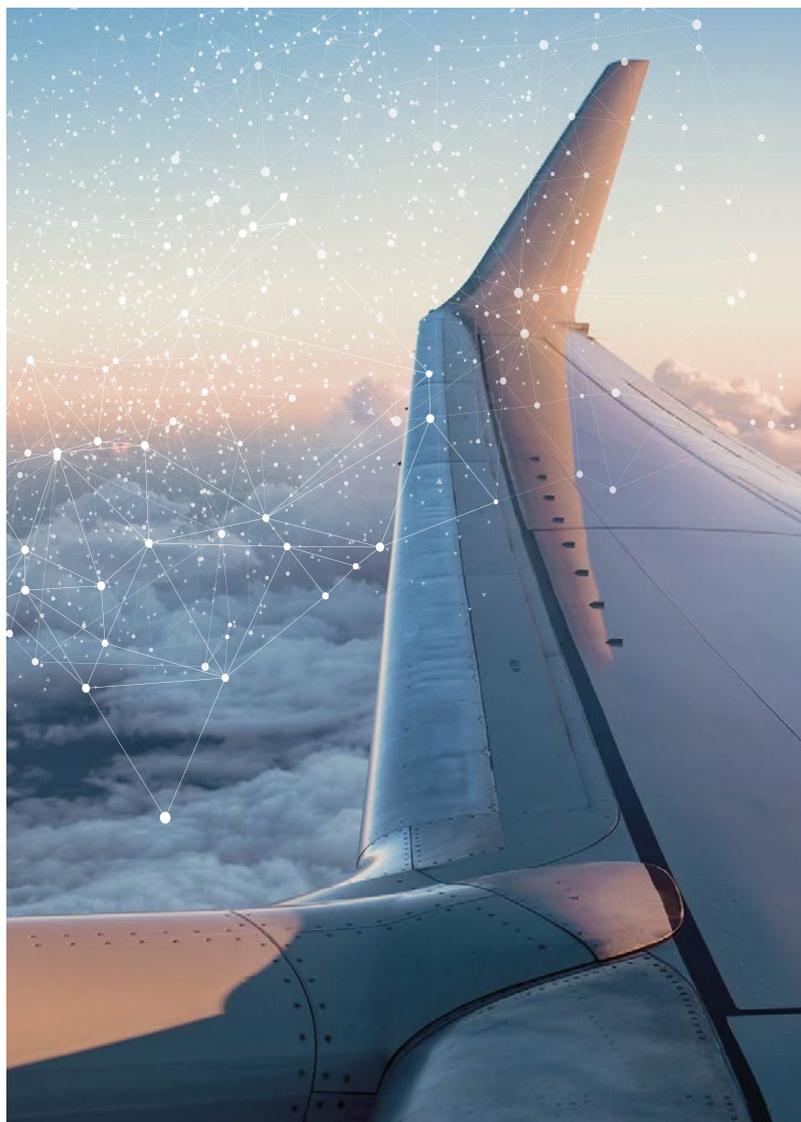


A SESAR exploratory research close-out meeting



*The results contained in this publication were made possible thanks to the dedication of researchers from across Europe and the oversight of the SESAR JU and its Scientific Committee.*

# Introduction



Since its establishment, the SESAR JU has conducted exploratory research activities aimed at expanding the boundaries of our knowledge on ATM and aviation in Europe. These activities are set with the context of an ever-changing aviation context and a broader programme of R&D work, which is delivering tangible solutions to improve all aspects of ATM performance.

## The changing world of aviation

The world of aviation is changing. Starting with the aircraft, which are set to become more autonomous, connected, intelligent and diverse. And then there is traffic, which is projected to grow significantly, from several thousand conventional aircraft to hundreds of thousands of air vehicles (such as drones), operating in all types of airspace, including cities. Added to that are increasing demands from passengers for smart and personalised mobility options that allow them to travel seamlessly and without delay.

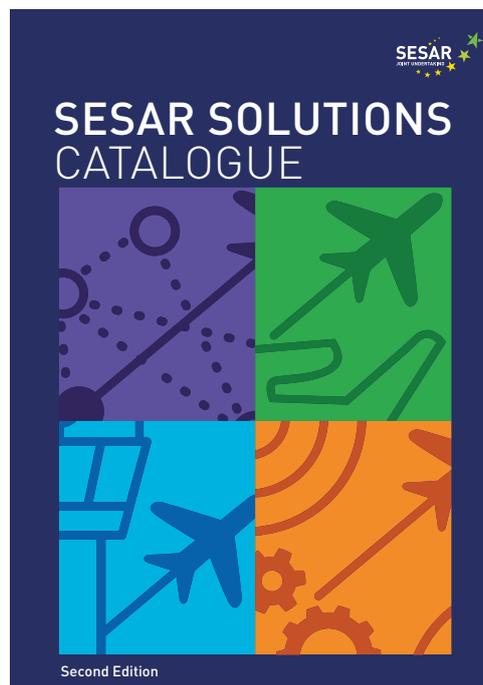
## From vision to reality

SESAR aims to deliver ATM system for Europe that is fit for the 21st century and capable of handling the growth and diversity of traffic safely and efficiently, while improving environmental performance. This vision relies on a concept of operations underpinned by technolo-

gies that enable improvements at every stage of the flight. Put simply, the vision sees the integration of all air vehicles with higher levels of autonomy and digital connectivity coupled with a more automated support for the management of the traffic. In this new paradigm, the vehicles will fly their optimum trajectories, relying on improved data sharing between vehicles and the ground infrastructure using mobile, terrestrial and satellite-based communication links. SESAR also addresses airport operational and technical system capacity and efficiency, introducing technologies such as satellite-based tools for more accurate navigation and landing, and mobile communications to improve safety on the airport surface. Meanwhile, data analytics and better data sharing through system-wide information management are allowing for better flight planning, airport operations and their integration into the overall Network.

## Delivering first building blocks for change

Since 2008, the SESAR JU has researched, validated and delivered a catalogue of more than 60 operational and technological solutions. These solutions are bringing tangible benefits in terms of enhanced safety, increased capacity, increased operational efficiency and resilience, lower running costs and an improved environmental footprint. Local implementations have already started, as well as synchronised deployment across 24 airports in Europe.



## SESAR 2020 and the innovation pipeline

Guided by the European ATM Master Plan, SESAR 2020 focuses on developing solutions in four key areas, namely airport operations, network operations, air traffic services and technology enablers. The programme also addresses emerging challenges such as the integration of drones and cyber security. The research is categorised into three strands: exploratory research, industrial research and validation and very large-scale demonstrations. These strands have been designed as an innovation pipeline through which ideas are transformed into tangible solutions for industrialisation.



## Exploring the boundaries

Through its exploratory research, the SESAR JU looks beyond the current R&D and what is already identified in the 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 JU is helping to future-proof Europe's aviation industry and to maintain its global competitive edge.

The key principles guiding SESAR 2020 exploratory research activities are:

- ▶ To bring together the brightest of minds in Europe to undertake research within but as well outside the scope of SESAR's industrial research programme;
- ▶ To consider innovations/technologies coming from non-ATM sectors, such as automotive, robotics, as well as in other safety critical industries, such as space, etc.;
- ▶ To foster a network of European ATM research capabilities and knowledge that will strengthen European competitiveness and its workforce;
- ▶ To create a mechanism in order to monitor and assess the maturity of exploratory research results and their integration into the SESAR innovation pipeline, where appropriate.

## What's beyond the horizon

Thanks to these building blocks and the innovation pipeline, SESAR is making progress towards more high performing aviation for Europe, underpinned by several key areas of R&D: automation, virtualisation, connectivity, data-sharing, and cybersecurity and safety. This progress is captured in the project results in this publication. With these results, SESAR enables the development of leaner, modular and more scalable systems that are easier to upgrade and interoperable with each other. In the longer term, virtualisation and the move towards "digitally connected aviation" will allow for more efficient and flexible use of resources, substantially improving safety and the cost efficiency of service provision and relieving congested airspace.

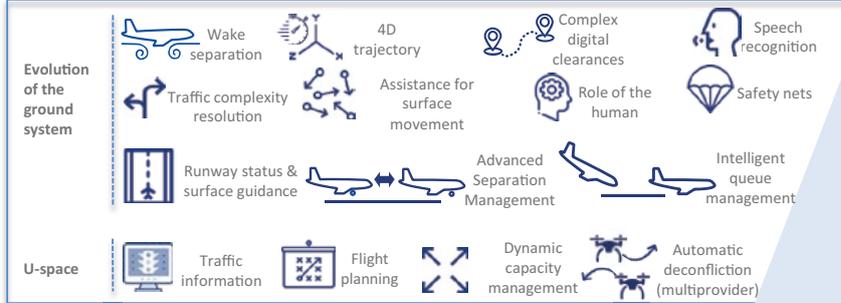
## SESAR innovations

## Coming next

### Airborne automation



### Ground automation



Automation levels

1

Human assistance

2

Partial automation

3

Conditional automation

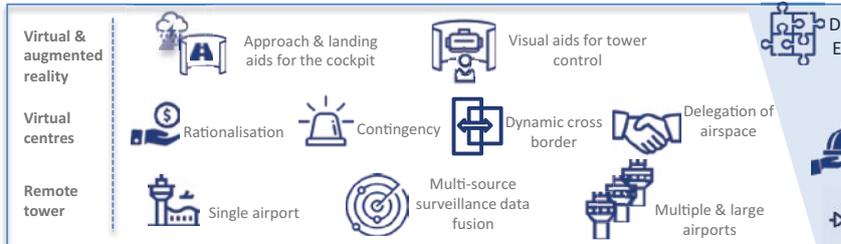
4

High automation

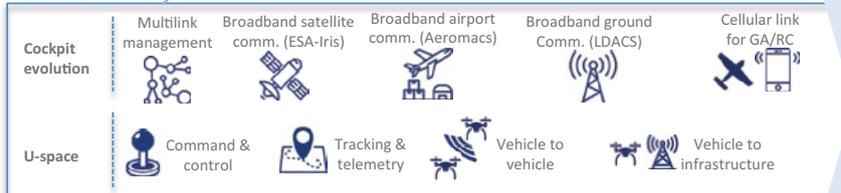
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Full automation

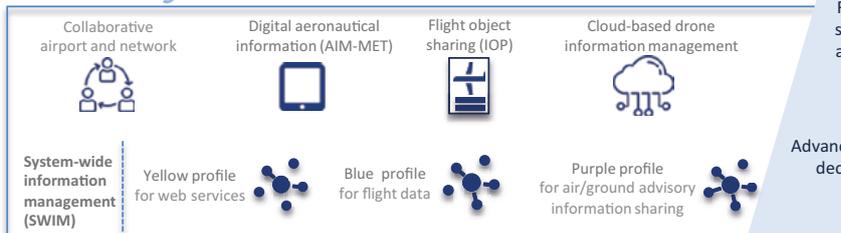
### Virtualisation



### Connectivity



### Data sharing



Urban air mobility

1  
Single pilot operations

Autonomous cargo

Digital cockpit assistant



Autonomous large passenger aircraft

Digital ground assistant



Emulating U-space

AI powered ATC environment

New standards for safety and security

Defragmented European Sky

Pan European service provision capability

All weather operations

CNS as a service

Fully dynamic airspace

Resilient operations

Pan European mobility of staff

Hyper connectivity for high automation

Next generation links

Internet of Things for aviation

Future data services and applications

Interconnected network

Passenger centric ATM

Advanced analytics for decision making

Open data

Multimodality

# What is in this publication?

Building on the exploratory research conducted in its first programme and following a call for proposals (ER1) in 2016 the SESAR JU selected and launched 28 projects for a total of EUR 20.4 million in funding within the framework the EU's Horizon 2020 research and innovation programme.

The projects covered a wide range of topics, which can be categorised into two streams:

## ATM EXCELLENCE SCIENCE AND OUTREACH

**ATM excellent science & outreach** aims at bridging ATM research and the wider research community and providing the necessary scientific support to ATM change either directly or indirectly to other funded research areas in other disciplines or sectors in the following areas:



### **Automation, robotics and autonomy**

ATM currently relies on high levels of human intervention in order to carry out essential controller tasks. Given the safety criticality of the industry, the uptake of automation has been slow. Several of the selected projects explored whether and in what ways automation could be used to deliver substantial and verifiable performance benefits while fully addressing safety concerns.



### **Complexity, data science and information management**

ATM is a complex business since the system is composed of systems within systems, each of which are designed and managed by different stakeholders. A number of projects made use of data science to explore the use of large datasets for the purpose of information management, knowledge creation and improved optimising planning and execution of ATM.



### **Environment and meteorology for ATM**

ATM has a critical role to play in reducing the environmental impact of aviation. This category of selected projects looks at different modelling tools with which to better assess and improve the environmental footprint of ATM/aviation. Projects were also selected to better understand the impact of weather phenomena and explore tools to better predict and integrate weather information into ATM processes.



### **Economics, legal and regulation**

Large parts of the European aviation ATM industry are undergoing significant changes in their institutional and economic structures due to market pressures, the emergence of new market entrants and innovation in business models. Projects in this category sought to better understand aviation market dynamics - taking into account economic, policy, regulatory and legal frameworks - and explore innovative business and operating models and drivers for sustainable growth.

## ATM APPLICATION ORIENTED RESEARCH

**ATM application-oriented research** aims to help mature new concepts for ATM beyond those identified in the European ATM Master Plan as well as help to mature emerging technologies and methods to the level of maturity required to feed the applied research conducted in the SESAR JU. This research theme addressed the following areas:



### **High-performing airport operations**

Airports in Europe are constrained by the availability of their busy runways. They are therefore in need of solutions to make their operations as efficient as possible. The selected projects looked at emerging technologies that can improve situational awareness for tower controllers, including new ways of displaying and presenting data on aircraft, vehicles and infrastructure in a manned airport visual control room (local or remote).



### **Advanced air traffic services**

The future European ATM system will be characterised by advanced service provision, underpinned by the development of automation tools to support controllers in routine tasks. With this in mind, the selected projects looked at tools to enhance and integrate departure and arrival processes, to support separation management, improve air and ground safety nets and systems to support flight planning with no reference to pre-defined waypoints.



### **Enabling aviation infrastructure**

Communication, navigation and surveillance (CNS) systems are the building blocks on which ATM operates. Despite many activities in the CNS domain there remain a number of areas where more fundamental research is needed, which were covered by several of the selected projects. These areas included assessing technologies developed outside ATM to support CNS and more flexible system architectures for ground and airborne systems, building on integrated modular avionics and an open interface approach to ground system development.



### **ATM operations, architecture, performance and validation**

Selected projects in this area looked at opportunities and limitations to trajectory-based operations; ATM architecture using novel approaches from systems analysis, architecture or complexity science; and tools to allow for the micro and macro modelling of performance in ATM, capable of capturing the interdependencies between different key performance Areas (KPAs).

The selected projects brought together of 80 academic and industry partners, such as universities, SMEs, research centres, airlines, manufacturers, air navigation service providers from across the European Union and EU Associated Countries (Switzerland, Norway, Iceland, Serbia, Israel, Turkey).



# ATM excellence science and outreach



**AUTOMATION,  
ROBOTICS AND  
AUTONOMY**



**COMPLEXITY,  
DATA SCIENCE  
AND  
INFORMATION  
MANAGEMENT**



**ENVIRONMENT  
AND  
METEOROLOGY  
FOR ATM**



**ECONOMICS,  
LEGAL AND  
REGULATION**

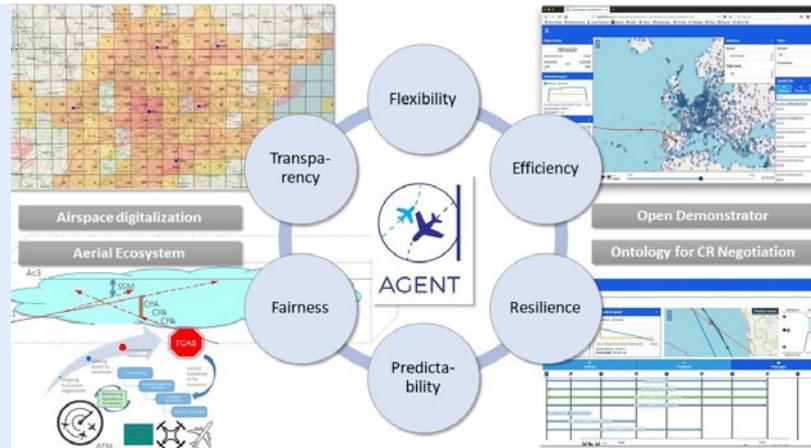


# Improving conflict detection and avoidance

Adaptive self-governed aerial ecosystem by negotiated traffic – AGENT

### Project Partners

- ASLOGIC 2011
- Cranfield University
- Technische Universität Braunschweig
- Universitat Autònoma de Barcelona (Coordinator)



### Benefits

- Better conflict and collision avoidance resolution
- Increased situational awareness of forecasted collision
- Improved airspace capacity
- Maintained levels of safety

As the demand for air travel increases, so does the need to adapt the current traffic alert and collision avoidance system in order to preserve high levels of safety while improving airspace capacity and efficiency.

With this in mind, the AGENT project researched and developed a framework, proposing trajectory manoeuvres that take into account interdependencies between human behaviour, automation and aircraft performance.

The framework provides air traffic controllers and pilots with the means to deal with situations of conflict between planes by allowing them to choose the best solution when changing trajectories according to specific characteristics of each conflict. The framework is designed to be cooperative, as the proposed solutions factor in the interests of all parties involved.

The framework opens up the possibility of creating new connections between cities, increasing flight frequencies and avoiding fuel consumption due to unnecessary manoeuvres, which will in turn reduce emissions and fuel costs.

An open demonstrator has been implemented to validate the framework and allow scientific community to test their own tools. Results achieved in remotely-piloted aircraft systems (RPAS) missions confirms the potential benefits of AGENT framework in the configuration of U-space.

**More information: [www.agent-aero.eu](http://www.agent-aero.eu)**



# Preparing the ATM workforce for an automated future



Facilitating the automation pace - AUTOPACE



## Project Partners

Alma Mater Studiorum -  
Universita' di Bologna

Centro de Referencia Investigacion,  
Desarrollo e Innovacion ATM (CRIDA)  
(Coordinator)

Universidad de Granada

Universidad Politecnica de Madrid

Univerzitet u Beogradu -  
Saobracajni fakultet

The progressive introduction of automation is changing ATM and in particular the way controllers work today. Controllers will focus on monitoring and supervising the system, with a minimum of tactical interventions. However, a challenge to automation is keeping the human in the loop, building trust and overcoming the fear of system failure.

AUTOPACE researched the skills and training strategies that will be necessary to address the challenges associated with automation and to enable controllers to do their job. The project first defined the most likely future operational scenarios in a 2050 timeframe for nominal and non-nominal situations. The project then developed a psychological model to better understand how human cognition and automation interact. With that the project was able to define a preliminary safety assessment detailing potential hazards for training strategies refinement.

The results of the project suggest that in the future, air traffic controllers should be offered not just technical training, but also psychological training covering: (a) cognitive training - to boost the use of appropriate cognitive processes to correctly monitor the system and (b) non-cognitive training - such as biofeedback to teach controllers to self-detect when their performance is decreasing and to react as needed.

The results of the AUTOPACE project are ready to be taken further into applied and industrial research.

**More information: [www.autopace.eu](http://www.autopace.eu)**

**Automation is changing ATM and in particular the way controllers work today**

**AUTOPACE proposes new controller training strategies to acquire not only technical competences but also psychological competences handling automated systems**

## Benefits

- Adapted training, equipping controllers with competences to work in automated environments
- Improved efficiency, by offering training of new competences in controlled simulation environments
- Enhanced safety



## Keeping an eagle eye on automation

Mitigating negative impacts of monitoring high levels of automation - MINIMA

### Project Partners

Alma Mater Studiorum -  
Università di Bologna

Deutsches Zentrum für Luft-  
und Raumfahrt (Coordinator)

Office national d'études et  
de recherches aérospatiales  
(ONERA)



### Benefits

- Improved interaction between controllers and automated system
- Increased levels of vigilance and situational awareness
- Improved safety and performance

Increasing automation in air traffic control is considered essential to improve the performance of Europe's air traffic management system. The challenge is to ensure that air traffic controllers remain in the loop to monitor effectively the system and step in when the task becomes too complex to handle for the automated system. However, experience in other domains shows that such a monitoring role can lower the attention span or results in a loss of situational awareness and skills.

With this in mind, the MINIMA project developed a vigilance and attention controller (VAC) tool using electroencephalography, which can measure in real-time controller vigilance and triggers adaptive automation functionalities when vigilance is waning.

The tool was tested by 15 controllers using two similar realistic scenarios: the first was a baseline scenario with the highest level of automation while the second scenario used the VAC tool to monitor and adapt the automation functionalities subject to vigilance levels. The VAC proved to successfully identify episodes of decreasing controller vigilance, and re-increase it through its adaptive automation system. The tool helped to introduce a level of interaction between the controllers and the system, making tasks more stimulating for the controllers.

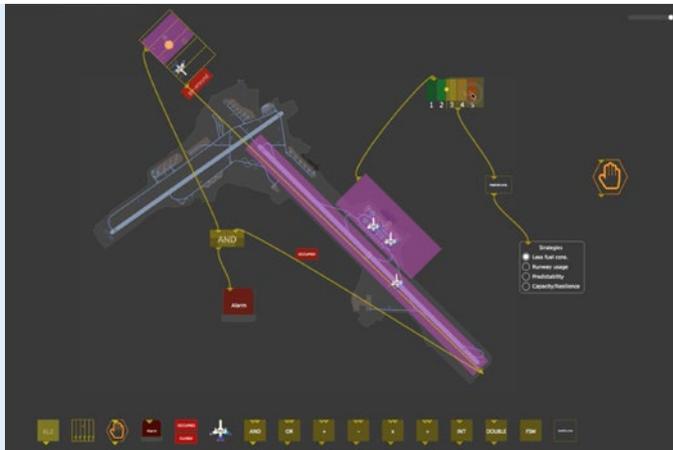
As a next step towards operational usability, researchers are looking at how to make the VAC more comfortable, easier to use and configure.

**More information: [www.minima-project.eu](http://www.minima-project.eu)**



# Taking control of airport complexity

Take control - TaCo



## Project Partners

Deep Blue (Coordinator)

Ecole Nationale de l'Aviation Civile (ENAC)

Malta Air Traffic Services Limited (MATS)

Airports are complex places, especially when it comes to managing the movements of civil and military aircraft and a myriad of service vehicles. It is not surprising then that SESAR members and partners have invested significant effort to research, develop and deliver a first set of automated tools to support controllers in managing airport surface movements.

The TaCo project took a fresh look at the challenge of complex surface operations especially in non-nominal conditions by exploring automation in other disciplines, such as robotics and gaming. Like air traffic control tools, video games such as real-time strategy games, use highly interactive graphics to enable gamers to manage the course of the game.

With these insights, TaCo partners developed a tool for guiding the controllers towards an optimised management of the movements of airport vehicles and aircraft: for example, it supports them in maximising the usage of the runway and minimising the global fuel consumption.

Moreover, the TaCo tool allows controllers to define the behaviour of alarms and automation through innovative user-programming techniques by using a domain specific graphic language. This tool can capture user requirements during the design phase of automation and has the potential to be applied to modify automation in real-time during operations.

The early results from TaCo indicate that automation strategies might be a valuable benefit in nominal circumstances even in airports that are not categorised as highly complex. In spite of the singularity of each airport, having a support tool that assists the controllers in achieving an optimised management of the movements is a transversal need that can be fulfilled by TaCo-like systems with no major changes in the concept.

**More information: [www.tacoproject.eu](http://www.tacoproject.eu)**

## Benefits

- Optimised management of airport surface operations
- Increased airport throughput
- Reduced fuel consumption



# Taking the stress out of automation

Human performance neurometrics toolbox for highly automated systems design – STRESS

## Project Partners

- Anadolu University
- Deep Blue (Coordinator)
- ENAC
- Eurocontrol
- Università degli studi di Roma La Sapienza



## Benefits

- Enhanced real-time assessment of the impact of automation on human performance
- Improved design of automation tools

STRESS examined the human performance issues, benefits and impacts of the shift towards increased automation. This refers to a new generation of air traffic control systems, expected to (partially) autonomously manage decision making and implementation tasks, currently carried out by air traffic controllers. The latter will still be responsible for running the system safely, but their role would be shifted from that of an active controller to one more like that of a monitor.

To tackle this topic, STRESS focused on the future human performance envelope (HPE) configuration. Based on the expected future controllers' role, STRESS chose vigilance, attention, mental workload, type of cognitive control on tasks and stress as relevant human factors to investigate, and developed neurophysiologic indicators for all of them. To study the impact of automation levels on the air traffic controllers' HPE, STRESS measured the neurophysiological signals of air traffic controllers' vigilance, attention, workload, stress and type of cognitive control during the execution of operational tasks, in a simulated air traffic control environment reproducing the complexity of future airspace scenarios and associated supporting technologies. As a result, the project provided automation design guidelines based on the HPE status.

The project delivered the following resources;

- Future ATC scenarios, including highly automated supporting technologies;
- A customised neurophysiological measurement toolbox for the future ATM, capable of monitoring the HP envelope in real time;
- Guidelines for the design of innovative technologies that are compatible with human capabilities and limitations.

The project's findings aim to provide insights into change management and the introduction of new systems. These insights aim to provide guidance not only for human performance assessment, but also for operational training design and delivery, as well as for the design of optimal competence profiles.

**More information: [www.stressproject.eu](http://www.stressproject.eu)**



## Seeing the bigger picture

Passenger-centric big data sources for socio-economic and behavioural research in ATM - BigData4ATM



### Project Partners

Agencia estatal consejo superior de investigaciones científicas (CSIC)

Fraunhofer-Gesellschaft

Ingeniería de Sistemas para la Defensa de España (ISDEFE)

Nommon Solutions and Technologies (Coordinator)

The Hebrew University of Jerusalem

Universitat de les illes Balears

Air transport performance objectives and decision-making processes have often overlooked the passenger perspective, mainly due to the difficulties to collect accurate, updated and reliable data on passenger needs and behaviour. The BigData4ATM project investigated how new data sources coming from smart personal devices can be used to overcome this lack of information. The project objectives were to:

- Explore and characterise new emerging data sources potentially useful for ATM socioeconomic studies.
- Develop methodologies that integrate and analyse multiple sources of data to extract passengers' behavioural patterns.
- Develop theoretical models translating these behavioural patterns into relevant and actionable indicators.
- Evaluate the potential applications of the new data sources through a number of relevant case studies.

**Passengers will benefit from a more efficient and predictable ATM system, enhancing the air transport experience**

**The use of big data sources from personal devices provides richer information about passenger behaviour at a reduced cost**

### Benefits

- Richer information on passenger behaviour
- Characterisation of door-to-door passenger journey
- Improved air traffic forecasts
- Better integration of air transport with other transport modes
- Enhanced coordination of airport landside and airside
- More efficient use of airport resources

The project successfully developed new approaches to characterise airport catchment areas, analyse the door-to-door passenger journey, and assess the impact of ATM disruptions on passenger behaviour. The insights gained from this information are expected to result in better integration of air transport with other transport modes, as well as in a more efficient coordination of airport landside and airside operations.

The project results show that new, unconventional data coming from smart personal devices open unprecedented opportunities for building a truly passenger-centric air transport system. Next steps will involve the application of the concepts and methodologies developed in BigData4ATM in one or more specific airports, which would work as a test environment to evaluate the benefits and practical implementation issues of the newly proposed solutions.

**More information: [www.bigdata4atm.eu](http://www.bigdata4atm.eu)**



# Trajectory prediction – letting the machine do the math

Data driven aircraft trajectory prediction research - DART

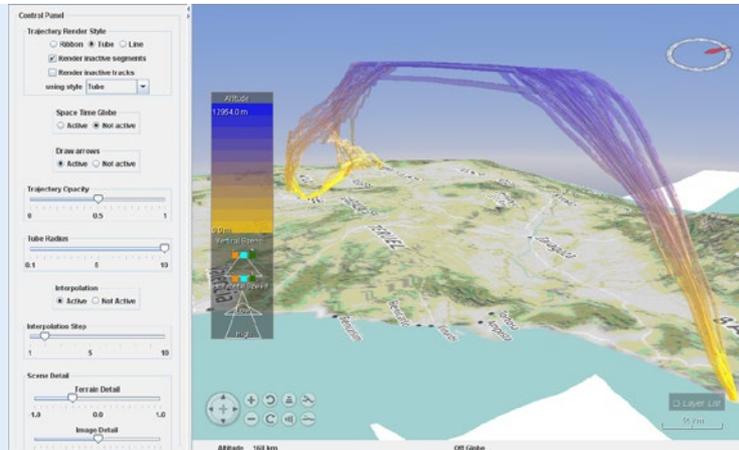
## Project Partners

Boeing Research and Technology Europe (BRTE)

CRIDA

Fraunhofer-Gesellschaft

University of Piraeus Research Center (Coordinator)



## Benefits

- Increased predictability
- Reduced delays thanks to early resolution of DCB issues
- Advancing collaborative-decision making and planning tools

The complex ATM system worldwide has reached its limits in terms of predictability, efficiency and cost effectiveness. DART explored the potential of data-driven techniques for trajectory prediction, and agent-based modelling approaches for assessing the impact of traffic to individual trajectories, thus accounting for ATM complex phenomena.

**DART delivered machine learning techniques to improve the accuracy of trajectory predictions, accounting for ATM network complexity effects**

Improvements with consequent benefits in these emerging areas of research can support the trajectory-based operations (TBO) paradigm.

The project focused on providing answers to the following major questions:

- What are the supporting data required for accurate trajectory predictions?
- What is the potential of machine learning algorithms to support high-fidelity aircraft trajectory prediction?
- How does the complex nature of the ATM system impact trajectory predictions?
- How can this insight be used to optimise the ATM system?

DART explored the potential of machine learning methods using historical data to increase the predictability for individual trajectories, and multi-agent collaborative reinforcement learning methods to resolve demand-capacity balancing (DCB) problems, supporting the incorporation of stakeholders' preferences into the planning process.

Results suggest that data-driven methods, compared to model-based approaches, can enhance trajectory prediction capabilities by exploiting patterns derived from historical data. In addition to that, agent-based methods can regulate flights effectively, reducing imposed delays, while resolving DCB problems.

**DART shapes the future towards collaborative decision-making processes among the stakeholders in the ATM system**

The DART developments pave the way towards advanced collaborative decision-making processes that support multi-objective optimisation taking the requirements of the different stakeholders in the ATM system into account at the planning phase.

**More information: <http://dart-research.eu>**



# Improving ATM efficiency through artificial intelligence



Machine learning of speech recognition models for controller assistance – MALORCA



## Project Partners

Austro Control

Air Navigation Services of the Czech Republic (ANS CR)

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

Fondation de l'Institut de Recherche IDIAP

Universität des Saarlandes (USAAR)

Significant progress has been made in recent years in artificial intelligence (AI) and in particular in machine learning applications like automatic speech recognition (ASR). Thanks to these advances, new technologies are emerging in a variety of domains, including aviation.

Nowadays, instructions from air traffic control (ATC) to pilots are usually given via voice communication. Automatic speech recognition can be used to convert the spoken words into text and extract the relevant information. It therefore offers the means to avoid the manual input of given ATC commands. The MALORCA project is a natural follow-up of the following speech recognition projects:

- AcListant®, which combines ASR with a controller assistance system resulting in an assistant based speech recognizer (ABSR). Command recognition rates of 95% were achieved.
- AcListant®-Strips, based on AcListant® enables greater arrival throughput by reducing controllers' workload for manual system input. Tested for Dusseldorf approach, the system allowed up to two more landings per hour.

However, there is a snitch in that these systems require manual adaptation for their deployment in new environments. To overcome this, the project designed a low-cost solution that adapts the speech recognition tools for use at other airports or approach areas. The solution automatically learns local acoustic and semantic patterns and controller models from radar and speech data recordings which are then automatically introduced into the ASR software.

The MALORCA project proposed to overcome the need for significant expert knowledge by employing novel machine learning algorithms that allow a semi-automatic adaptation of the initial basic ABSR system to a target-domain (i.e. Prague and Vienna approach).

The performance of the trained ABSR system was successfully evaluated by air traffic controllers in Vienna and Prague in January 2018. The next logical step is to bring the ABSR technology, continuously learning from daily-recorded data, into the ops room.

**More information: [www.malorca-project.de](http://www.malorca-project.de) and [www.aclistant.de](http://www.aclistant.de)**

## Benefits

- **Reduces command recognition error rates of the baseline system from 7.9% to under 0.6% for Prague approach and from 18.9% to 3.2% for Vienna approach**



# Getting the “best” from data sharing

Achieving the benefits of SWIM by making smart use of semantic technologies – BEST

## Project Partners

- Eurocontrol
- Frequentis AG
- Slot Consulting
- SINTEF (Coordinator)
- Universität Linz



## Benefits

- Better understanding of the potential for using semantic technologies in ATM information management
- Enables filtering and distribution of information using meta-data
- Partial automation of (currently labour-intensive) compliance validation processes
- Automated modularisation, with potential benefits for governance
- Better understanding of scalability issues

### SEMANTIC CONTAINERS:

These can be combined with SWIM services to associate meta-data with ATM information, making it easier to find exactly the information required, and to automate its distribution and replication

OWL: short name for the web ontology language – a language for representing rich and complex knowledge about things as an ontology, in a form that be directly processed by computer software

Better and more accurate data exchange is critical for delivering high performance ATM and aviation worldwide. System-wide information management (SWIM) is a key enabler in this endeavour, providing the framework to allow seamless digital information sharing between the right stakeholders at the right time, no matter where they are located in the world.

However, the full benefits of SWIM can only be achieved if advanced support can be provided for developing smart SWIM-based applications that manage information effectively, and semantic technologies offer a promising way to do that. With this in mind, the BEST project investigated how semantic technologies can be used effectively to maximise the benefits of adopting SWIM.

Based on several use cases, the project produced guidelines about how to use ontologies in flexible ways to describe meta-data, and how these can

be used in innovative yet scalable ways. The project also demonstrated how the ATM information reference model (AIRM) and various data exchange models can be transformed into web ontology language (OWL) representations, allowing these models to be processed by semantic technologies.

The project produced tools to automate the transformation process, as well as compliance validation tools to automate consistency checking between different models. The project also developed a modularisation tool, allowing large and complex models (such as AIRM) to be automatically split into smaller, more manageable units.

**More information: <http://project-best.eu>**



# Minimising the environmental impact of aviation



Air traffic management for environment - ATM4E



## Project Partners

DLR (Coordinator)

Envisa

Technische Universität Hamburg

Technische Universiteit Delft

Manchester Metropolitan University

The University of Reading

With the increase in traffic in Europe, stakeholders are looking for ways to reduce the environmental impact of aviation, taking into account climate impact, air quality and noise issues simultaneously. However, comprehensive assessments with data on all three environmental aspects are not available for flight planning.

To address the situation, the ATM4E project developed a methodology to integrate multi environmental criteria into impact assessments done during the flight planning process. The method expands a concept developed for climate optimisation of aircraft trajectories, by introducing air quality and noise impact as additional criteria or dimensions, together with the climate impact of aircraft trajectory (CO<sub>2</sub> and non-CO<sub>2</sub> emissions).

The project also developed algorithms to determine environmental impacts based on meteorological information available through the system-wide information management (SWIM). Results showed that depending on the prevailing weather situation, high resolution environmental information provided as part of the MET service could enable the optimisation of aircraft trajectories with the potential to reduce the climate impact by around 20% for specific routes.

The results suggest that identifying those routes with a large reduction potential enables aviation to improve considerably its environmental performance.

**More information: [www.atm4e.eu](http://www.atm4e.eu)**

**Assessing environmental impact of aviation during flight planning is a prerequisite for environmental optimisation of aircraft operations**

**Climate optimisation could lead to climate impact reduction of more than 20% with 1% fuel penalty**

## Benefits

- Improved environmental information
- Improved air quality
- Better environmental performance



# Weathering the weather at airports

Probabilistic Nowcasting of Winter Weather for Airports - PNOWWA

## Project Partners

Austro Control

DLR

Finnish Meteorological Institute (FMI) (Coordinator)



## Benefits

- Increased airport capacity (e.g. fewer delays, better ATM preparedness)
- Improved safety
- More efficient use of ATM resources

Adverse weather conditions can play havoc with airport operations, limiting or putting a stop to aircraft movements, runway maintenance, de-icing, tower control and even luggage handling. Having accurate meteorological data and forecasts means that airport operators can prepare for the worst in advance. But weather can change in a matter of hours. That is why partners in the PNOWWA project are turning to nowcasting, very short-term (0-3h) probabilistic winter weather forecasts with a 15-minute-time resolution.

**The use of probabilistic forecasts in ATM are to support timely operations in surface management and ATM decision making, thereby increasing airport capacity, reducing delays and promoting safety**

Focusing on snow, the partners extrapolated weather movements based on radar echoes and predictability of changes in snowfall intensity caused by underlying terrain (such as mountains and seas). Within these nowcasts, the projects provided information on the probability of a wide range of events, such as runways freezing over or decreased visibility. Over the course of the winter of 2017, the project partners demonstrated their model in Austria and Finland, allowing them to

gather airport feedback on the applicability of the model and its scalability to other airports.

These results enable the quantification of the uncertainties related to delays in ground operations due to winter weather situations. When applied to ATM applications, the PNOWWA method will enhance timely operations in surface management and ATM decision making, thereby increasing airport capacity, reducing delays and promoting safety.

**More information: <http://pnowwa.fmi.fi>**



# Mastering meteorological uncertainty in aviation



Meteorological uncertainty management for trajectory-based operations – TBO-Met



## Project Partners

Agencia Estatal de Meteorología

MeteoSolutions

Paris-Lodron-Universität Salzburg

Universidad Carlos III de Madrid

Universidad de Sevilla (Coordinator)

A better understanding of the factors that lead to uncertainty in air traffic is key when planning, executing, monitoring and synchronising trajectories between ground systems and aircraft. Having more accurate trajectories that factor in uncertainty can in turn increase the predictability of traffic, which has knock on benefits such as increased capacity, improved efficiency and reduced environmental impact.

To this end, the TBO-Met project focused on three research topics: trajectory planning, storm avoidance, and sector demand analysis, considering meteorological forecast uncertainties. The weather forecasts were obtained from ensemble prediction systems and nowcasts, which provide information about wind uncertainty and convective zones (including individual storm cells).

To address mid-term trajectory planning, the project developed a stochastic optimisation approach to plan the most efficient trajectories with low levels of uncertainty. The methodology is capable of trading-off predictability and cost efficiency (flight time or fuel consumption). To address storm avoidance, the project developed a probabilistic trajectory predictor, which proactively proposes possible deviations in order to avoid stormy conditions. As for addressing sector demand, the project defined a methodology to provide a probabilistic sector demand based on the uncertainty of the individual trajectories. The approach is able to quantify the impact of improved trajectory planning considering weather forecast uncertainty on sector demand.

The overall conclusion of the project is that ATM efficiency can be enhanced by integrating weather forecast uncertainty.

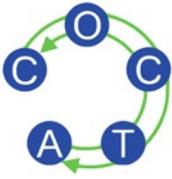
**More information:** <https://tbomet-h2020.com>

**When meteorological uncertainty is taken into account, the results show that:**

- the predictability of aircraft trajectories can be increased
- storm avoidance can be better anticipated
- the prediction of sector demand can be improved

## Benefits

- Reduction of airlines' buffer times
- Better-informed decision making
- Increase of declared sector capacities
- Better identification of demand-capacity balancing measures



## Flexible and efficient ATM service provision in Europe

Coordinated capacity ordering and trajectory pricing for better-performing ATM - COCTA

### Project Partners

Hochschule Worms

University of Warwick

Univerzitet u Beogradu -  
Saobracajni fakultet  
(Coordinator)



### Benefits

- **More efficient provision of air navigation services**
- **Increased choice for airspace users**
- **Incentives for reduced CO<sub>2</sub> emissions**

Air navigation service providers (ANSPs) have to decide on their capacity provision for a particular day of operation several weeks or even months in advance, whereas airspace users need flexibility in flight planning and prefer to make their route choice decisions at shorter notice. This contributes to a mismatch between planned capacity and actual demand in the European ATM system.

To tackle this problem, the COCTA project developed an innovative conceptual framework to improve efficiency of air navigation service provision in Europe by a better coordination of capacity and demand management:

On the capacity side, the Network Manager asks for airspace capacities in line with expected demand, employing a network-centred, demand-driven approach, as opposed to the current, largely supply-driven and piecemeal practice, with predominantly local (ANSP) perspectives.

**Network-oriented capacity planning improves the overall cost efficiency of ATM in Europe**

**Innovative trajectory products/options enable airspace users to prioritise flights within the network in a fair and transparent manner**

On the demand side, the Network Manager offers different trajectory options to the airspace users, including novel concepts of flexible trajectories. One option is for an airspace user to pay less in exchange for granting the Network Manager some flexibility to move the flight with pre-determined spatial and temporal margins. Another option allows airspace users to decide on a flight trajectory within certain margins shortly prior to departure and for a premium. These trajectory options or products are tailored to capture the different business and operational needs of airspace users, thereby contributing to an optimised network performance.

The project studied the potential improvements achievable through the proposed framework, as well as trade-offs between the different key performance indicators (KPIs) in a large-scale case study. According to initial results, the framework could accommodate the same traffic volume with significantly reduced capacity and dramatically reduced cumulative delay in the network.

**More information: [www.cocta-project.eu](http://www.cocta-project.eu)**



# An appetite to compete

## Competition for Air Traffic Management - COMPAIR



### Project Partners

Nommon Solutions and Technologies

Slot Consulting

The Hebrew University of Jerusalem

Transport & Mobility Leuven (Coordinator)

Europe is a patchwork of markets in ATM service provision. The question is: which market structure is most favourable to increasing the performance of ATM, including airports? The answer is a complex one that partners in the COMPAIR project addressed. Partners in the project looked at a number of options that could increase competition, including performance regulation with variations in ownership and governance models, tender of licenses for en-route air traffic services, and flight centric, sector-less operations. The project also analysed the effects of unbundling the terminal control in Sweden, UK, Spain and Germany (at mostly regional airports).

The models applied by the project suggest that introducing competition in the market via outsourcing service provision may lead to a reduction in charges by up to half the current levels. It also showed that open tendering is likely to lead to a defragmentation of the system as companies tend to win more than one tender. The results suggest that with these options a maximum allowed market share of 40% can ensure sufficient competition. Competition of this nature will determine the uptake of new technologies and enable a high performing ATM system.

**ATM providers competing on a per-flight basis (from origin to destination) or per-airline, rather than per geographical zone could lead to a significant reduction in costs and requires advanced technology development**

### Benefits

- Increased efficiency of service provision
- Increased technology uptake
- Decreased fragmentation for some of the considered scenarios

**More information: [www.compair-project.eu](http://www.compair-project.eu)**

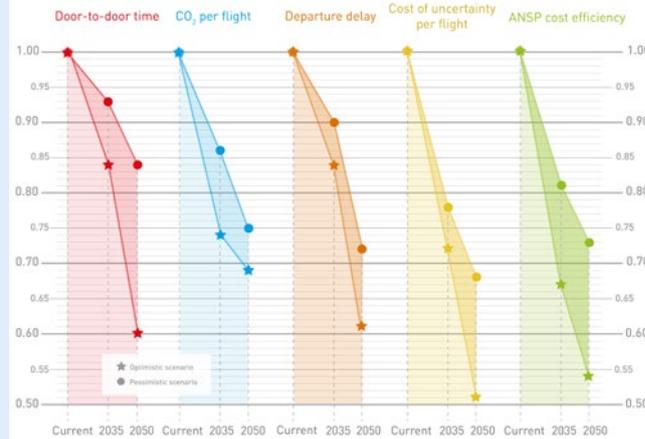


# Evaluating trade-offs in air traffic management

Market forces trade-offs impacting European ATM performance - Vista

## Project Partners

- Belgocontrol
- Eurocontrol
- Fundacion Instituto de Investigacion Innaxis
- Icelandair
- Norwegian Air Shuttle
- Swiss International Air Lines
- University of Westminster (Coordinator)



## Benefits

- Flexible, modular 'what-if' simulator
- Demonstrated KPA synergies & conflicts
- Supported policy evaluation & target setting
- Current, 2035 & 2050 scenarios

What are the main trade-offs in air traffic management between the various key performance areas? The Vista project examined the effects of market forces (e.g. fuel prices, economic development), technologies and regulatory factors on European performance in ATM, through the evaluation of stakeholder and environmental indicators. Trade-offs were assessed and visualised within and between periods, and between stakeholders.

The tool evaluated indicators for airspace users, passengers, airports, air navigation service providers and the environment

New indicators were evaluated, such as door-to-door travel times, tactical costs of uncertainty incurred by airspace users, NO<sub>x</sub> emissions, delay costs and reactionary effects

Vista models current and future timeframes, based on the evolution of these effects. The Vista model is holistic since it covers the three phases of ATM - strategic, pre-tactical and tactical. It captures a typical, busy day of operations. The model was able to estimate the impact of the above-mentioned factors on these different ATM phases independently and/or as a coupled system, providing a unique assessment of how indicators change in different scenarios and execution phases.

The model may readily be extended to support decision-making and network analysis. Furthermore, the tool may be used to simulate and assess long-term traffic and capacity projections.

**More information: [www.vista-eu.com](http://www.vista-eu.com)**

# ATM application oriented research



HIGH-  
PERFORMING  
AIRPORT  
OPERATIONS



ADVANCED  
AIR TRAFFIC  
SERVICES



ENABLING  
AVIATION  
INFRASTRUCTURE



ATM  
OPERATIONS,  
ARCHITECTURE,  
PERFORMANCE  
AND VALIDATION



## A fully immersive airport tower experience

The embodied remote tower - MOTO

### Project Partners

Deep Blue (Coordinator)

ENAC

Rijksuniversiteit Groningen

Universita' degli studi di Roma  
La Sapienza



### Benefits

- **Multimodal platform for VR simulation of tower operations to validate future augmented remote tower concept**
- **Neuro-physiological classifiers to monitor the sense of presence and human performance in remote towers**
- **Prototypes of augmented multimodal solutions to support remote tower operations**

Europe is experiencing rapid growth in the number of remote control tower deployment projects in recent years. With advances in camera, sensor and infrared technology, controllers are given a realistic “out-of-the-window” view of the remotely-located airport allowing remote provision of all tower services. SESAR researchers are now investigating how to make this virtual experience even more immersive by exploiting controllers’ senses in addition to their visual sight.

The project explored the introduction of multimodal stimuli (auditory and vibrotactile), designing dedicated augmented prototypes aimed at supporting controllers performance in remote tower operations. Partners measured the impact of these stimuli, in terms of workload, performance, sense of presence and situational awareness.

Initial outcomes suggest that spatialised audio information may support controllers shifting attention towards potentially critical events, improving performance but, at the same time, requiring more resources (higher workload). Additional human-in-the-loop studies are recommended to further explore the obtained results in a wider range of operative scenarios.

The project also explored the advantages in the use of virtual reality and head mounted display (HMD) technologies to validate the impact of multimodal stimuli in remote tower operations. These advantages deriving from these technologies can also offer benefits for exploration of innovative ATM concepts and scenarios for future training activities.

**More information: [www.moto-project.eu](http://www.moto-project.eu)**



# Keeping an augmented eye on air traffic control



Resilient synthetic vision for advanced control tower air navigation service provision - RETINA



### Project Partners

Alma Mater Studiorum  
Universita' di Bologna (Coordinator)

CRIDA

Consorzio SICTA - Sistemi Innovativi  
per il Controllo del Traffico Aereo

ENAV

Eurocontrol

Luciad

Controllers in airport towers rely on being able to see aircraft taxiing, taking off and landing in order to manage them safely and efficiently. But when bad weather sets in, their visual situational awareness can be impaired, leading to a reduction in throughput. The results from the RETINA project are showing the promise that augmented reality holds for enhancing air traffic control operations, particularly in low-visibility conditions.

**As trust in digital data grows RETINA's concept will allow the controller to have a heads-up view of the airport traffic even in low visibility conditions similar to the synthetic vision currently used in the cockpit**

### Benefits

- Improved situational awareness for controllers
- Increased airport capacity and throughput
- Improved flight punctuality and reduced emissions

Using synthetic vision and augmented reality technologies, RETINA has developed a set of goggles through which controllers can see synthetic information overlaid on the actual "out-of-the-window" view. With these goggles, the controller can have a heads-up view of the airport traffic, call sign and aircraft type, supplemented by additional information, such as wind velocity and direction, airport layout and runway status, even during low-visibility procedures.

**RETINA builds upon SESAR technologies, such as remote tower, safety nets, SWIM, to provide augmented reality tools for the tower controller**

From a technological perspective, RETINA investigated two different augmented reality systems: conformal head-up displays (to coincide with the tower windows) and see-through head-mounted displays.

For each augmented reality system, a proof-of-concept was implemented and validated in a laboratory environment by means of human-in-the loop real-time simulations where the external view was provided to the user through a high fidelity 4D model in an immersive environment that replicated the out-of-the tower view.

During the validation, both subjective qualitative information and objective quantitative data were collected and analysed to assess the RETINA concept. The results showed that the RETINA concept is a promising solution to improve the human performance in the control tower, increasing resiliency at airports to low visibility and preserving safety.

**More information: [www.retina-atm.eu](http://www.retina-atm.eu)**



# Improving trajectory prediction through understanding uncertainty

Combining probable trajectories – COPTRA

## Project Partners

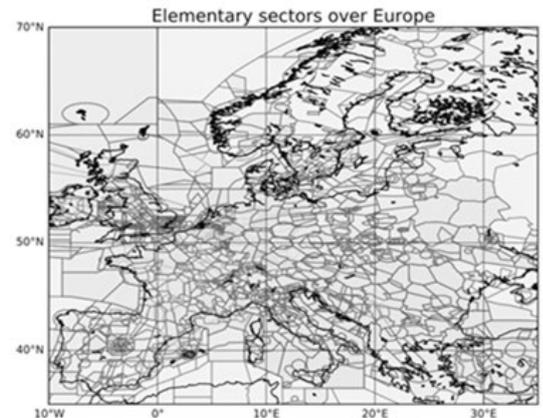
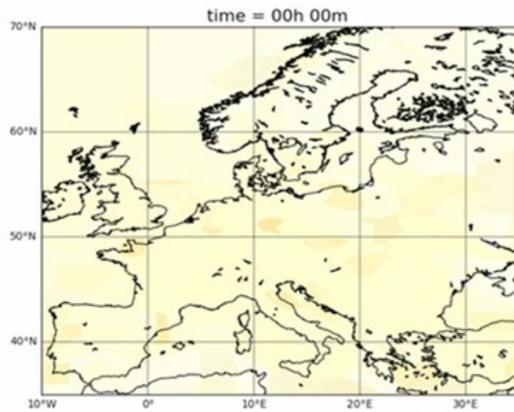
Boeing Research & Technology Europe (BRTE)

CRIDA (Coordinator)

Eurocontrol

Istanbul Teknik Universitesi

Universite Catholique de Louvain



## Benefits

- Visualisation of uncertainty
- More accurate and stable demand prediction
- Quantitative understanding of delay propagation dynamics in space and time

ATM is gradually moving towards the notion of allowing aircraft to fly their preferred trajectory, otherwise known as trajectory-based operations. One of the challenges related to the implementation of TBO is the ability to identify, model and manage the uncertainty associated to a trajectory.

**The work performed in COPTRA to model uncertainty, allows us to be certain of our uncertainty**

The integration of the uncertainty models in the planning systems improves the trajectory predictions and supports the assessment of the feasibility of integrating the models into existing demand and capacity balancing (DCB) tools. The COPTRA project researched three areas related to uncertainty modelling:

- Defining and assessing probabilistic trajectories in a TBO environment;
- Combining probabilistic trajectories to build probabilistic traffic prediction;
- Applying probabilistic traffic prediction to air traffic control planning.

**Key to enabling TBO is the ability to deal with the numerous sources of uncertainties inherent in ATM**

COPTRA showed that in addition to quantifying uncertainty through data analytics, it is possible to limit it through model-driven state estimation techniques. This enables not only to include flight intent or initial condition uncertainties but also to take into account model uncertainties.

COPTRA's models provide us with a clear quantitative understanding of delay propagation dynamics in space and time. The project results provide insight into how to achieve more efficient ATM operations in the future.

**More information: [www.coptra.eu](http://www.coptra.eu)**



## Generating user-preferred trajectories

An optimisation framework for trajectory based operations - OptiFrame



### Project Partners

Consorzio Futuro in Ricerca (CFR)

Eurocontrol

Lancaster University (Coordinator)

Netherlands Aerospace Centre (NLR)

The trajectory-based operations (TBO) concept is a cornerstone of the future ATM system. The OptiFrame project developed an optimisation framework for TBO, which assigns 4D trajectories to flights based on stakeholders' preferences and priorities. In other words, the OptiFrame approach incorporates the preferences and priorities of stakeholders in the design of the 4D trajectories.

These preferences were modelled by means of a multi-objective optimisation mathematical model that provides the capability of identifying the trade-offs between flight departure delays, flight efficiency, and flight route charges. In addition to visualising the listed trade-offs, the proposed approach offers the capability to analyse solutions at a microscopic level. Indeed, the project also looked in detail at alternative solutions, such as attributing values to the identified key performance indicators (KPI) for each airspace user and/or visualising the 4D trajectory as well as the values of the identified KPIs for each flight.

**The framework includes preferences and priorities for TBO, enabling trade-off analysis among KPIs**

The project's proposed approach raises the need for collaborative decision-making process that ensures convergence by all stakeholders towards a commonly-agreed solution.

**More information: [wp.lancs.ac.uk/optiframe](http://wp.lancs.ac.uk/optiframe)**

### Benefits

- **Better understanding of the trade-offs between departure delay, flight efficiency, and flight route charges**



# Partaking in better decision making in aviation

Cooperative departures for competitive ATM network service - PARTAKE

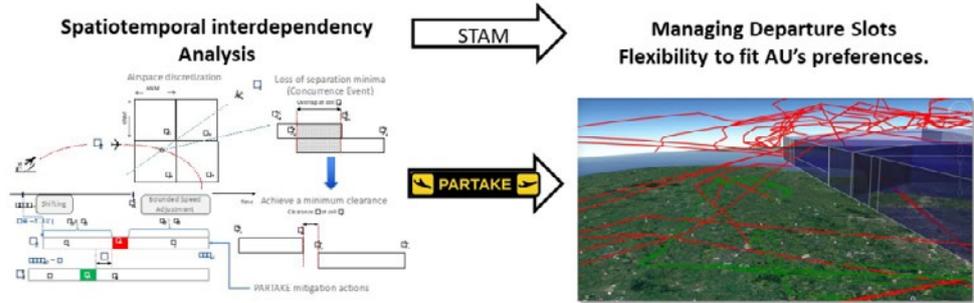
## Project Partners

ASLOGIC 2011

Cranfield University

ENAC

Universitat Autònoma de Barcelona [Coordinator]



## Benefits

- Short-term ATFCM measures
- Advanced ATM Metrics
- Measurable hotspot detection
- ATM digitalisation
- Integration of micro and macro level dynamics
- Mitigation of downstream effects
- Multi-stakeholder transparency

Despite the availability of a huge amount of (real-time and forecast) data about airports, aircraft, airspace, no tools exist today that can analyze time-space interdependencies between these elements. The PARTAKE project has developed a decision support system to prioritise the departure of aircraft, taking into account information from the airport (on taxiways and runways status), as well as from the airspace users on their preferences and the aircraft, including its trajectory. With this data, the system can identify areas of airspace where the demand is higher than capacity. In doing so, action can be taken to delay departures or expand the separation between aircraft in congested traffic areas. More specifically, the research paves the way for new innovations in several areas:

- Advanced tactical capacity management: Design of new operational metrics to predict traffic behaviour and implement more efficient resources allocation mechanisms.
- Dynamic capacity balancing (DCB): A short-term ATFCM measures (STAM) fine tuning algorithm to compute the departure time without affecting the ATFCM pre-flight assignments.
- Optimised airspace user operations: Analysis of available airspace to fit with a new conflict free trajectory considering both: aircraft on the ground waiting for clearance and aircraft in flight.

The project tested the tool using traffic data (air and ground) from London's terminal manoeuvring area. It showed the tool helped to minimise the number of conflicts and the need for tactical capacity management measures. With that, the tool has the potential to improve punctuality while lowering fuel consumption and emissions.

**More information: [www.partake-aero.eu](http://www.partake-aero.eu)**



## Optimising airspace through dynamic use of wake vortex



Wake vortex simulation and analysis to enhance en-route separation management in Europe - R-WAKE



### Project Partners

A-Syst

Deep Blue

GTD sistemas de informacion (Coordinator)

M3 systems Belgium

Technische Universität Braunschweig

Universitat Politecnica de Catalunya

The R-WAKE project addressed the risk and safety study of the wake vortex encounter (WVE) hazards in en-route airspace, and the identification of potential enhancements to the current separation schemes. The aim is to enable traffic and trajectory management improvements, and expected benefits in safety, airspace capacity, and flight efficiency of the European ATM system. Applying a simulation-based approach, the project delivered five tangible results:

- An ATM simulator that includes high-fidelity WVE dynamic risk models, referred to as R-WAKE System, tailored to support the project research approach.
- A WVE hazard severity baseline, defined as a matrix of upset parameters thresholds per severity class, developed and assessed with contributions of experienced pilots and air traffic controllers.
- A public database of simulation results, which constitutes an evidence body to support new separation scheme proposals, containing the upset and severity class computed for a large number of encounter scenarios, involving different aircraft types, geometries, separations, and weather conditions.
- The R-WAKE-1 concept proposal, which consists of six new separation schemes designed to increase safety against WVE hazards and also airspace capacity, looking at the minimum wake separation in the three dimensions: lateral, vertical, longitudinal, and also combined lateral-vertical, and wind-dependent dynamic separations.
- A feasibility and impact assessment of the concept, concluding that there is enough justification for proposing R-WAKE-1 as a new SESAR Solution, as a first step in a roadmap of identified incremental evolutions towards a long-term R-WAKE concept for optimising en-route separation minima provision.

### Benefits

- Increased safety
- Optimised airspace capacity
- Increased flight efficiency

**More information: [www.rwake-sesar2020.eu](http://www.rwake-sesar2020.eu)**



# Total precision surveillance

Satellite ADS-B for lower separation minima application – SALSA

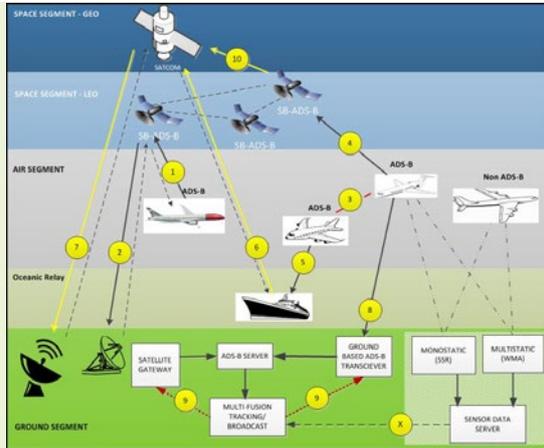
## Project Partners

Airbus Defence and Space (Coordinator)

DLR

NAV Portugal

Redu space services



## Benefits

- Improved safety
- Increased airspace capacity
- Increased flight efficiency

Developed as a viable low-cost alternative to conventional radar, space-based automatic dependent surveillance-broadcast (ADS-B) can monitor and control aircraft with greater precision and in areas of airspace that have no radar coverage today. Because of its high precision capabilities, ADS-B has the potential to maximise airspace through the reduction of separation between aircraft.

The SALSA project evaluated the performance and value of ADS-B in the context of enhanced surveillance and revision to separation standards in the non-radar airspace. Specifically, the project looked at what conditions required for the introduction of lower separation minima on transoceanic flight routes, particularly between Europe and the US, where traffic density is considerably high during morning and evening peak periods.

By combining space-based ADS-B with other sources of surveillance based on ground, air and oceanic relays, SALSA developed a system-of-systems approach. It found that space ADS-B when augmented with the enhanced controller-pilot data links can maximise the use of enhanced surveillance and the operational benefit of revised separation minima.

The project provided recommendations on satellite-based air traffic surveillance using ADS-B and its application to reduced separation minima which could be used as the basis for further developments and eventual later certification.

**More information: [www.airbus.com/salsa.html](http://www.airbus.com/salsa.html)**

### Key recommendations include further study into the:

- Maturity/viability assessment of space ADS-B, including the service availability monitoring
- Impact of CPDLC availability and recommendations
- Impact of navigational and surveillance integrity and recommendations
- Maturing validation models – collision risk, prediction, operator interfaces



# A low-cost navigation solution for small aircraft

Navigation of airborne vehicle with integrated space and atomic signals - NAVISAS



## Project Partners

Centre Suisse d'électronique et de microtechnique SA - recherche et développement (CSEM)

Shark.Aero

Tekever ASDS (Coordinator)

Thales Alenia Space Italia

Airspace is a finite resource subject to mounting demand by all types of vehicles (commercial jets, military, small aircraft, helicopters, balloons and drones). Increasingly ATM stakeholders are looking towards satellite-navigation systems to manage the traffic more efficiently. However, these systems can fail like any other so a back-up is always needed.

The NAVISAS project developed a concept for small aircraft to obtain alternative positioning, navigation and timing (A-PNT) information when satellite navigation fails while keeping performance and efficiency consistent with the airspace requirements. NAVISAS investigated the possibility of combining navigation data from multiple constellations (e.g. GALILEO and GPS) with an advanced inertial measurement unit (IMU) based on atomic gyroscopes implemented using microelectromechanical systems (MEMS) technology. The project scope was extended and included an assessment of vision-based navigation in flight, which was confirmed as a viable option for small aircraft.

**This low-cost navigational tool can serve as a backup to when an aircraft's satellite navigational capabilities are lost. It can also serve as a main navigation tool, for instance in specific drone operations**

The results of NAVISAS could pave the way for a new cost-effective instrument that can be used by small aircraft to ensure navigation performance levels consistent with evolving airspace and air traffic. Atomic gyroscopes may become a technological enabler of future high-grade and low-cost inertial reference systems, hence opening high performance inertial system market to lower-end aircraft. The results of this project also suggest that these systems would offer a substantially lower cost alternative to grade laser gyros currently used by commercial aviation.

**Vision-based navigation could provide a low-cost APNT capability in the event of a satellite outage**

The project also provided a roadmap on how this concept can be further matured, deployed and adapted to other aircraft beyond small aircraft in operations under visual flight rules (VFR) and instrument flight rules (IFR).

**More information: <https://navisas.tekever.com>**

## Benefits

- Maintained and improved navigational capabilities
- Low-cost alternative to existing back-up systems

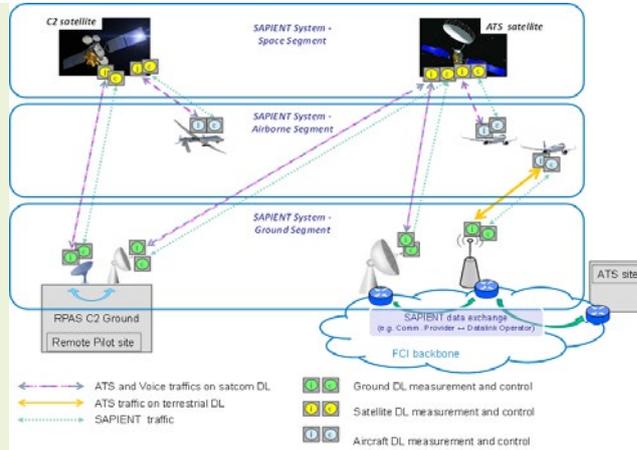


# A “disruptive” approach to air traffic management

Satellite and terrestrial architectures improving performance, security and safety in ATM - SAPIENT

## Project Partners

- Business Integration Partners
- Frequentis
- SITA Information Networking Computing
- Thales Alenia Space Italia (Coordinator)
- Universita' di Pisa
- ViaSat Antenna systems



## Benefits

- Improved predictability of data link performance
- Decreased level of air-ground communication issues
- Improved efficiency of ATM services delivery

A better connection between the aircraft and ground systems in ATM is seen as the key that will unlock greater efficiency in our skies. The SAPIENT project looked at innovative applications in communications, navigation, surveillance (CNS), focusing on improvements to air-ground datalinks. It also looked at how to incorporate remotely piloted aircraft systems (RPAS) flying beyond line of sight missions.

**Greater operational and cost efficiency is expected since the solution will reduce the need for voice communications as well as lower the use of spectrum**

The research looked at the integration of 4D trajectory estimates with data obtained through the dynamic and accurate monitoring and measuring of the performance of air-ground datalink communications between the aircraft transceivers and ground infrastructure.

**The SAPIENT solution provides a new innovative communication application in the field of the future CNS/ATM system**

The concept enables air and ground datalink equipment to monitor, process and exchange communication performance along a flight path, in order to confirm data link settings or report any possible anomalies that need to be managed in advance.



## Taking a holistic view of ATM performance

Assessment of performance in current ATM operations and of new concepts of operations for its holistic enhancement - APACHE



### Project Partners

Advanced Logistics Group

ENAC

Universitat Politecnica de Catalunya (Coordinator)

Univerzitet u Beogradu - Saobraćajni fakultete (FTTE)

ATM is progressively transitioning to a performance based system. Yet, properly assessing ATM performance and conveniently capturing trade-offs among key performance areas (KPAs) still present some research challenges for the ATM community. In this context, APACHE addressed three main research needs:

- Some of the current performance indicators (PIs) are proxy indicators that complicate setting performance target levels or drawing clear conclusions.
- Current PIs might not be able to properly capture ATM performance in the future operational paradigm foreseen in the SESAR concept of operations.
- In the majority of cases, KPAs and/or SESAR Solutions show complex interdependences that are not well understood.

**The APACHE simulator can provide computations of optimal trajectories and/or airspace sectorisations under several optimality criteria and/or constraints**

### Benefits

- Better performance indicators
- Improved understanding of performance trade-offs and theoretical limits
- Initial assessment of new ATM concepts and historical analysis.

APACHE provided a novel ATM simulation system, used with two different purposes: to simulate different operational contexts to perform what-if assessments; and to provide advanced models and optimisation tools that can support the implementation of novel and more accurate PIs. In this context, the developed system is able to generate optimal trajectories and airspace sectorisations considering a wide range of optimality criteria, supporting the calculation of new PIs using these trajectories/sectorisations as references.

The APACHE simulator and the new proposed PIs were demonstrated by:

- performing a preliminary impact assessment of long-term ATM concepts (such as free-routing and advanced demand and capacity balance mechanisms);
- monitoring performance from historical data sets;
- analysing interdependencies between some representative KPAs and SESAR solutions; and
- estimating the theoretical optimal limits for certain KPAs, under different optimality assumptions.

**Enhanced PIs complement current Performance Framework and can better capture ATM performance**

Some of the proposed PIs showed the potential to complement current performance framework. A future research need is to enable a more accurate and robust computation of "advanced" performance indicators, in order to better capture and infer preferences and operational practices of AUs and ANSPs and to better isolate the contribution of the different stakeholders into the overall performance of the ATM system.

**More information: <https://apache-sesar.barcelonatech-upc.eu>**



# Delivering high performing aviation

Advanced user-centric efficiency metrics for air traffic performance analytics – AURORA

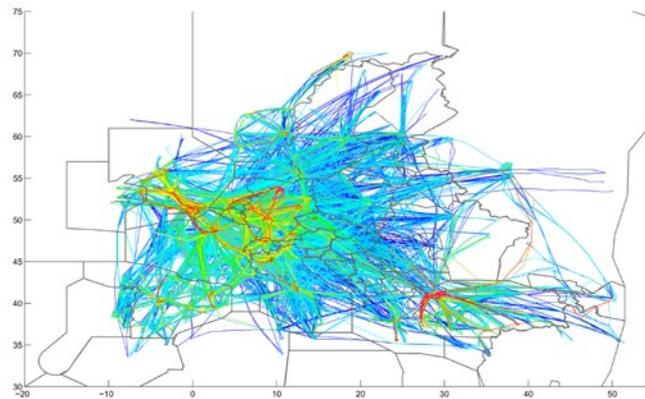
### Project Partners

Boeing Research & Technology Europe

CRIDA (Coordinator)

Flightradar24

CeADAR - University College Dublin



### Benefits

- Improved flight efficiency indicators considering weather
- Indicators based on fuel and costs
- Real-time indicators

A performance-driven ATM system is recognised as a critical element for the sustainability of Europe’s aviation and air transport sectors. This requires performance indicators representing stakeholder needs. Currently, flight efficiency, as defined in the Single European Sky Performance Scheme, measures the horizontal excess en-route distance compared to the geodesic distance. This view of efficiency is very limited since it does not take into account other sources of inefficiencies, namely meteorological conditions or the vertical profile of the flight, and it does not address key aspects for the airlines’ business strategies such as fuel consumption or costs.

**AURORA’s flight efficiency indicators compare actual fuel consumption and costs with achievable targets and clearly show possible efficiency improvements**

AURORA sought to address this issue and explored new efficiency indicators that encapsulate fuel consumption, schedule adherence, route charges and overall cost efficiency of flights. A key difference between these new efficiency indicators and today’s indicator is that their calculation requires the generation of user-preferred trajectories, i.e. fuel and cost-optimal trajectories, considering the impact

of weather conditions and without the need of confidential information from airlines. AURORA demonstrated that flight inefficiency in terms of costs is not necessarily aligned with inefficiency in terms of horizontal difference, and that the new indicators can better capture these cost-based inefficiencies. The new indicators were validated by a group of airlines in terms of representativeness, transparency and usability.

The project also proposed indicators to measure how fairly the inefficiencies in the system are distributed among airlines. These indicators can serve to quantify the differences in the inefficiencies experienced by airlines in a given area.

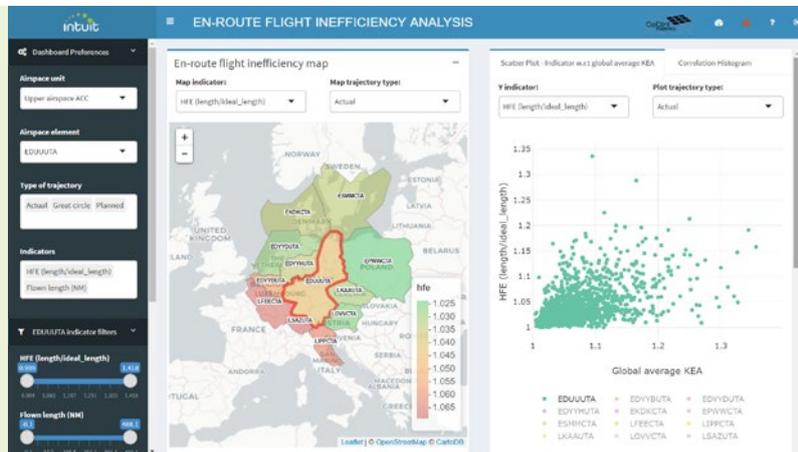
AURORA also developed a methodology based on big data to calculate these new efficiency indicators in real time. AURORA demonstrated the benefits of monitoring efficiency indicators in real time for the resolution of short-term traffic imbalances, taking into consideration the impact on flight efficiency.

**More information: <http://aurora-er.eu>**



# Visualising performance trade-offs in ATM

Interactive toolset for understanding trade-offs in ATM performance - INTUIT



## Project Partners

- Advanced Logistics Group
- Fraunhofer-Gesellschaft
- Nommon Solutions and Technologies (Coordinator)
- Transport & Mobility Leuven
- Universidad Politecnica de Madrid

The performance of the ATM system results from the complex interaction of interdependent policies and regulations, stakeholders, technologies and market conditions. Trade-offs arise not only between key performance areas (KPA), but also between stakeholders, as well as between short-term and long-term objectives.

INTUIT addressed the need for suitable performance modelling techniques and explored the potential of visual analytics and machine learning to improve our understanding of the trade-offs between KPAs and identify cause-effect relationships between indicators at different scales.

As a first step the project carried out a systematic characterisation of available ATM performance datasets, producing a data inventory that can serve as reference for future research activities. Then, a detailed review of the literature on performance interdependencies and a consultation process with ATM stakeholders led to the definition of a research agenda at the intersection of ATM performance and data science.

From the list of research questions included in this research agenda, three use cases were selected to demonstrate the potential of the investigated techniques. In the first case study, airline route choices were analysed and a model was developed to estimate the impact of changes in route charges on the overall ATM performance. The second case study showed how flight-inefficiencies within a particular area control centre are correlated with flight properties derived from both the flight plan and the ideal route, such as heading, altitude and airspace crossed. The third case study demonstrated how ATM performance can be measured at a finer spatial and temporal level and investigated the relationship between sector configurations and air traffic flow management (ATFM) regulations.

**Visual analytics and machine learning can provide innovative insights into ATM Performance**

Interactive visual interfaces were developed for all use cases to enable human-information discourse and to facilitate interpretation and communication of the modelling results.

**More information: [www.intuit-sesar.eu](http://www.intuit-sesar.eu)**

## Benefits

- Mapping of ATM performance datasets
- Better understanding of interdependencies between KPAs
- Visualisation tools for performance monitoring and analysis



# Gamifying change management in ATM

Participatory Architectural Change Management in ATM Systems - PACAS

## Project Partners

Deep Blue

SINTEF

Università degli studi di Trento (Coordinator)

Universiteit Utrecht



## Benefits

- Collaborative change management platform
- Involvement of heterogeneous stakeholders
- Increased participation through gamification

The ATM system is a complex systems-of-systems and all of its subsystems synergistically co-operate, through the creation of tight interdependencies among the institutions, enterprises, humans, hardware and software systems. Due to strong interdependencies, any change introduced might trigger changes in other parts of the system and it is a challenge to understand all possible consequences of a design decision. For this reason, it is important to involve multiple ATM domain stakeholders in change management processes.

PACAS' main objective was to support change management by investigating how to better understand, model and analyse changes at different layers of the ATM system, while capturing how architectural and design choices influence the overall system. The project developed an innovative participatory change management process wherein heterogeneous stakeholders could actively participate in the architectural evolution of the ATM system.

**Due to strong interdependencies in an ATM system, architectural and design choices influence the overall system and collaborative multi-stakeholder multi-disciplinary change management is required to ensure a coherent and consistent approach. This may be strengthened by gaming, modelling and automated reasoning**

The novelty of PACAS relies on three key components of the participatory change management process. First, the process is implemented as a gamified collaborative platform to increase participation. Second, domain specific modelling languages are supported to ease the contribution of multiple ATM domain stakeholders, each having a different view on the system. Third, the platform supports complex impact analyses through automated reasoning techniques. This allows better trade-offs and ultimately better change decisions to be made.

The web platform developed by the project has already been tested with a sample of a solution project of SESAR, results so far indicating that it could potentially be useful for supporting the design of new operational concepts and technologies being developed within SESAR.

**More information: [www.pacasproject.eu](http://www.pacasproject.eu)**

## Conclusion and next steps

The outcomes of the projects are exemplary of what can be achieved by going beyond the current horizon of knowledge in ATM and aviation and by applying tools and methodologies from other disciplines to address the challenges facing the industry. The project results described in this publication vary in maturity, but work is already underway to see how to integrate the most mature and promising of concepts into the industrial research activities of the SESAR JU.

At the same time, the SESAR JU has launched further research activities (see annex 2), addressing important challenges such as satellite signal jamming, improved airport surface movements using existing surveillance technologies and models to improve traffic predictability. The JU also launched Engage, a knowledge transfer network, whose aim is to inspire new researchers and helping to facilitate the transfer of results from fundamental and applied research into industrial research.

These activities will aim to ensure that promising research is progressed, and higher maturity results are delivered, thus supporting a more effective innovation pipeline in the context of the SESAR 2020 programme. Ultimately, through its exploratory research activities, the SESAR JU will support and facilitate the development of a future skilled workforce that is able to keep innovating and improving the ATM system.



# ANNEXES

## Annex 1

# Completed SESAR exploratory research activities



### SESAR and the Horizon 2020 research and innovation framework programme

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.
AGENT	Adaptive self-Governed aerial Ecosystem by Negotiated Traffic	699313
APACHE	Assessment of Performance in current ATM operations and of new Concepts of operations for its Holistic Enhancement	699338
ATM4E	Air Traffic Management for environment	699395
AURORA	Advanced User-centric efficiency metRics for air traffic perFORMance Analytics	699340
AUTOPACE	AUTOMATION PACE	699238
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
COCTA	Coordinated capacity ordering and trajectory pricing for better-performing ATM	699326
COMPAIR	COMPetition for AIR traffic management	699249
COPTRA	COmbining Probable TRAjectories	699274
DART	Data-driven AiRcraft Trajectory prediction research	699299
INTUIT	Interactive Toolset for Understanding Trade-offs in ATM Performance	699303
MALORCA	Machine Learning of Speech Recognition Models for Controller Assistance	698824
MINIMA	Mitigating Negative Impacts of Monitoring high levels of Automation	699282
MOTO	the embodied reMOte Tower	699379
NAVISAS	Navigation of Airborne Vehicle with Integrated Space and Atomic Signals	699387
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 net- work sErvice.	699307
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

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
STRESS	Human Performance neurometricS Toolbox foR highly automatEd Systems deSign	699381
TaCo	Take Control	699382
TBO-Met	Meteorological Uncertainty Management for Trajectory Based Operations	699294
Vista	Market forces trade-offs impacting European ATM performance	699390

## Annex 2

# Ongoing SESAR exploratory research activities

Project Name	Description	Participating organisations
Engage	The network aims to stimulate the transfer of exploratory research results towards ATM application-oriented research. The network will establish a knowledge hub, in which members across the research community are continuously involved. This will include an observatory and undertake the role of devising and maintaining the long-term roadmap development of innovative and interdisciplinary ATM concepts beyond SESAR 2020. The knowledge hub will be the one-stop, go-to source for information in Europe.	<ul style="list-style-type: none"> <li>• Innaxis Research Institute</li> <li>• Univerzitet u Beogradu - Saobracajni fakultet</li> <li>• Technische Universiteit Delft</li> <li>• Frequentis</li> <li>• Università degli studi di Trieste</li> <li>• University of Westminster (Coordinator)</li> <li>• Eurocontrol</li> <li>• European Aviation Safety Agency</li> </ul>
EVOAtm -Evolutionary ATM. A modelling framework to assess the impact of ATM evolutions	The project aims to build a framework to better understand and model how architectural and design choices influence the ATM system and its behaviours, and vice versa how the expected ATM overall performances drive the design choices. The EvoATM project will model a specific part of ATM system combining the agent based paradigms with evolutionary computing.	<ul style="list-style-type: none"> <li>• Centro italiano ricerche aerospaziali (CIRA) (Coordinator)</li> <li>• ASLOGIC 2011</li> <li>• Centro de Referencia de Investigación, Desarrollo e Innovación ATM (CRIDA)</li> <li>• ISSNOVA</li> <li>• Projecto, Empreendimentos, Desenvolvimento e Equipamentos Científicos e de Engenharia (Pedece)</li> <li>• Université autonome de Barcelone (UAB)</li> </ul>
ENVISION -Enhanced situational awareness through video integration with ADS-B surveillance infrastructure on airports	The project aims to make use of technical progress in CCTV cameras, light detection and ranging (LIDAR) technology and image processing techniques, and at taking advantage of reduced equipment costs, to provide regional and local airports safe and affordable surface movements surveillance capabilities.	<ul style="list-style-type: none"> <li>• ALTYs Technologies (Coordinator)</li> <li>• ENAC</li> <li>• Eurocontrol</li> <li>• Graffica</li> </ul>

Project Name	Description	Participating organisations
ADAPT -Advanced prediction models for flexible trajectory-based operations	The project proposes strategic models to predict the volume, flexibility and complexity of traffic demand taking into account both individual flights and network infrastructure (i.e. sectors and airports). The aim is to enable early flight information sharing in order to identify potential network bottlenecks and the degree of flexibility of all flights. At the tactical level, the extent to which strategically assessed pre-departure and en-route flight flexibility mitigates actual network congestion, will be evaluated.	<ul style="list-style-type: none"> <li>• Deep Blue</li> <li>• TU Delft</li> <li>• University of Westminster</li> <li>• Università degli Studi di Palermo</li> <li>• Università degli studi di Trieste (Coordinator)</li> </ul>
GATEMAN -GNSS navigation threats management	Global Navigation Satellite System (GNSS), such as the Galileo constellation, will become the primary means of aircraft navigation in the mid and long term. However, GNSS signals are vulnerable to threats, especially to jamming and spoofing, which may cause the total loss of navigation. The project will research multiple measures that could be deployed on most aircraft to manage these threats, either on their own or in a collaborative fashion with other aircraft.	<ul style="list-style-type: none"> <li>• GMV Innovating Solutions (Coordinator)</li> <li>• Istituto Superiore Mario Boella (ISMB)</li> <li>• Tampere University of Technology</li> </ul>
COTTON - Capacity optimisation in trajectory-based operations	The project aims to maximise the effectiveness of capacity management processes in trajectory-based operations taking full advantage of available trajectory information. Specifically, the projects explore the integration of demand and capacity and flight centric solutions.	<ul style="list-style-type: none"> <li>• CRIDA (Coordinator)</li> <li>• Deutsches Zentrum für Luft- und Raumfahrt (DLR)</li> <li>• ENAC</li> <li>• Eurocontrol</li> <li>• TU Delft</li> <li>• Universidad Politécnica de Madrid (UPM)</li> </ul>
EMPHASIS -Empowering heterogeneous aviation through cellular signals	The project aims to increase safety, reliability and interoperability of general aviation/rotorcraft (GA/R) operations both with commercial aviation and with emerging drones operations. These aspects are foreseen as critical elements to secure and improve airspace access for GA/R users in future airspace environment and improve operational safety of their operations.	<ul style="list-style-type: none"> <li>• Airbus</li> <li>• Evektor-Aerotechnik</li> <li>• Honeywell (Coordinator)</li> <li>• Tampere University of Technology</li> </ul>
Domino - Novel tools to evaluate ATM systems coupling under future deployment scenarios	The project will develop a set of tools, a methodology and a platform to assess the coupling of ATM systems from a flight and a passenger perspective. The platform will allow ATM system designers to gain insight on the impact of applying new mechanisms. It will provide a view of the impact of deploying solutions in different manners, e.g., harmonised vs. local/independent deployment, and information on the criticality of elements in the system and how this might be different for different stakeholders.	<ul style="list-style-type: none"> <li>• Eurocontrol</li> <li>• Innaxis Research Institute</li> <li>• Università di Bologna</li> <li>• Università degli studi di Trieste</li> <li>• University of Westminster (Coordinator)</li> </ul>

## Annex 3

# Glossary

ABSR	Assistant based speech recogniser
ADS-B	Automatic dependent surveillance-broadcast
AI	Artificial intelligence
AIRM	ATM information reference model
ANSPs	Air navigation service providers
A-PNT	Alternative positioning, navigation and timing
ASR	Automatic speech recognition
ATC	Air traffic control
ATM	Air traffic management
AUs	Airspace users
CNS	Communication, navigation and surveillance
DCB	demand and capacity balancing
ER1	First SESAR exploratory research call for proposals - ER1
EU	European Union
GA	General aviation
GA/R	General aviation & rotorcraft
GNSS	Global navigation satellite system
GPS	Global positioning system
HMD	Head mounted display
HP	Human performance
HPE	Human performance envelope
IFR	Instrument flight rules
IMU	Inertial measurement unit
IR	Implementing rules
JU	Joint Undertaking
KPAs	Key performance areas
KPI	Key performance indicator
LIDAR	Light detection and ranging
MEMS	Microelectromechanical systems
OWL	Web ontology language
PIs	Performance indicators
R&D	Research and development
RPAS	Remotely piloted aircraft system
SES	Single European Sky
SESAR	Single European Sky ATM Research
STAM	Short-term ATFM measures
SWIM	System-wide information management
TBO	Trajectory-based operations
VAC	Vigilance and attention controller
VFR	Visual flight rules
WVE	Wake vortex encounter









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