# CZECH TECHNICAL UNIVERSITY IN PRAGUE

Faculty of Transportation Sciences

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# Identification of Research Potential of the Department of Air Transport

Master's thesis

2019

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# MASTER'S THESIS ASSIGNMENT

(PROJECT, WORK OF ART)

Student's name and surname (including degrees):

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Code of study programme code and study field of the student:

**N 3710 – PL – Air Traffic Control and Management**

Theme title (in Czech): **Identifikace výzkumného potenciálu Ústavu letecké dopravy**

Theme title (in English): Identification of Research Potential of the Department of Air Transport

## Guides for elaboration

During the elaboration of the master's thesis follow the outline below:

- Overview of Future plans for ATM system
- Creation of a mind map and identification of the most up-to-date scientific research sections for the years 2019 to 2022.
- Introduction of the identified areas for further research
- Comparison of research capabilities of Department of Air Transport with identified parts for research.
- Summary and recommendations for the Department of Air Transport + Roadmap with a view to a year 2025.

Graphical work range: according to the instructions of master's thesis supervisor

Accompanying report length: at least 55 pages of text (including pictures, graphs and tables, which are part of accompanying report)

Bibliography: ICAO: Global Air Navigation Plan

EUROCONTROL.int

EC: Flightpath 2050

Master's thesis supervisor: **doc. Ing. Jakub Kraus, Ph.D.**

Date of master's thesis assignment: **July 8, 2019**
(date of the first assignment of this work, that has be minimum of 10 months before the deadline of the theses submission based on the standard duration of the study)

Date of master's thesis submission: **December 2, 2019**
a) date of first anticipated submission of the thesis based on the standard study duration and the recommended study time schedule
b) in case of postponing the submission of the thesis, next submission date results from the recommended time schedule

ČESKÉ VYSOKÉ UČENÍ TECHNICKÉ V PRAZE
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Prague ........................................................................ July 8, 2019

**Abstract**

With a constant growth of air transport around the world, there are significant needs for innovation and modernisation of existing air traffic management/communications, navigation and surveillance (ATM/CNS) systems. The purpose of this master's thesis is the identification of the most current research areas in a global ATM system, comparison of the primary research & development (R&D) sections with research capabilities of the Department of Air Transport at the Czech Technical University in Prague, particularly with ATM systems laboratory focusing on research in ATM/CNS domain, and subsequently recommend a view to the year 2025 in a specific roadmap with steps required for further exploration. The first part of the thesis provides a comprehensive overview of the modernisation of ATM system worldwide, including programmes, visions and strategies of different organisations focused on ATM system innovation. The following part focused on the process of identification of the current research areas was done by the quantitative approach using a created mind map as an instrument for further exploration of the most current topics, together with the qualitative approach performed in the form of in-depth research combined with structured interview with academics and experts working on CNS/ATM research from Department of Air Transport in the Czech Technical University, Prague. Results from both methods were compared to the research capabilities of the Department of Air Transport and critically analysed. The last section of the thesis summarises outcomes and presents the areas as well as topics that are in alignment with the research abilities of the Department of Air Transport and offers recommendations for potential improvement as well as topics suggested for further research.

**Keywords**

ATM, CNS, Air Transport, modernisation, research, innovation, SESAR, GANP, European ATM Master Plan

REGINÁČ, J.*Identification of Research Potential of the Department of Air Transport*. Prague: Czech Technical University in Prague, Faculty of Transportation Sciences, 2019. 106 p. Supervisor doc. Ing. Jakub Kraus, Ph.D.

Předkládám tímto k posouzení a obhajobě diplomovou práci, zpracovanou na závěr studia na ČVUT v Praze Fakultě dopravní.

Nemám závažný důvod proti užívání tohoto školního díla ve smyslu § 60 Zákona č. 121/2000 Sb., o právu autorském, o právech souvisejících s právem autorským a o změně některých zákonů (autorský zákon).

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V Praze dne 2.12.2019

Bc. Jan Regináč

I would like to sincerely express my thanks to my master's thesis supervisor, doc. Ing. Jakub Kraus, Ph.D. for his valuable advice, guidance and his willingness to help in every situation. Above all, I want to express my gratitude to my family for their support during my studies.

Bc. Jan Regináč

# Contents

# 1. Introduction

Air traffic management (ATM) has seen several significant improvements in recent decades. However, much of the global ATM system is still constrained by conceptual approaches which originated in the twentieth century. These older ATM capabilities not only limit air transport capacity, but they are also responsible for the unnecessary emissions of gases stored in our atmosphere. Thus, a fully harmonised global air navigation system based on modern performance-based procedures and technology is the solution to these problems. [1]
Nevertheless, this is just one part of the problem. As technology is moving forward, it is necessary to consider the new entrants into aviation, because if not addressed properly, it could cause significant issues in the air traffic management system worldwide. This problem is lying in the hearts of many people within the aviation community, and it is crucial to address situation collaboratively and as effectively as possible. One of the most significant reactions to these rising challenges emerged in October 2018 at the Thirteenth Air Navigational Conference, which was held in Montreal, Canada. The main reason why the conference was held was to agree on the 21st-century vision for the air traffic management development and to determine specific steps that need to be taken in order to turn this vision into reality. This major event brought together stakeholders from the aviation community worldwide, hosted more than 1,100 participants from 116 Member States and 32 international organisations. All participants discussed the variety of topics but above all the new revisions to the Global Navigation Plan. Purpose of this plan is to provide vision and direction on modernisation for all member states of the ICAO. [2]
President of the ICAO Council, Dr Olumuyiwa Benard Aliu, gave the following notice in his keynote speech: "*Aviation today is on the brink of some major transformations. This is reflected in the fantastic growth in aircraft passenger and cargo traffic volumes that are poised to more than double by 2035, the increasing deployment of drone technology, the launch of autonomous, suborbital, and supersonic activities, as well as other innovations such as artificial intelligence and blockchain technologies. Accordingly, our goal is to define our collective vision of a safe, interoperable, seamless and global civil air traffic management system for the 21st-century.*" [2]
The new technological progress is evident and inevitable. Air traffic is going to grow, and there must be a consistent effort to improve the current ATM. The modernisation should be done in such way that modern ATM system will be able to accommodate anticipated air traffic growth and integrate all new entering technologies in an innovative, efficient, safe and environmentally friendly manner.
The purpose of this thesis is to identify the most current R&D areas addressing such challenges

as mentioned above and subsequently compare the identified areas with research capabilities of the Department of Air Transport (hereinafter referred as “DAT”) at the Czech Technical University in Prague, particularly with ATM systems laboratory focusing on air traffic management and communication, navigation, surveillance (ATM/CNS) domain and eventually determine the potential for the Department’s current or future research.

The first part of the thesis is devoted to the well-arranged overview of leading organisations involved in modernising ATM around the world. The overview provides the introduction to their modernisation programmes, visions and objectives. In this chapter, the main emphasis was put on the European modernisation process where Single European Sky ATM Research (hereinafter referred as “SESAR”) can be considered a leader in the innovation of ATM systems. Accordingly, its SESAR 2020 programme served as a foundation for identifying the actual research areas due to its cutting edge research&development progress.

Next chapter describes progress in more details, and above all, the chapter provides the methodology of the identification chosen for this thesis. The identification process itself is done with the help of created mind map and Matlab software, in the case of a quantitative approach. On the other hand, qualitative method relied on in-depth research of strategic documents of SESAR. Both methods propose a list of themes that are later on compared with DAT research capabilities, particularly with the ATM systems laboratory. The chapter concerning the comparison contains the list of projects and grants where DAT has participated, moreover concluded structured interviews conducted with experts working on ATM modernisation at the ATM systems laboratory at DAT. This chapter also provides a comparison aiming at the possible intersection of identified areas with areas of research undertaken at DAT. Moreover, it proposes the future R&D needs for identified areas and suggests themes for final theses for future students relating to the identified areas. In addition, two roadmaps with a view to the year 2025 are suggested to DAT.

Eventually, the last chapter concludes the thesis and provides the recommendations for future research at DAT. This thesis intends to serve as a foundation of the current R&D themes that can be further explored either by students in the framework of final theses or research conducted in Students’ projects at DAT.

# 2. Overview of future plans for ATM system

The intention behind this chapter is to inform, as well as to introduce the latest updates of the Global Air Navigation Plan (hereinafter referred to as "GANP") in order to provide a necessary insight into the most relevant strategic document regarding the modernisation and evolution of the future ATM system. The chapter advances correspondingly to the approach of GANP, as it proceeds a maiori ad minus, from the modernisation strategy at the global level (GANP strategy) through the regional level of planning (ATM system modernisation in Europe) to the national strategies of individual states (NextGen, CARATS, OneSKY).
A large part of this chapter focuses intensely on the introduction of the modernisation process of ATM in Europe, involving many different organisations. The situation in Europe is described in more details not only because the Czech Republic, as a member of the European Union, is obliged to act in accordance with the legislation adopted by the European Commission, but also because European airspace is considered the most challenging for air navigation. Besides, the European program SESAR is considered to be a global leader in the modernisation of ATM.
Then, this chapter also offers insight into the American continent by introducing the main modernisation program taking place in the United States. Lastly, it provides a brief introduction of the modernisation programs initiated in other parts of the world, mostly programmes in the Asian-Pacific region.

## 2.1. ICAO Global Air Navigation Plan Strategy

The ICAO has to acknowledge both the demands from the society and the aviation community. The aviation today must meet high standards, especially lowering the noise levels produced by aircraft, environment-friendly aviation, maintaining the high safety level, building resilient infrastructure and lastly cost-effective air navigation systems. [3] All these standards must be met in order to generate results with high-quality socio-economic benefits as required.
This section will take a look at the basic structure and features presented in the GANP defined by ICAO as follows: "*The Global Air Navigation Plan (Doc 9750) is the ICAO's highest air navigation strategic document and the plan to drive the evolution of the global air navigation system, in line with the Global Air Traffic Management Operational Concept (GATMOC, Doc 9854) and the Manual on Air Traffic Management System Requirements (Doc 9882). It also supports planning for local and regional implementation.*" [4]

### 2.1.1. GANP evolution

In the first place, it is necessary to provide a brief insight into the history of the Global Air Navigation Plan evolution which has its roots in the 1993's list of published reports called the Future Air Navigation System (hereinafter referred as "FANS"). These recommendations were first introduced as the FANS concept and were later generally referred to as CNS/ATM - Communications, Navigation, Surveillance/Air Traffic Management. [1]

Later on, the FANS initiative had received requirements from the ICAO's member states to react to the growing air transport and new technologies which were emerging during the 1990s. It was then evident that the creation of a strategic planning document which would address the coordination of the process of research and development for all member states was more than necessary. [1]

The reaction from ICAO presented itself in 1998 in the form of a standalone version of the Global Air Navigation Plan for CNS/ATM systems (Doc 9750). [1] Nonetheless, regular revisions and overall evolvement of the GANP were continuously needed in order to react to the growing air transport. The evolution of the document is presented in Figure 2.1. The second edition of GANP was published 2002, the third edition 2007, fourth edition 2013, the fifth edition 2016 and the sixth edition was published as an interactive electronic document called GANP PORTAL in 2019. [4] Each of the mentioned editions brought new approaches and objectives to tackle the emerging problems in air transport. The latest, sixth edition will be scrutinised in more details in the following sections. In 2004, as a consequence of major requirements in terms of the


Figure 2.1: GANP evolution. [1]

transition to more practical solutions that came from ICAO member states and air transport industry stakeholders, two ATM implementation roadmaps were formed and later published in the third edition of the GANP as Global Plan Initiatives (GPIs). [1]

Profound changes in the Global Air Navigation Strategy occurred in the fourth edition of the GANP, where the 15-year strategic approach methodology reflected the current technologies at that time and predicted future development. As a result, the new Aviation System Block Upgrades (hereinafter referred as "ASBU") were presented. ASBU are arranged in six small steps to reach the objectives starting in 2013 and continuing until 2031 and beyond. This approach supports a reliable foundation for future investment strategies concerning the development of the new technologies, procedures and operations in air transport. [1] The main objective of the fourth edition of GANP was to: "*Increase the capacity and improve the efficiency of the global civil aviation system.*" [5]

Since the fourth edition, the GANP has been regularly updated and maintained every three years in order to achieve the evolution of the global air navigation system and to ensure that harmonised, integrated and the globally interoperable seamless system turns into reality.

The fifth edition should serve as a *"comprehensive planning tool to support the development and implementation of harmonised global air navigation system"* [1], and one of the main objectives was to *"provide international and overarching framework of a global investment"*. [1]

The newest edition of GANP is the sixth edition created in 2019, which aims to encourage the evolution and transformation of the global air navigation system. The goal is to promote investment in aviation, to provide guidance in the investment of R&D programs in the same direction, to support the implementation of newly developed solutions, to make the aviation more cost-effective and lastly to achieve all expectations of society as well as the aviation community. [3,4]

### 2.1.2. GANP 2019 web portal

As a matter of fact, the air navigation system can be considered as one of the most complex systems in the world. Therefore, the precise strategy in the development of such a system is necessary. To provide a large amount of information aligning with the complexity of the air navigation system, the latest version of GANP has shifted from the paper planning documents to the extensive interactive web portal to provide information and data in a more orderly manner. [3]

The GANP content is newly organised into a multilayer structure, each layer being adapted to the different viewers, that allows for better communication with senior and technical managers as well as every state or stakeholder stays well informed. The four-level structure is composed of global (strategic and technical), regional and national level (illustrated in Figure 2.2). It provides a framework for the alignment of regional, sub-regional and national plans. The four-level structure enables effective decision making by providing a stable strategic direction for the development of the air navigation system with the relevance, including the actual technical content. [4] The four layers of the GANP are presented below as follows:


Figure 2.2: Multilayer structure of GANP 2019. [4]

**GLOBAL STRATEGIC LEVEL:**

The global strategic level is introduced as an electronic document which is available in 6 different official ICAO languages. Strategic level serves as a decision-making tool by providing a high-level direction towards progress in the global air navigation system. [4]

Generally speaking, the main role of the strategic level is to drive the evolution of the air navigation system. The global strategic level includes the GATMOC vision, conceptual roadmap and global performance ambitions. [3]

The vision behind this document is following. ICAO member states and stakeholders involved in air navigation and air transport in general aim to create the globally interoperable system as well as the common approach towards new emerging trends, technologies and challenges. This concept presents a more holistic approach towards the development of air navigation system that would be based on its strengths and opportunities, rather than focusing on simple partial improvements.

Strong commitment and investment are required from all members of the aviation community to achieve this vision successfully. Global air traffic environment becomes more and more complex, and it is necessary to react to the new demand for airspace and new technologies. The transformation itself is not an end goal but the way on achieving the vision. Hence the strategy for the transformation of the global air navigation system reacts on the ambitions of the ATM system performance as well as ambitions of states that demand using the available and also the new technologies. [4]

The aviation industry has to ensure its position in innovation and modernisation of the global air navigation system. Unless the industry continues to do so, there is too much at risk for the global economy and citizens in the future. [4]

**GLOBAL TECHNICAL LEVEL:**

The attainment of the global air navigation system relies on the technical managers who carry forward the improvement of the air navigation system and are supported by decision-makers. There is no finish line in developing the air navigation system; therefore, continuous improvements ensure that the system adapts to global, regional and local challenges in a timely manner. This level is derived from the global strategic level to support technical managers in the implementation and planning of new operational changes and procedures. Additionally, global technical layer ensures attaining the system performance together with interoperable systems and harmonisation. [4]

Furthermore, the global technical layer contains features presented and deconstructed in more details hereafter [4]:

- Two global technical frameworks:
  "*The Basic Building Blocks (BBB) that outlines the basics of the robust air navigation system by defining basic air navigation services provided for international civil aviation. An updated version of the ASBU framework for implementation that provides the aeronautical community with the performance benefits expected from implementing new operational air navigation enhancements.*

- *An associated framework including a catalogue of key performance indicators and targets.*

- *A performance-based method for planning and implementation of air navigation operational improvements.*" [4]

**REGIONAL LEVEL:**

This level addresses the regional and subregional performance needs, operational issues, differences and opportunities via the ICAO regional air navigational planning, which is cooperated with the global strategic and global technical layers. [4]

To put it in another way, it includes the R&D programs being undertaken in the world, for instance, SESAR, NextGen, CARATS. These programs have been brought together in the hope that they will actively participate in the definition of the future direction for investments. Secondly, they shall be focusing on developing operational improvements. Hence R&D programs have the major part in resolving the strategy level of GANP based on their predictions and future demand anticipation. [3]

The regional level also introduces the regional planning in the form of three volumes document where volumes I and II consist of information regarding the requirements aligned with the BBB framework. Eventually, Volume III follows the performance management process for choosing an appropriate ASBUs. [3,4]

**NATIONAL LEVEL:**

States and stakeholders must cooperate in alignment with global and regional plans in the implementation and development of their national air navigation system. It shall be noted that the national level in GANP is not a responsibility of ICAO but the states. ICAO takes its participation solely in inspiring the nations to develop their air navigation plans with the intention that the states will build their air navigation system by implementing the BBB and ASBUs. Thereupon by this action, the national air navigation system will contribute to the seamless and harmonised global modernisation process. [3,4]

### 2.1.3. GANP conceptual roadmap

It is essential to realise that the primary purpose of the global strategic level is to anticipate the future of air navigation, react to the future demand and new emerging technologies as well as to visualise the possible solutions that would help to solve the possible rising problems. As the aviation industry becomes increasingly complex, it is significant to stay alert and implement even the technologies that had not been initially intended for the aviation community but might contribute to the possible advancement of the system. Aviation becomes increasingly interconnected and automated. The transformation towards the digitalisation using big data, machine learning and upcoming technologies are genuinely inevitable. The conceptual roadmap was developed to propose a different stance on how to manage the air navigation system. The system shall be approached more holistically rather than merely improving the current system technologies. [4]

The next 20 years will be crucial for ATM, which should be able to handle increasing traffic of regular airliners accompanied by new types of aircraft operating in high flight altitudes as well as low altitude operations. The current air navigation system has to undertake changes that are defined in GANP strategic level as four broad evolutionary areas, namely: [4]

- "*Flight operations in a digital rich environment.*
- *Time-based operations enabled by an information revolution.*
- *Trajectory-based operations enabled by full connectivity through the internet of aviation.*
- *Total performance management system focus on business/mission needs.*" [4]

### 2.1.4. GANP performance ambitions

It is significant for aviation to put the most substantial emphasis on safety, security, capacity and progressively on the environment, however, other ambitions has to be taken into consideration as well, so that the air transport can function on the highest level possible. To realise the transformation of the air navigation system, a set of specific performance ambitions has been determined by ICAO at the Global strategic level. These 11 Key Performance ambitions serve as qualitative indicators as well as directions for the achievement of Key performance objectives which were determined by ICAO at Global technical level. In general, the performance objectives provide the qualitative knowledge about the contribution to the performance of air navigation system after the implementation of certain ASBU. For quantitative tool which would measure the past, current and future performance of the system, ICAO has developed the KPI Key Performance Indicators Catalogue which can help to resolve the level of the air navigation system performance. [3,4]

As noted in ICAO ASBU Tutorial: *"The KPIs are quantitative means of measuring current/past performance, expected future performance as well as actual progress in achieving performance objective."* [4]

As can be seen, all three key performance ambitions, key performance objectives level and key performance indicators are interconnected. For the illustration, the ICAO has introduced these 11 key performance ambitions (Table 2.1) at the Global strategic level, which are paramount in the progressing the evolution of global air navigation system.

Table 2.1: Summary of the GANP performance ambitions. [4]

| **KPA** | **Ambition** |
|---|---|
| Access and equity | No aviation community member excluded or treated unfairly. |
| Capacity | Nominal capacity easily scalable with demand. |
| | Disruptive events do not interrupt service provision and do not significantly affect the performance of the system. |
| Cost-effectiveness | No increase of total direct ANS cost while maintaining the safety and quality of service. |
| | Significant increase of ANS productivity, irrespective of demand. |
| Efficiency | Reduction of the gap between the flight efficiency achieved and desired optimum trajectory of airspace users. |
| Environment | ANS induced inefficiencies to be progressively removed to contribute to the global ICAO aspiration goals for CO2 emissions. |
| | To benefit from achieved flight efficiency gains. |
| Flexibility | To absorb required changes to individual business and operational trajectories. |
| Interoperability | Essential at an operational and technical level. |
| Participation by ATM community | Pre-agreed level of participation to make maximum shared use of the air navigation resources. |
| Predictability | No increase in ANS delivery variability including asset availability. |
| Safety | Zero ANS related accidents and significant (50%) reduction of ANS related serious incidents. |
| Security | Zero significant disruptions due to the cyber incidents. |

### 2.1.5. GANP BBB framework

The Basic Building Block is the part of the global technical level and serves as a foundation for any robust air navigation system. The BBB block is presented for the first time in this edition of the GANP. In its essence, this framework is nothing new but mandatory requirements, standards, procedures and essential services according to ICAO SARPs document. The BBB framework includes the aerodrome operations, CNS, ATM, meteorology, search and rescue, and aeronautical information. [3,4]

The BBB framework can be considered more as a baseline for any operational improvement ASBU in this case. For moving towards the evolution and improving the global air navigation system, it is necessary first to know the basic services and use these services as a ground for

further advancement. Hence, the BBB framework is not meant to be an evolutionary step but rather the essential ground for stable development in a safe and orderly manner. [4]
Fundamentally, states must insist on setting the BBB foundation in their national air navigational plans to enable the provision of seamless air navigation improvements that will result in an advancement of the quality of the services and create benefits to the all aviation community. [4]

### 2.1.6. GANP ASBU framework

As has been noted before, the fourth edition of GANP introduced the ASBU framework. The ASBU Framework stands for Aviation System Block Upgrades, a system that serves as an engineering planning and implementation tool. It aims to deliver harmonisation of ATM improvement and modernisation programs effectively. The ASBU framework belongs to the global technical layer and provides the technical solutions to advance the evolutionary steps proposed in the conceptual roadmap at the global strategic level. [4]
The ASBU framework serves not only as a set of all possible solutions but rather as a list of operational improvements showing which technologies are ready to implement and also the technologies that are still being developed. Hence, the stakeholders' investments into the newly available solution can be determined confidently and accurately. With this in mind, the ASBU framework methodology is a crucial element of the GANP, and for this reason, it deserves to be described in more details. The following Figure 2.3 illustrates the ASBU key concepts wherein each of the concepts will be briefly introduced below precisely as stated in the latest version of GANP: [4]

**ASBU Thread:**

Based on the evolutionary steps determined in the conceptual roadmaps in GANP Global strategic level, different concepts were introduced for various areas of the air navigation system. These areas are called Threads in ASBU framework. Threads have been categorised into three groups (operational, information and technology threads). [4]

**ASBU Element:**

*"An ASBU element is a specific change in operations designed to improve the performance of the air navigation system under specified operational conditions."* [4]

**ASBU Enabler:**

*"They are the components (standards, procedures, training, technology, etc.) required to implement an element."* [4] Their objective is to set out the requirements that are necessary to

guarantee an effective element implementation.

**ASBU Block:**

ASBU Block is defined as *"a six-year timeframe whose starting date defines a deadline for an element to be available for implementation"* [4] as well as all enablers associated to the element must be ready for implementation by the year of the ASBU Block. Blocks are divided by their deadlines as follows: 2013, 2019, 2025, 2031... [4]

**ASBU Module:**

A module is defined as *"a group of elements from a thread that, according to the enablers roadmap, will be available for implementation within the defined deadline established by the ASBU Block."* [4]

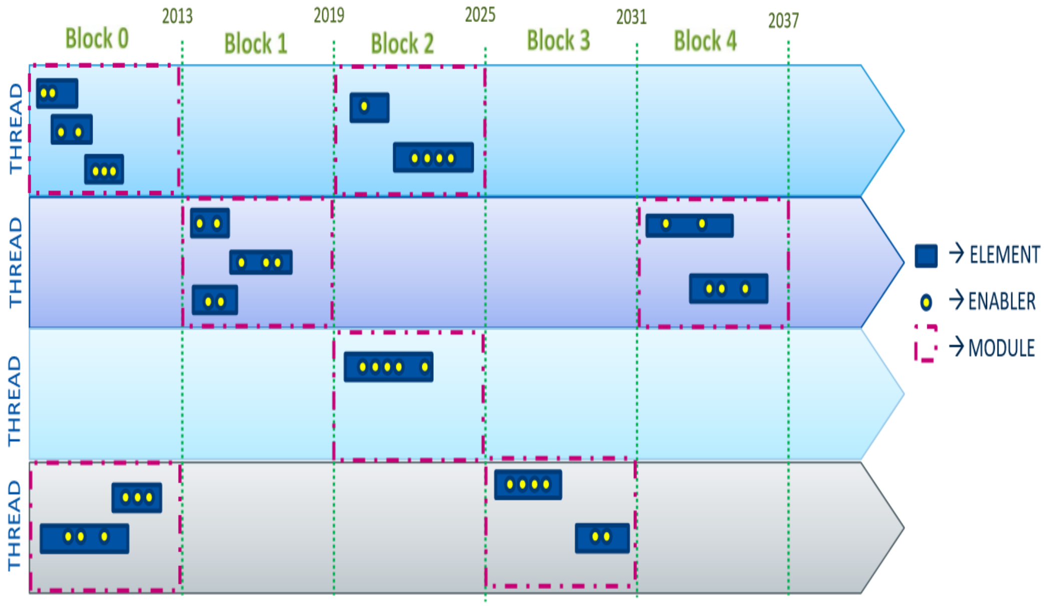


Figure 2.3: The ASBU concept. [4]

### 2.1.7. GANP performance framework

The last part of the global technical layer describes the performance framework. A performance-based method has been presented earlier in the ICAO document - Manual on Global Performance of Air Navigation System. ICAO decided the document be simplified due to its high complexity in order to facilitate the provision of comprehensive information, helping the decision-makers to set their priorities. [3]

This result-oriented performance-based approach is defined in a six-step method that is recommended to be followed while implementing the new ASBU into the air navigation system. ICAO developed the six-step method to identify the optimal solutions aligned with the operational requirements as well as the performance needs of state and regional air navigation systems to achieve the harmonisation of the air navigation system globally. [3,4]

The method can be applied at global, regional and local levels and the particular steps are illustrated in the Figure 2.4. The first two steps serve for the definition of the scope, context and

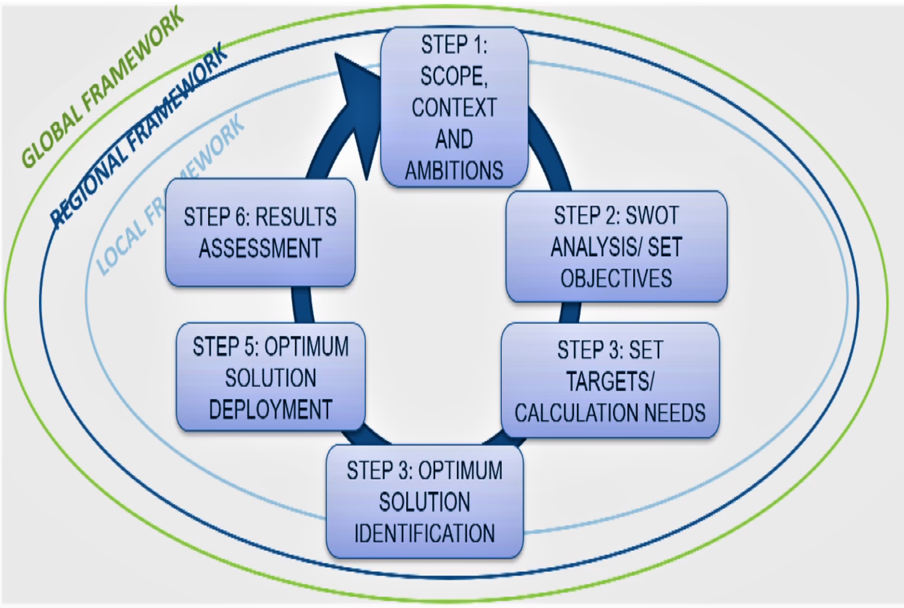


Figure 2.4: Six-steps method. [3]

ambitions of the air navigation systems either in local, regional or national level. Furthermore, they deal with identifying the strengths, weaknesses, opportunities and threads occurring in the particular air navigation system in order to analyse which are the objectives that need to be set to achieve better performance of the system. [3,4]

Steps 3 and 4 determine targets and calculate necessary investments into the implementation of solutions required for improving the functionality of the navigation system. Targets and objectives should be set in a way which ICAO describes as SMART (Specific, Measurable, Achievable, Relevant and Time-bounded) to successfully achieve the objectives. Meanwhile, the step 4 shall help to select the suitable potential solution from the list of solutions (ASBU) and facilitate the decision making regarding the investment into the solution particular air navigation system based on the SWOT analysis and performance objectives completed in the previous steps. [3,4]

Step 5 relates to the process of solution deployment itself. In other words, it covers the process of tracking solution deployed in favour of assessing the benefits that result from the implementation of chosen solution where the assessment and results obtained from the deployment is the last step of this method. To sum up, the fifth and sixth step involve the process of monitoring and reviewing the performance of the deployed solution. [3,4]

This six steps method is a continuous method executed on local, regional and global level invented for seamless harmonisation of the air navigation system around the world which will not happen straight away but as a long term strategic action.

## 2.2. Modernisation of ATM system in Europe

The previous sections described the GANP, which is paramount in regards to the global air navigation system strategy. Meanwhile, this section is devoted to the situation in the European air traffic management system which can be considered, based on the knowledge from previous sections, as the regional level of planning in GANP. The situation in Europe will be described in more details not only because the Czech Republic is a member state of the European Union but also because European airspace is considered the most challenging for air navigation. For this reason, the European air navigation system should become a leader in innovation and research & development programs.

The process of modernisation of the European airspace started when the EU accepted three successful strategical packages. These three packages gradually liberalised the European market by focusing on air carrier licencing, market access and fares. These progressive steps in terms of regulations facilitated the Single European market took and opened new possibilities for airlines to thrive. In consequence of the liberalisation of the market, the demand for air traffic expanded and to ensure safe and efficient air transport; necessary changes had to be taken in the field of ATM. [6]

The pivotal year for ATM modernisation started in 2004 when the European Parliament approved the Single European sky initiative. The highly ambitious goals set in this program intended to transform European airspace to tackle the problems with capacity, congestion and delays caused by increasing traffic. In 2009 SES II package followed with greater emphasis on cost-effectiveness and environmental impact of air transport. [6]

To progress the SES initiative to become a reality, SESAR, standing for Single European Sky ATM Research, was established. In 2015, the European Commission proposed a comprehensive Aviation Strategy for Europe, introducing the goals for the future development of air transport and emphasise maintaining the leading global position in aviation. This Aviation Strategy ensures to boost the European economy and promises to benefit its citizens by offering more connections and lower fares. [6]

European Commission regularly monitors the performance of ATM with the help of the High-Level Groups. Namely, The High-Level Group (HLG) on Aviation and Aeronautics Research

which introduced their vision in Flightpath 2050, secondly, HLG on Aviation Regulation developing proposals to build regulatory framework, as well as determining evolution of EASA and EUROCONTROL organisations. Recently, the European Commission established The Wise Persons Group aiming to provide recommendations to speed up the progress of SES. These groups were established in order to propose the future direction of ATM in Europe. [6]
Lastly, there are many plans and documents regarding the modernisation of Europe ATM and setting the future strategy for the European region. All of the European ATM community works together to achieve goals and high ambitions set in the strategic documents. In this section below, the plans and organisations will be presented in more details. The figure 2.5 presented in the EU Aviation Strategy summarises how European air transport works.


Figure 2.5: How European air transport works. [15]

### 2.2.1. Single European Sky

The Single European Sky is a significant project of the European Commission in the area of air transport which has its roots in the year 1999. Its highly ambitious goals intend to improve the current norms on safety in ATM, to ensure the sustainable growth of the air transport system as well as to improve the performance of ATM system in Europe to ensure that all requirements from the aviation community and airspace users are fulfilled. [7,8]

The crucial milestone year was in 2004 when European Parliament and European Commission adopted the four regulatory packages so-called SES I. These legislation packages determined a regulatory foundation for seamless and safe ATM system with ambitious objectives focused on increasing the capacity, defragmenting European airspace, increasing the safety standards and flight efficiency, to reduce environmental impact and to lower the costs related to service provision. [7,8]

To achieve these objectives, the European Commission set the following highly ambitious goals [9]:

- "*Enable a 3-fold increase in capacity which will also reduce delays both on the ground and in the air*
- *Improve safety by a factor of 10*
- *Enable a 10% reduction in the effects flights have on the environment*
- *Provide ATM services to the airspace users at a cost of at least 50% less*" [9]

The SES I package was amended in 2009 within the second regulatory package so-called SES II as a reaction to the requirements of the member states to create a simpler and more efficient regulatory framework for aviation. SES II package changes focus from capacity to the performance of the system in general. The focus remained mainly in key areas (safety, capacity, environment, cost efficiency). The amendments to the SES I package presented a broad EU extensive performance scheme, focused on refocusing the Functional Airspace Blocks (FABs) that no longer deal with airspace only but service provision above all, Network Manager, and extending the competences of EASA. [7,8]

As a result of a certain dissatisfaction from the part of the European Commission regarding the process of implementation of legislation packages SES I and SES II., Commission proposed in the year 2013 another amendment of the regulatory framework in the new package SES II+. This proposal, however, has not been accepted positively by member states and for now, it is not sure whether and in which form will be the new legislative SES II+ accepted. [7,8]

Nonetheless, the update of SES II+ focuses on seven main areas, namely:

- "*Independence and resources of National Supervisory Authorities (NSAs)*
- *Support services*

- *Customer focus*
- *Performance scheme and the Performance Review Body (PRB)*
- *Functional Airspace Blocks (FABs)*
- *Network Manager (NM)*
- *EASA, Eurocontrol and the institutional landscape*" [7]

The latest released document regarding the SES and its implementation process was published in April 2019. It is called "*The Report of the Wise Persons Group on the Future of the Single European Sky*" wherein the ten recommendations were proposed in order to speed up the process of implementation in order to achieve the desired goals of SES initiative.

### 2.2.2. Single European Sky ATM Research - SESAR

SESAR stands for the Single European Sky ATM Research, and it is vastly considered to be the main technological pillar of the broad Single European Sky initiative focusing on modernisation and harmonisation of the European ATM system. [10,11]

"*SESAR's goal is to define, develop and deploy the operational solutions, the operational solutions with technology enablers needed to increase the performance of the European ATM system. The SESAR lifecycle is composed of three parts: definition, development, and deployment.*" [10]

Two pivotal phases are being executed in the framework of the SESAR programme simultaneously. Namely, the Research and Development phase (2008–2020+) focusing on the development of new solutions, procedures and technologies to improve the European ATM system. While the second, Deployment phase (2014–2020+), plays an essential role in managing the projects and implementing newly invented technologies, procedures and concepts into the European ATM system. [11]

The R&D phase is coordinated by the SESAR Joint Undertaking (SESAR JU) established in 2007 to coordinate and concentrate all R&D efforts in the European Union. Besides, SESAR JU defines the main objectives of SESAR in European ATM Master plan, which drives innovation and modernisation of European ATM through the comprehensive roadmap for the evolution of the European ATM system. [10]

"*SESAR JU is a public private partnership between the main public stakeholders (EU represented by European Commission and EUROCONTROL represented by its agency) and European aviation service and manufacturing industry.*" [10]

Meanwhile, the deployment phase is in the hands of the SESAR Deployment Manager (SESAR DM) established in the year 2014. For the purpose to effectively implement newly invented SESAR Solutions requiring synchronised deployment as part of a Common Project mandated by EU law. [11]

"*The SESAR DM is a not-for-profit international association established under Belgian Law, composed of leading airlines, airports and air navigation service providers, selected by the European Commission to perform the SESAR DM function.*" [10]

#### Vision of SESAR

The world is undoubtedly moving towards a new age where humanity will be progressively dependent on new technologies, digitalisation, artificial intelligence, big data processing. That is to say; all newly emerging technologies are being developed to enhance the general well-being of the society. It can be said that the aviation sector will be certainly one of the first adaptors in using such technologies due to its constant emphasis on modernisation, safety and efficiency of the air transport system as well as providing the best services to society. SESAR highlighted some of the new concepts and technologies in its vision from which is obvious that the future awaiting us is going to be exciting.

According to SESAR "*The main objective of SESAR is to modernise European ATM system by defining, developing and delivering new or improved technologies and procedures (SESAR Solutions)*" [12]

To do that SESAR must keep thinking far ahead in the future and anticipate the evolution of the aviation as well as to adequately react on the new demands from aviation community in terms of new entrants into the market such as drones, high altitude RPAS, smart personal mobility. ATM system is an essential enabler for air transport, therefore, SESAR must deliver the most effective and state of art solutions to tackle new challenges evolving in the European ATM system.

"*In support of the EU Aviation Strategy and the Single European Sky (SES), SESAR aims to deliver an 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 digital technologies that enable improvements at every stage of the flight.*" [12]

SESAR desires seamless integration of highly automated and digitally connected aircraft with the help of more sophisticated ATM system supported by automation, artificial intelligence and new technologies to maintain the safety at the highest levels possible and to ensure the efficacy of the system as such. To turn the vision into reality, the movement towards digitalisation is inevitable whether it is through artificial intelligence, big data, augmented or virtual reality. The adaptation to the new technologies is necessary for a view of building the new ATM ecosystem that will be able to accommodate the diversity of traffic safely, efficiently and with the minimal ecological footprint. SESAR's vision towards a new era of aviation and future innovations is well-depicted in following Figures 2.6 and 2.7, confirming that the future of aviation and ATM is going to be undoubtedly fascinating. [12]

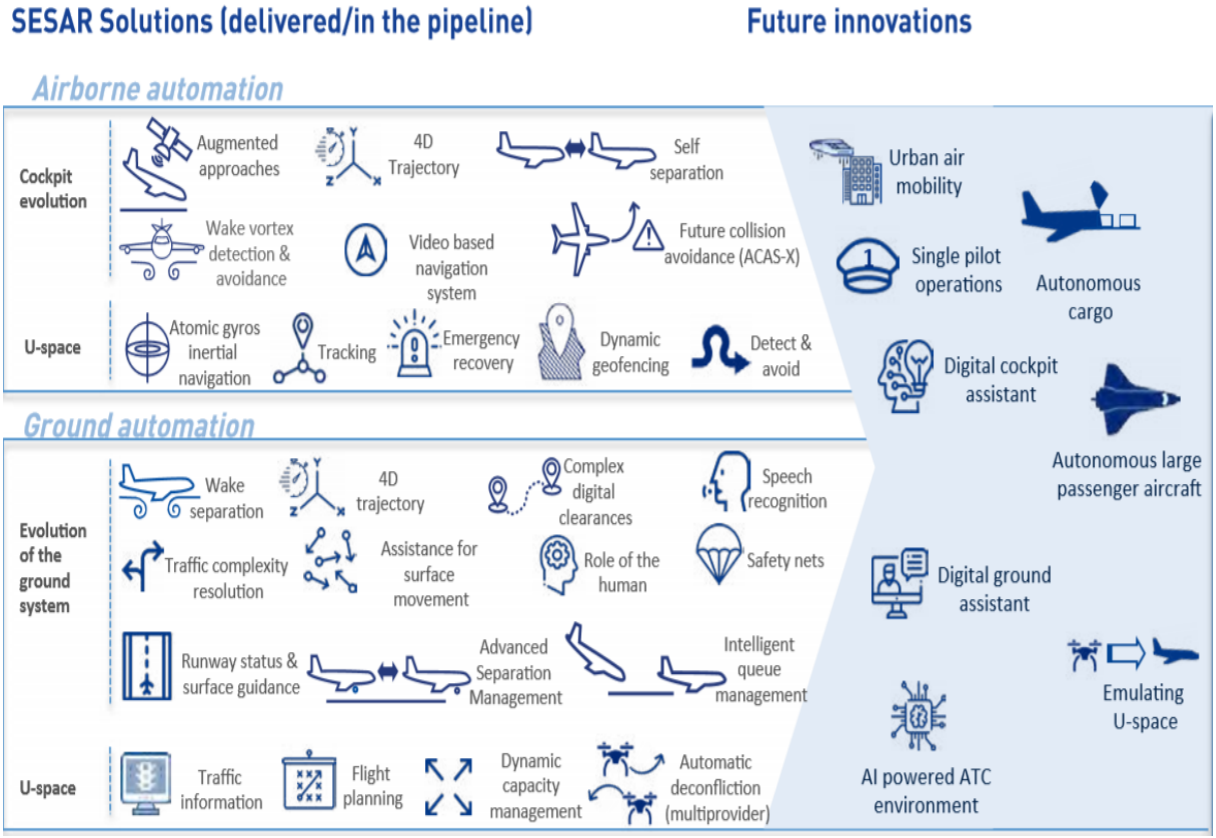


Figure 2.6: SESAR's vision for airborne and ground automation. [12]

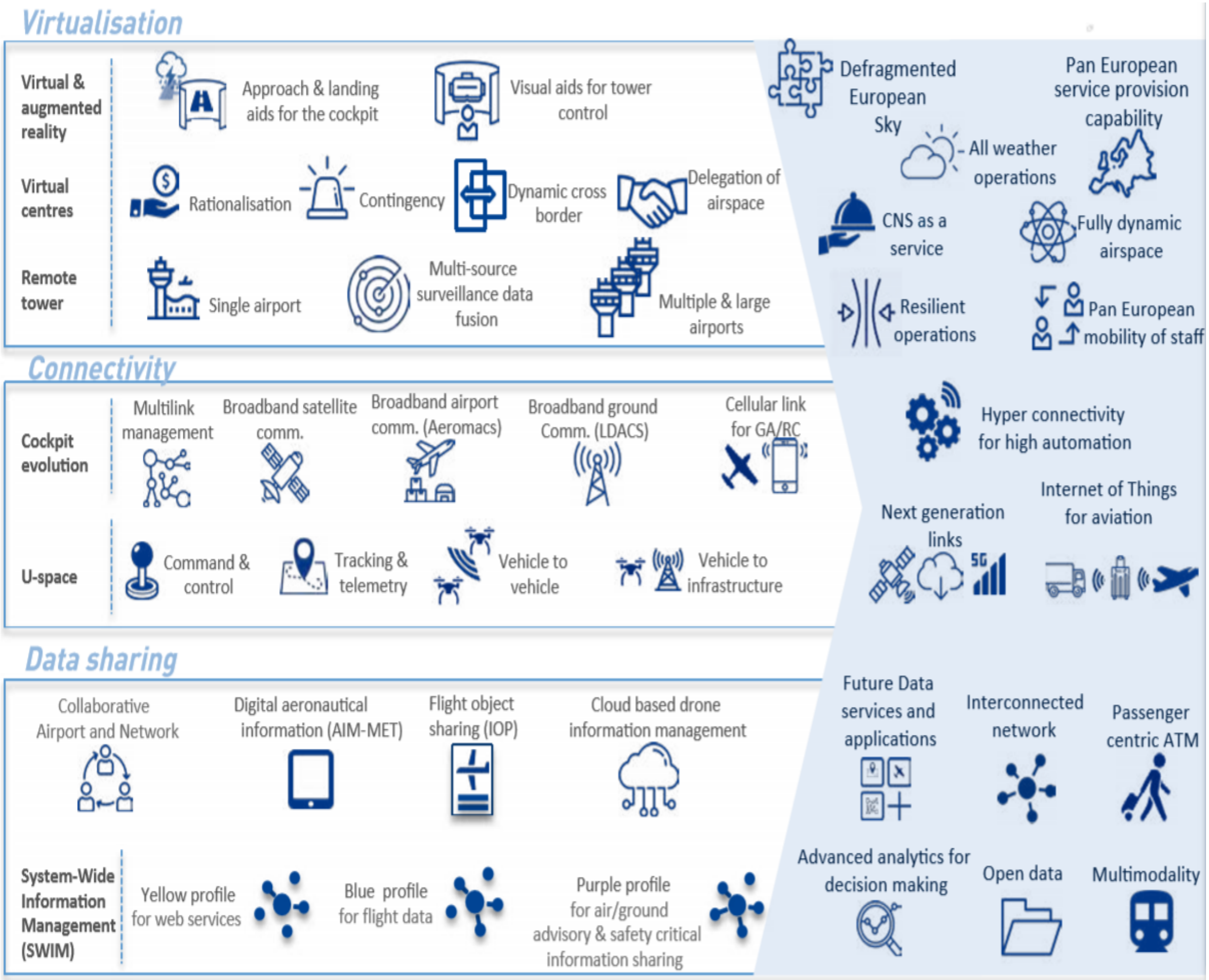


Figure 2.7: SESAR's vision for virtualisation, connectivity and data-sharing. [12]

### 2.2.3. European ATM Master plan

Within the framework of the Single European Sky initiative and its technological pillar SESAR, the European ATM Master Plan serves as a main comprehensive planning tool defining the priorities in the R&D process of ATM in Europe and connecting these activities with the deployment of solutions in the view of achieving the SES performance targets and provides the vision for the European ATM system between now and 2035. [13,14]

It promises a system which focuses more on flight-centric operations and customers, a system that is intelligent, agile and responsive to fulfil future aviation performance requirements. The Master plan is not just a vision, but it defines the R&D priorities as well as the deployment options and the roadmaps for advancing the new generation system. The Master plan allows all phases of the SESAR lifecycle to remain actively connected. The plan also provides the performance gains that stakeholders can obtain in the key areas (safety, cost efficiency, capacity, environment and security) by implementing relevant solutions matching their needs. [14]

With the Master plan, stakeholders can assure their future investments and anticipate the expected benefits. It also allows for deployment synchronisation to ensure that the substantial changes can be executed when needed. This collaborative and holistic approach in planning and implementation means that European stakeholders continue to contribute to the global ATM performance. As described in the first section about GANP, the European Master plan represents the regional level of planning in the global scope. [14]
The content of the Master plan is structured similarly as GANP into three layers as shown in the Figure 2.8 below which allows stakeholders to view information which is relevant to them whether they are executives, planners or those implementing technical or operational solutions. [14]

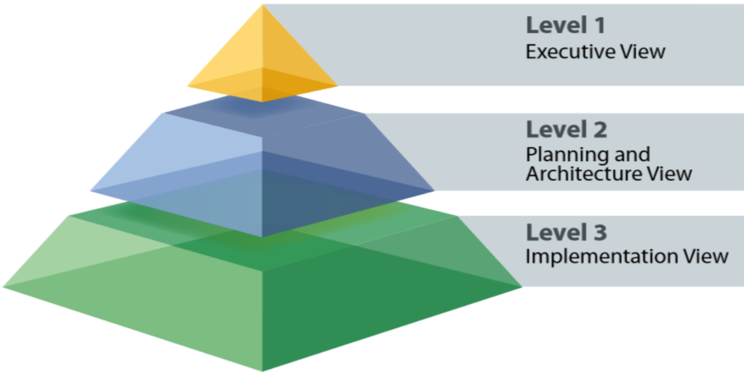


Figure 2.8: Three levels of the European ATM Master plan. [14]

### 2.2.4. European Aviation Strategy

The European Commission published the European Aviation Strategy in 2015. The purpose of this initiative is to strengthen the leadership position regarding the air transport in the global scope, to boost the European economy, to create high-level aviation job positions, to foster the modernisation and overall innovation of European air transport. European Commission focuses on three main priorities in this strategy [15]:

- "*Tapping into growth markets, by improving services, market access and investment opportunities with third countries, whilst guaranteeing a level playing field;*
- ***Tackling limits to growth in the air and on the ground, by reducing capacity constraints and improving efficiency and connectivity;***
- *Maintaining high EU safety and security standards, by shifting to a risk and performance based mind-set*" [15]

In this framework, EU needs to act also in the following areas:

- "*Reinforcing the social agenda and creating high quality jobs in aviation;*
- *Protecting passenger rights;*
- ***Embracing a new era of innovation and digital technologies;***
- *Contributing to a resilient Energy Union and a forward-looking Climate Change Policy.*" [15]

Above mentioned priorities and actions are the main focus of the Aviation Strategy for Europe. The highlighted points relate in its content to the main topic of this thesis, hence, are briefly presented below in more details. The priority "*Tackling limits to growth in the air and on the ground, by reducing capacity constraints and improving efficiency and connectivity*" contains four goals that need to be addressed, namely:

- **Completing the SES** - Achieving SES initiative is a dream of aviation stakeholders in the European aviation community, and despite its establishment more than a decade ago this dream is still far away from making it into reality. Even though there were certainly positive changes in advancement of air traffic management systems as a result of SES initiative, the project is still not delivering expected benefits in raising capacity, improving safety, cost-effectiveness and reducing environmental impact. It can be said that the technology is still not harmonised neither cutting edge. As an essential step, stated in Aviation Strategy for Europe, adopting SES II+ package has emphasised that would, for example, yield more effective functional airspace blocks and network functions.
  EU strongly relies on the development activities carried out by SESAR JU as well as their deployment through SESAR DM in the modernisation of European Airspace. SESAR plays an important role not only in Europe but its influence reaches worldwide. EU supports research and development activities via its programmes HORIZON 2020 and Connecting Europe Facility. [15]
- **Tackling capacity limits** - "*In 2035, according to EUROCONTROL, European airports will be unable to accommodate some 2 million flights due to capacity shortages. There will be more than 20 airports operating at or near full capacity for six or more hours per day, against just 3 in 2012, leading to an additional average airport-related delay of 5-6 minutes per flight.*" [15] The results after such delays would cost an enormous amount of money and would negatively impact the economy of the EU. [15]

These predictions do not seem very optimistic for future ATM, and it is, therefore, more than crucial to approach this capacity problem as soon and as efficiently as possible. European Commission, for instance, "*urges an adopting of slot regulation to enable the optimal use of the busiest EU airports*" [15] as one of the steps for improvement. [15]

- Boosting the efficiency of airport services.
- Better connectivity within EU and worldwide. [15]

Another area of interest described in the EU aviation strategy is "*Embracing a new era of innovation and digital technologies*". This area mainly focuses on unleashing the full potential of drone operations in European airspace, which brings many opportunities but challenges as well. High level of importance being safety regarding the integration of drones into the airspace, therefore, EU must provide the regulations and rules for safe integration for various types of drone operational requirements which can be seen in Figure 2.9. [15]
Europe, with its actions towards Single European Sky, can be considered as a leading example considering the international aviation policy and as a game-changer in the modernisation of air traffic management systems. The EU aviation sector needs to overcome the capacity constraints coming from inefficient use of current technologies and not completely harmonised air traffic system by constant investments into R&D and deployment of new solutions to move towards future seamless air transport. Europe aviation sector is considered as a leader in global aviation, and the EU takes steps, that are highlighted in this aviation strategy, towards maintaining the leading position in the future.

### 2.2.5. Flightpath 2050 and ACARE

Strategic document Flightpath 2050 was published in 2011 and was written by High-Level Group on Aviation Research set up by the European Commission. As a response, the ACARE (Advisory Council for Aeronautics Research in Europe) came up with document SRIA (Strategic Research and Innovation Agenda) in 2012 considered as a roadmap and a path to accomplish highly ambitious goals set in Flightpath 2050. The aviation is a very dynamic sector, seeing that, ACARE published the updated SRIA in 2017, which addresses newly emerged challenges. This section briefly introduces the goals set in the original Flightpath 2050 and provides an introduction into the path of meeting such goals presented in the documents published by ACARE. [16]
ACARE works closely together with all important aviation stakeholders and regulatory bodies, industries, manufacturers, states (European Commission, SESAR JU, Clean Sky). It is critical

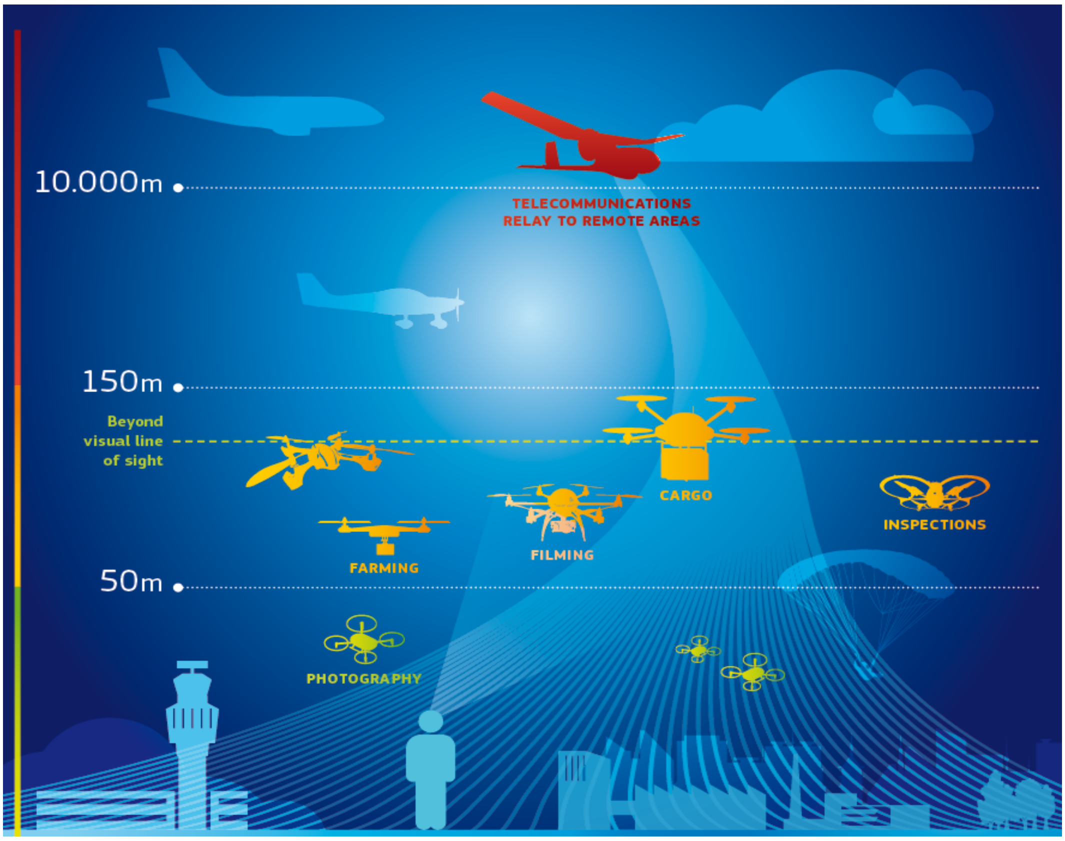


Figure 2.9: Drones operations now and in the future. [15].

to harmonise the research and development activities and remain a tight collaboration with all stakeholders involved in the modernisation of air transport in Europe. How the innovation process from vision to a particular solution progresses is depicted in Figure 2.10. [16]

Flightpath 2050 proposes the main areas of concern and presents key challenges and visionary steps needed to evolve European air transport. The challenges addressed in Flightpath 2050 are the following: [17]

- "*Maintaining global leadership*
- *Meeting societal & market needs*
- *Maintaining and extending industrial leadership*
- *Protecting the environment and energy supply*
- *Ensuring safety and security*
- *Prioritising research, testing capabilities & education*" [17]

Each challenge area includes specific goals that need to be addressed. To demonstrate, the goals of *Meeting societal & market needs* from the ACARE document are presented below:

- "*European citizens are able to make informed mobility choices.*
- *90% of travellers within Europe are able to complete their journey, door-to-door within 4 hours.*
- *A coherent ground infrastructure is developed.*
- *Flights arrive within 1 minute of the planned arrival time.*
- *An air traffic management system is in place that provides a range of services to handle at least 25 million flights a year of all types of vehicle.*" [16]

The newest update of ACARE document complements above-ordered challenges and goals with concrete steps (actions). In the ACARE document, one page is dedicated to each action area expressing how the challenge can be addressed. Furthermore, ACARE provides roadmaps defining actions and targets reaching to 2050. As an example was again taken the Challenge – *Meeting societal & market needs* providing the action areas as follows:

- "*Understand customer, market and societal expectations and opportunities*
- *Design and implement an integrated, intermodal transport system*
- *Develop capabilities to evaluate mobility concepts, infrastructure and performance*
- *Provide travel management tools for informed mobility choices*
- *Deliver mobility intelligence: journey information, data and communication*
- *Provide tools for system and journey resilience, for disruption avoidance and management*
- *Evolve airports into integrated, efficient and sustainable air transport interface nodes*
- *Design and implement an integrated information, communication, navigation and surveillance platform*
- *Develop future air traffic management concepts and services for airspace users*
- *Address cross-cutting issues: system intelligence, human factors and automation support, autonomy and resilience*" [16]

It can be seen that not all of the action areas and challenges address the air traffic management development but rather the aviation sector in general. Despite this fact, it was necessary to introduce the documents mentioned above to provide to a reader whole picture of how the European Commission proceeds in the modernisation of air transport in Europe.

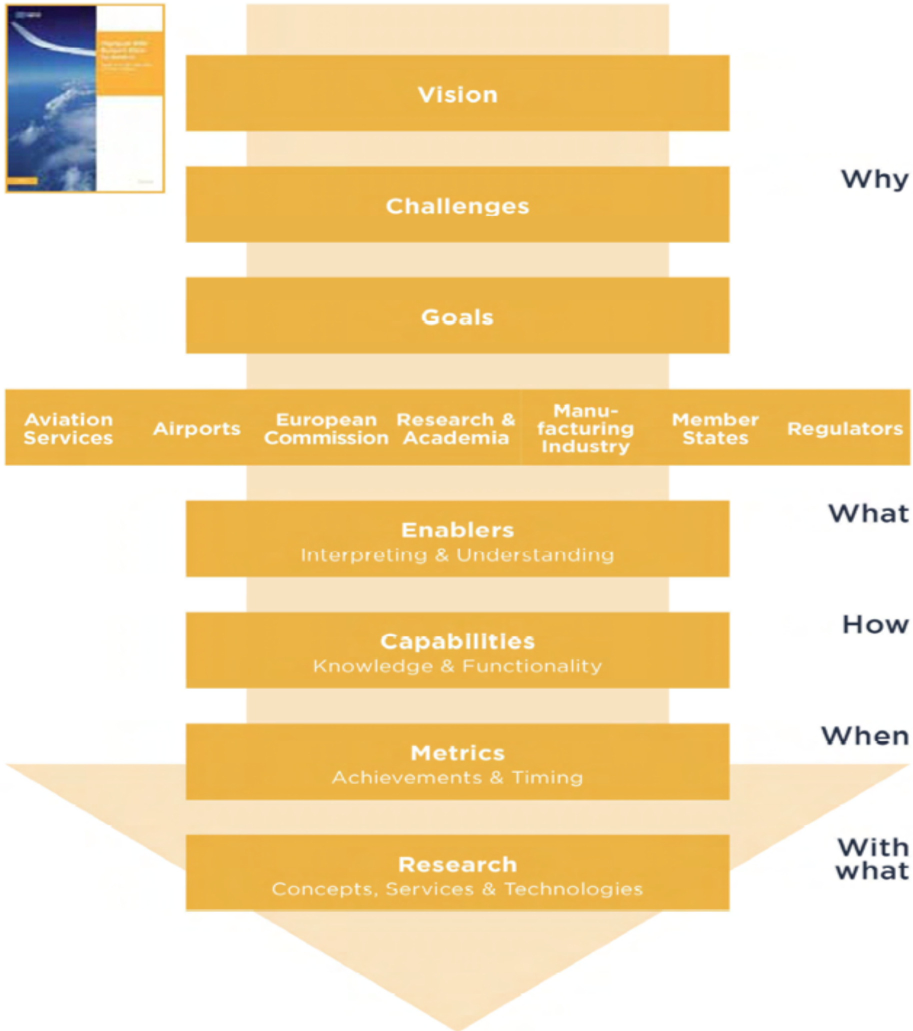


Figure 2.10: ACARE progress of innovation. [17]

### 2.2.6. Future airspace architecture proposal

Future airspace architecture is the latest document published by SESAR in 2019 regarding the reconstruction of the European airspace to prevent delays, longer flight times and more CO2 emissions caused by extra fuel burn. In 2015 "*European Parliament adopted the EU aviation strategy described above and stated that airspace as it is can be considered as a part of EU single market*" [15], therefore the defragmentation of the airspace caused by states boundaries and their Flight Information Regions should be solved to enhance the efficiency of the all air traffic management system in Europe. European Commission was called upon with the concept to implement EUIR European Upper Information Region and entrusted SESAR JU and Network Manager to elaborate a study on the project of SES Future Airspace Architecture. [18]

SESAR and Network Manager collaboratively produced the report on this study where based on their simulations in the year 2035 predicted level of delays will be the highest in the history –

"*(8.5 minutes average enroute delay per flight in 2035 compared to the highest level of delay-5.4 minutes during the Kosovo crisis)*" [18]. Hence, SESAR and Network Manager urge the necessity to increase the pace of modernisation of ATM systems or the traffic delays will continue to rise to an unacceptable level. [18]

The capacity problems caused by the inefficient use of airspace are not new and have been already asserted in Single European Sky as one of the principal goals in 2004. Notwithstanding, Single European Sky is still not delivering the expected benefits, and the defragmentation of airspace remains significant. In this context, the study of future airspace architecture provided the list of limiting factors (see Fig. 2.11) which cause capacity constraints in the current ATM system and served as a foundation for this study. Suggesting a new approach that would yield into a Single European Airspace System was created in alignment with the European ATM Master plan, SES and SESAR. [18]

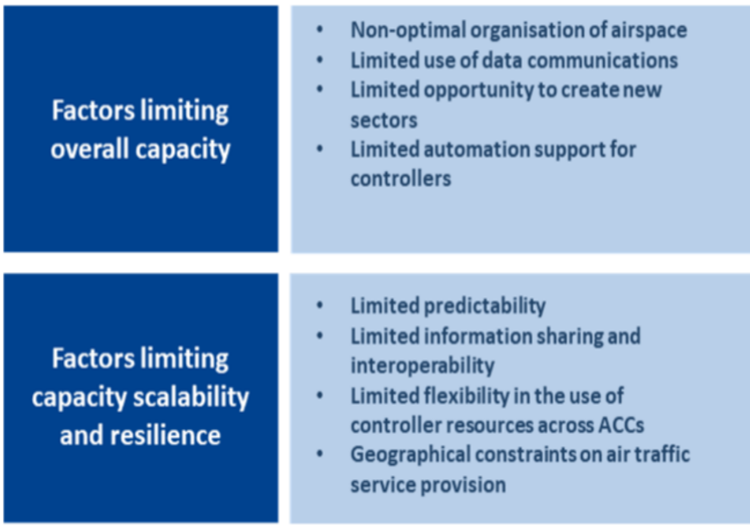


Figure 2.11: Limiting factors. [18]

SESAR and Network Manager suggested how should such an airspace architecture resemble. Single European airspace system would be based on stable connection and optimisation of resources across the network using the state of art technology to provide the data abundant and cyber secure ecosystem leading into higher cooperation between the air navigation providers. This proposed architecture is closer to the SESAR's vision and ready to approach the new entrants competently into the system, such as drones and high altitude operation systems. The proposal of the airspace architecture is illustrated in Figure 2.12 furthermore, the new architecture promises the following results: [18]

- "*Deliver an optimised airspace structure, supported by operational harmonisation;*

- *Enable ATM capacity and scalability to handle all en-route airspace air traffic safely and efficiently, even according to the highest traffic growth forecast or during traffic growth stagnation or downturn;*
- *Allow all flights to operate along (or at least as close as possible to) user-preferred routing across the entire airspace;*
- *Promote an optimal use of ATM resources, reducing current inefficiencies and ATM costs for airspace users (AU) and society;*
- *Increase the overall resilience of the system to all types of incidents, in terms of safety, efficiency and capacity;*
- *Continue to facilitate the civil and military access to European airspace.*" [18]

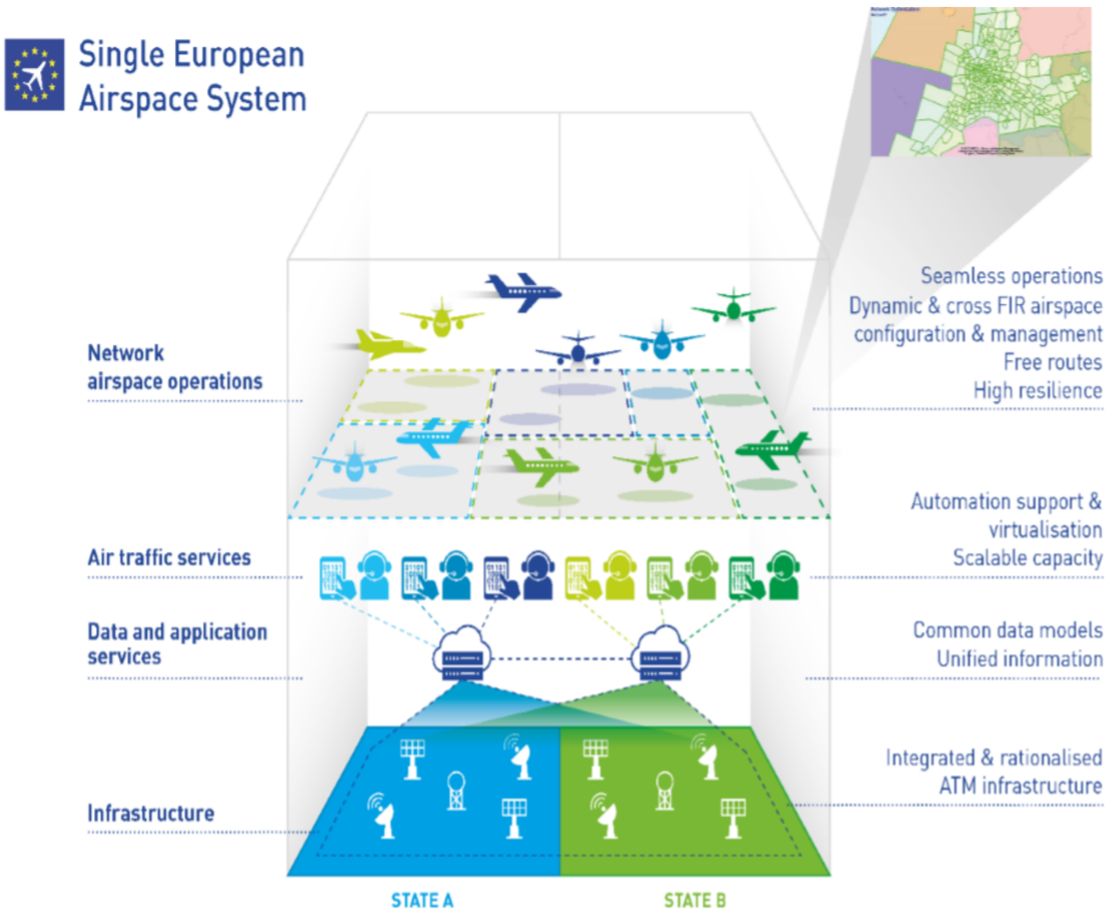


Figure 2.12: Future airspace architecture in Europe. [18]

The future architecture study does not serve as a transitional plan with precise steps but rather as a strategy on how the future airspace could be reconfigured to be more optimised, harmonised and efficient. This study further takes into consideration various transitional speed in different states according to their local needs and capabilities. One of the conditions to assure the early implementation noted in this proposal is to reward the early movers via the creation of some legal, financial framework to keep the states motivated to make improvement efforts heading towards single airspace. The illustration Fig. 2.13 below exhibits a transition proposal with five years milestones towards the single European airspace system. Additionally, the figure presents operational, technological solutions as well as new concepts of navigating aircraft, allowing the reconfiguration progress of European airspace. [18]

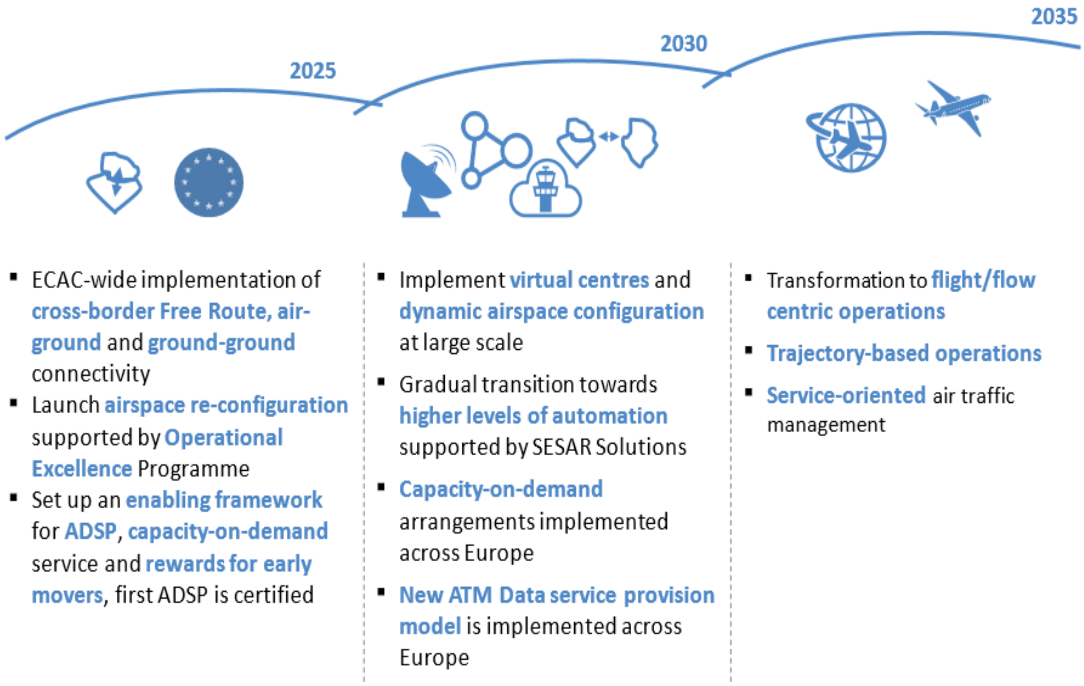


Figure 2.13: Towards the Single European airspace. [18]

SESAR JU has already taken into consideration the proposal study and published a new document called Transition plan which contains the operational and technical dimensions of the target architecture described above and introduces three important measures to achieve the reconfiguration of European airspace. These three measures are:

- "*Launch an airspace re-configuration programme supported by an operational excellence programme to achieve quick wins;*
- *Realise the planned roll-out related to mature SESAR Solutions supporting the implementation of crossborder free route, and air-ground and ground-ground connectivity;*
- *Accelerate market uptake of the next generation SESAR technologies and services in order to prepare the de-fragmentation of Europe's skies through virtualisation and the free flow of data among trusted users across borders.*" [19]

## 2.3. Modernisation of ATM system in the USA

### 2.3.1. NextGen

Meanwhile, in the United States, the Federal Aviation Administration (FAA) came up with the modernisation of the National Airspace System (NAS) program called Nextgen or Next Generation Air Transportation System. The program could be considered as a sibling to the SESAR Single European Sky ATM Research due to its similar approach towards modernisation. With the help of aviation stakeholders, Nextgen strives to improve the NAS by implementing new cutting edge technologies instead of building upon past conventional navigation infrastructure. It can be remarked that the Nextgen is not a single program but rather a set of initiatives regarding development and implementation of new technologies, innovative concepts as well as operational airspace procedures to enhance the NAS to become a more efficient, safer, resilient and more predictable system. [20,21,22]
The Nextgen program was being formulated back in the early 2000s. It was officially adopted in January 2004, when "*Department of Transportation published the Integrated Plan for the Next Generation Air Transportation System.*" [22] Nextgen is now divided into four stages, as can be seen in Figure 2.14 below. These stages are Foundational infrastructure, Expanded NextGen, Realize NextGen, Leverage NextGen and each period brings NextGen goals to the next level and new visions leading to better NAS. [22,23] The NextGen programme promises to deliver the following benefits by the implementation of its new state of art technologies.

- "*Fuel savings for aircraft operators*
- *Reduction in emissions due to more direct and efficient routes and approaches*
- *Reduced separation minimums*
- *Reduced congestion*
- *Better communications across the airspace system and its users*
- *Standardised access to weather information*
- *Improved onboard technology*" [22]

As has been noted above, the NextGen program consists of new smarter, satellite-based and digital technologies and procedures facilitating the evolution of NAS to being safer, environmentally friendly and efficient in increasingly congested airspace. The specific elements of NextGen which all together enable these benefits are as follows: [21]

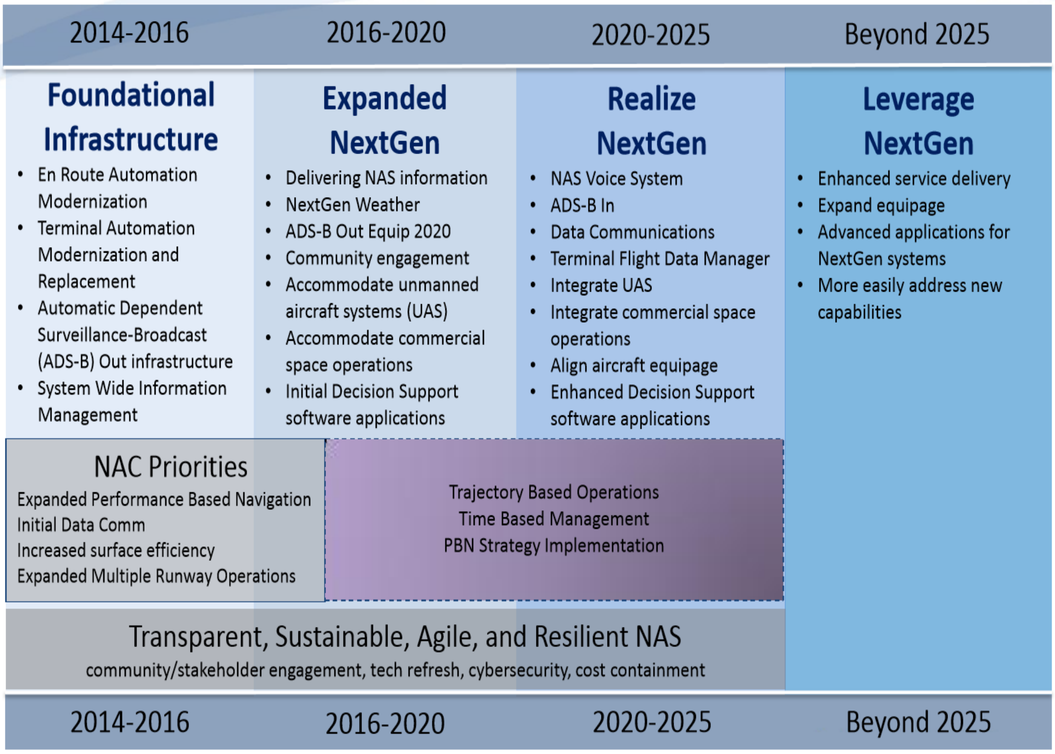


Figure 2.14: Future of NAS. [23]

- **Automatic Dependent Surveillance Broadcast - ADS-B**

  ADS-B is a technology based on satellite signals rather than radars. ADS-B provides more accurate surveillance services to ATC and to other traffic equipped with ADS-B enabling to handle traffic more safely both in the sky and on the ground. Via this equipment, the messages are sent periodically between air traffic controllers and aircraft as well as among the aircraft to determine the position, altitude, heading, ground speed and vertical speed of the aircraft, call sign and ICAO identifier. ADS-B is dependent on high integrity position source on board of the aircraft. The ADS-B provides a radar-like surveillance service to ATC and other traffic as well by broadcasting the aircraft position and other data to other ADS-B equipped aircraft and network of the ground stations which later relay the data to the ATC displays. Once turned into a reality completely, this technology will provide real-time traffic information on both controllers and pilots displays which will yield safer air traffic management even in very congested airspace conditions. [20,21,22]

- **Performance Based Navigation - PBN**

  Concept PBN specifies performance requirements on aircraft navigation systems in terms of accuracy, integrity, continuity, availability and functionality that are essential for navigating aircraft on ATS routes, departure and terminal procedures or in designated airspace.

[21,24] The unique PBN concept shifts from conventional ground-based navigational aids (e.g., VOR, NDB, ILS) towards aircraft's navigation performance. Performance requirements are defined in the way of being able to select navigation sensors and equipment which should be relied on being in alignment with specific navigation performance specifications. Set of PBN applications and navigation specification was defined by ICAO in details to ensure harmonised implementation in countries and regions around the world. Two main specification groups were established, RNAV-aRea NAVigation and Required Navigation Performance - RNP. The main difference among the stated specifications is the capability of "*onboard monitoring and alerting*" in case of RNP increasing a pilot's situational awareness and alerting him when navigation performance is not satisfactory. To determine which performance specification should be used depends on the level of air traffic control services in the intended airspace. If aircraft intends to fly into the area of satisfactory radar coverage, it is sufficient to rely on RNAV. In the opposite case, the RNP specification is required. [20,23,24]

- **System Wide Information Management - SWIM**

  SWIM is an FAA program that facilitates efficient and precise information sharing among aviation stakeholders (airspace users, air traffic controllers and operators) through a single access point. It ensures a more collaborative and secure exchange of ATM data between approved data users and applications. [20, 21]

- **Data Communications - Data Comm**

  Data Comm can be considered progress towards a more digital way of communicating between an ATCo and a pilot. It facilitates an exchange of controller-pilot messages mutually with the provision of clearances as well as other relevant instructions faster and more effectively via datalink communication. As a result of replacing voice communication, datalink communication will reduce controllers' workload and thus will also help to increase their ability to safely and efficiently handle more traffic. [20,21,22]

- **Next Generation Network Enabled Weather - NNEW**

  The FAA designed NNEW program due to the negative impact of weather conditions on the punctuality of a substantial number of flights in the past. The system uses powerful computations for numerical forecasting based on a massive amount of weather information obtained from weather observation sensors around the globe. This new approach to the dissemination of accurate weather information is reachable through a single national weather information system. It will enable controllers and operators better flight planning based on the real-time weather forecast as well as will help with better decision making yielding to the reduction of several delays caused by adverse weather conditions. [20,21,22]

- **Decision Support Systems - DSS**
  DSS consists of three systems (tools) helping air traffic controllers with efficient and safe air traffic management, namely Traffic Flow Management System, Time Based Flow Management and Terminal Flight Data Manager. Collectively these systems provide information about air traffic flow in the NAS allowing demand and capacity imbalances abatement, better control of traffic in the sky based on time instead of a distance, as well as improving movement of aircraft on the ground. [20]

- **Automation**
  Level of automation in aviation goes hand in hand with the continuous progression of technology. Automation promises more reliable and more effective decision making; consequently, it is highly beneficial for air traffic control. One of the NextGen programs is to use the latest technology in air traffic control facilities across the United States to be specific; new cutting-edge computer systems have been deployed – Standard Terminal Automation Replacement System (STARS) and En-Route Automation Modernisation (ERAM) providing a platform for facilitating the abovementioned NextGen capabilities. [20]

Following the implementation of all mentioned NextGen components will the air traffic control move from a system relying on knowing the current position of aircraft to an even safer and precise trajectory oriented operation system based on time predictions concerning where an aircraft will be at significant points throughout its flight which results in enhanced capacity and performance of the system. [20]
Although there has been significant progress in the modernisation of NAS witnessed in the United States due to innovative approach of NextGen and setting the foundation infrastructure, the Figure 2.14 Building the Future of NAS shows there is still a lot to do in the future to fulfil the operational benefits promised by NextGen program. [23]

## 2.4. Modernisation of ATM system in the world

The most significant plans and modernisation programs were introduced in prior sections. Even though greater importance was put on the European region, both SESAR and NextGen programs can be recognised as global leaders in the innovation of ATM systems. They continuously bring new solutions into the ATM systems. By their actions, they set an example to other parts of the world, therefore, play an essential role in defining the vision in Global Air Navigation Plan as successful game changers in the domain of ATM modernisation.

Needless to say, aviation is a global industry helping to connect all parts of the world, and the principal role of ICAO is to guarantee harmonisation in the modernisation of ATM systems globally. Hence, every innovation program should be compatible with the aforementioned ICAO ASBU methodology to achieve desired outcomes. As it has been noted in the European Aviation Strategy document, the Asia Pacific region estimates truly rapid growth in air transport in the following years:

"*With an annual growth forecast of 6%, scheduled passenger traffic in the Asia Pacific region is likely to grow faster than in other regions until 2034 when it accounts for 40% of world air traffic. China is expected to become the world's largest air transport market, overtaking the United States of America in 2023 in terms of number of passengers carried.*" [15]

To handle such a challenging level of predicted traffic growth, the development of ATM systems is crucial. Countries from the Asia Pacific region have started several innovative programmes to advance their ATM systems. This section will give light on a few of them, specifically China's Civil Aviation ATM Modernisation Strategy (CAAMS), OneSKY in Australia, Collaborative Actions for Renovation of Air Traffic Systems (CARATS) Japan. Nevertheless, the growth in air transport is happening globally. There exist many modernisation programmes and strategies in other regions as well, for instance, worth mentioning is Brazilian SIRIUS, which is a leading programme of the South American region.

### 2.4.1. China's Civil Aviation ATM Modernisation Strategy – CAAMS

As was noted in the previous citation, "*China is expected to become the world's largest air transport market in 2023*" [15]. This upcoming challenge will remarkably stress Chinese ATM capabilities. Hence, the steps leading to the modernisation of ATM technologies and service capabilities were determined in their strategy to safely accommodate such demand for air transport. The strategy was determined to effectively implement solutions resulting in developing the modern ATM, which is according to China's hugely ambitious goal supposed to become the best ATM in the world by 2030. [25] There are four main performance areas contained in CAAMS: safety, capacity, efficiency and services. The related performance targets in these areas are as follows:

- "*Safety - to reduce air traffic control-induced accidents by 90% compared to the statistics from the year 2015.*
- *Capacity - to enhance flight operation assurance and support capabilities three times over the level of 2015.*
- *Efficiency - to limit the average flight delays due to traffic control to less than 5 minutes.*
- *Services - to provide air transport with comprehensive, economical and predictable air navigation services, support reduction of flight operations' carbon emissions by 10% and provide flexible, facilitated and assured services for general aviation.*" [26]

The amount of money invested in CAAMS, concretely 8 billion USD [25], which in comparison with 1.6 billion budget of SESAR 2020 [9] show that China takes the modernisation of their ATM system seriously and intends to take over the global position in Air Traffic Management. There are seven integral elements of China's modern air traffic management operational concepts included in CAAMS: Airspace organisation and management, traffic flow collaboration management, High-density airport operations, trajectory-based operations, multiple-mode separation management, civil-military joint operations and performance-based services. [26]
All of these concepts and operations are planned to be supported by new ATM cutting edge technologies and systems such as SWIM, 4D trajectories, enhanced weather reporting and also ADS-B. [26]

### 2.4.2. Australia – OneSKY

Australia set a bold ATM modernisation plan as well, which was named OneSKY and is estimated to be the most complex transformation of ATM in Australia's aviation history. [27] Civil Airservices Australia and Department of Defence operate together to evolve the mutual civil and military air traffic system termed CMATS. The conventional civil and military ATM systems will be replaced by a cutting edge single integrated system considered to be one of the most exceptional integrated ATM systems in the world. The system will be responsible for managing more than 11% of the Earth airspace which Australia currently holds. [27] Seeing that, the project of this scale, managed in collaborative efforts of defence and civil bodies, has not been achieved anywhere in the world and accordingly sets a global example in the coordination of civil and military ATM. [27]
The prime intentions of OneSKY are to provide a reliable ATM system, an adaptable ATM system, a national ATM system, appropriate maintenance to the ATM system and appropriate

support of the ATM system. According to the latest update, the new harmonised ATM OneSKY system will be fully delivering benefits and completely functional by the year 2025. [28] OneSKY will magnify the operational and costs effectiveness, produce a more resilient system, increase safety and security as well as will decrease delays and CO2 footprint. The alliance of civil and military ATM facilitates more reliable and more efficient information sharing through common data provision resulting in greater situational awareness of both civil and military controllers. Mutual FIR will provide benefits in better use of airspace satisfying all airspace users. This OneSKY future system will deliver various operational capabilities into the Australian airspace that will be based on modern technologies and concepts, for instance, ADS-B, trajectory-based operations as well as advanced system information sharing. [27, 28]

### 2.4.3. Japan – CARATS

Japan, with its capital Tokyo, being the largest metropole in the world, is another critical node in the ATM network. Japan is both aware of this fact together with increasing traffic growth. Therefore, since 2010 Japan proceeds towards the innovation of its ATM systems through CARATS (Collaborative Actions for Renovation of Air Traffic Systems) initiative in which sets targets aimed for the year 2025. Objectives of CARATS are as follows: [29]

- "*Safety – Increase the level of safety five times*
- *Capacity – Double the capacity in congested airspace*
- *Services – Improve service level (punctuality and reduction of flight time) by 10%*
- *Operational efficiency – Reduce fuel consumption by 10%*
- *ATS productivity – increase ATS productivity by 50%*
- *Environment – reduce CO2 emissions by 10% per flight*" [30]

To achieve these ambitions, CARATS shall transform its conventional ATM systems into a system based on modernised procedures and technologies. CARATS program determines the eight areas of focus, but the foremost importance remains on the realisation of Trajectory-based operations. Other areas set in the program are, for instance: "*ensuring information sharing for collaborative decision making, promotion of performance-based operations and implementation of satellite navigation.*" [29]

### 2.4.4. Singapore Centre of Excellence for ATM

Singapore recognises the example set by SESAR and NextGen. It takes steps to become an early adopter of ATM modernisation to avoid rising future capacity and safety issues associated with air traffic increase. Singapore is the central hub in the Asia Pacific region; thus, it is another significant link in global ATM. With this in mind, Singapore progresses responsibly with a project to build Singapore as a "Centre of Excellence" which would serve as the main ATM knowledge hub and R&D core containing the world expertise in ATM innovation and delivering solutions to meet their own, as well as the whole Asian Pacific ATM, needs. Seeing that, Singapore plans to become so-called "Mekka" for the experts, organisations, industries working on the ATM modernisation. This effort will not only generate benefits regionally in the Asia Pacific territory but also contribute to ATM community in the global scope by evolving innovative technologies, concepts and operational procedures. [31,32]

### 2.4.5. Brazil – SIRIUS

Brazil is a vast country comparable to the size of the United States or Europe yet is still a developing country considering the level of ATM systems readiness. It stays far behind the progress of NextGen and SESAR. Project SIRIUS brings together various projects regarding, for example, ATM, Safety, CNS, Meteorology intending to provide benefits and improvement of Brazilian ATM national system. Projects SIRIUS also relies on the latest ATM technologies and procedures, which besides the objectives of SIRIUS are the following: enhance operational safety, PBN implementation, flexible use of airspace, implementation of ATFM, improved communication infrastructure and others. [33]

The opening chapter should provide an insight into the process behind the modernisation of ATM systems around the globe. Firstly, it was essential to present a framework of GANP and ASBU methodology facilitating the global harmonisation and interoperability of ATM systems and R&D plans. Later the particular programmes were presented, revealing the impact of GANP and ASBU methodology, essentially it could be noticed that the visions, aims and operational targets are somewhat similar in all introduced modernisation programmes and their slight differences occur simply due to the special needs of the region or nation and due to their current readiness level of ATM systems infrastructure.

# 3. Identification of the scientific research sections

The purpose of this chapter is to identify the most current scientific research sections in ATM. This chapter is devoted to the description of the chosen methodology used for identification. Firstly the mind mapping is introduced, subsequently, the details on the process of mind map creation and the created mind map itself are provided and lastly approaches chosen to identify the research sections are submitted. Identified results proposed in this chapter serve for subsequent comparison with the capabilities of DAT.

## 3.1. Mind map creation

### 3.1.1. Mind maps, mind mapping

Mind maps, mind mapping, have been defined as "*non-linear visual representations of ideas and their relationships*" [34]. Mind maps include a network of interconnected and related concepts, ideas, knowledge. In mind mapping, however, any idea can be linked to another. While creating a mind map, spontaneous thinking is required, and the process of mind mapping intends to find creative associations among ideas. Thus mind maps are essentially association maps. The methods of formal mind mapping presumably began with Tony Buzan in the 1970s. These methods included the use of lines, colours, figures and diagrams to facilitate knowledge restoration. [35]
Buzan himself defines mind mapping as follows: "*Mind Map is a visual tool for holistic, therefore integral thinking that supports all brain functions - especially memory, creativity, learning and all thinking.*" [36]
The primary use of mind mapping is to create an association of ideas. However, another use is for memory recall, although the benefits of mind mapping may be marginal. In general, it is easier to remember the scheme or pictures than to remember the description. [35]
Mind maps can be used widely for instance for decision-making, brainstorming, problem-solving, studying and memorisation planning, researching and consolidating information from multiple sources, organising information, gaining insight on complex subjects. [37]
Mind mapping has been used in various fields including finance, economics, marketing, executive education and medicine but also more creative professions such as art and design, advertising. In addition to these direct use cases, data obtained from mind maps can be used to enhance many other applications; for instance, expert search systems, search engines and search. [38]

The advantages of mind mapping involve mainly its free form and unlimited structure. Mind mapping thus promotes creative thinking and promotes brainstorming. [35]
Variety of software for mind-mapping has been developed which enable to organise large amounts of information, data, and complex subjects into well-arranged structures, thus, providing clear insight into the particular problem.
In the case of this thesis, free XMind mapping software was used for mind maps creation, aiming to identify current ATM research sections. Mind maps enabled comprehensive organising of information and gaining insights into the highly complex subject of ATM R&D.

### 3.1.2. Process of the mind map creation

Mind maps were chosen because they can represent ideas that are linked around a central theme, as well as mind maps, are considered as a natural method of organising and visualising complex data, in this case, research areas in the ATM.
To create the mind map which would enable to identify the most current research sections, the research of the plans for ATM modernisation had to be undertaken. Using the keywords (ATM modernisation, SESAR, GANP, European ATM Master plan) in the Google Search Engine, led to further exploration of the SESAR Joint Undertaking website (www.sesarju.eu). As was described in Chapter 2 - *Overview of future plans for ATM system*, SESAR is considered as the technological pillar of the broader Single European Sky initiative aiming to modernise and harmonise Europe's air traffic management system. "*SESAR's goal is to define, develop and deploy the operational solutions with technology enablers needed to increase the performance of the European ATM system.*" [10] In order to provide a reader with more profound insight into the research& development activities of SESAR, it is needed to present the actions of the current SESAR 2020 programme and its Innovation pipeline process.
**SESAR 2020** - SESAR program focuses on building next-generation air traffic management in Europe as well as supports the SES initiative together with European Aviation strategy planning to move European economy ahead and ensure Europe's leading position in the aviation industry. SESAR 2020 follows the previous SESAR I (2008–2016) that focused on two phases simultaneously, namely the definition, development and deployment phase. The current SESAR 2020 programme, which aims to develop highly innovative technologies and operational solutions, has been put into practice since the year 2016 and will proceed to the year 2024. Primarily, SESAR 2020 concentrates on research and innovation in several domains, namely, integrated aircraft operations, high capacity airport operations, advanced airspace management and services, opti-

mised network service performance and a shared ATM infrastructure of operations systems and services. [39]

SESAR 2020 will work jointly with airspace users of all categories (professional staff organisations, regulatory and standardisation bodies, global partners, scientific community) and founding members (EUROCONTROL and European Union) with the budget of 1.6 billion euros to deliver the most up to date solutions to advance the ATM system in the European region. [39]

The following Figure 3.1 clearly illustrates the process, how the SESAR 2020 proceeds in its research&innovation activities, SESAR calls this development the Innovation pipeline through which concepts are changed into the practical solutions available for industrialisation. The whole process starts with EU Aviation Strategy and Single European Sky objectives which are filled into the European ATM Master Plan that serves as a primary planning roadmap for SESAR's R&D activities. The Innovation pipeline contains three different strands of the R&D process to be specific:

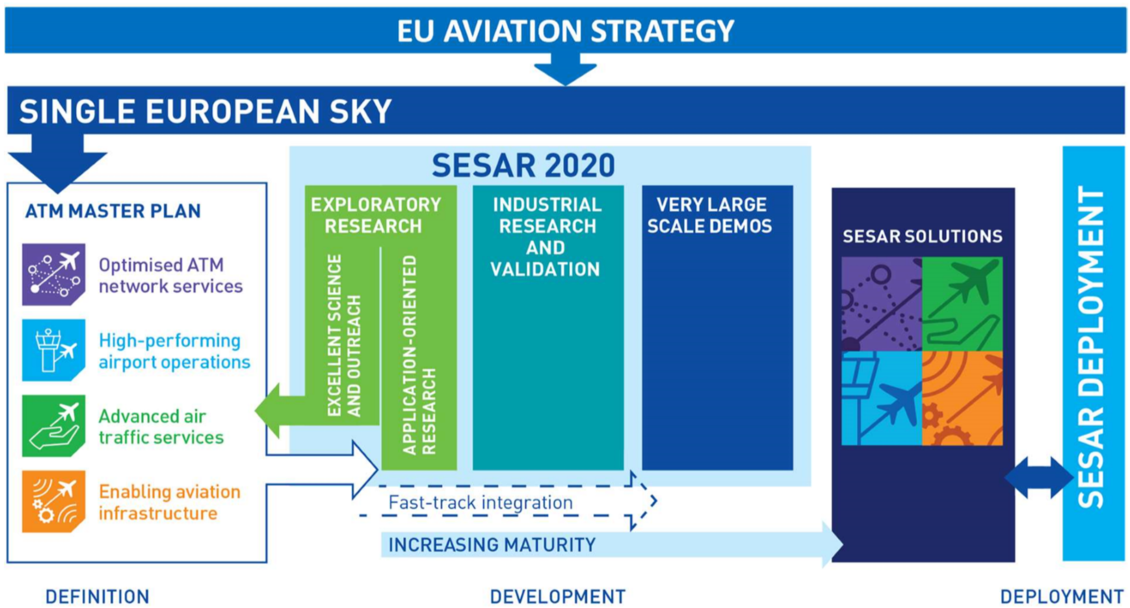


Figure 3.1: Innovation pipeline-from the EU Aviation Strategy to SESAR Solutions. [40]

- **Exploratory research**, contains two areas called excellent science and outreach and application-oriented research. In ER projects SESAR explores new ideas, technologies and concepts not only from areas of aviation and ATM that are not yet identified in European Master Plan but also concepts coming out from different industries, for instance, automotive, robotics, system engineering and aspires to transition these innovative concepts into aviation and ATM context. The projects below this category are being undertaken often by scientific and academic communities organising consortia together with manufacturing companies, air navigation service providers and others aiming to investigate new ideas and apply them in air traffic management. [40,41]

- **Industrial research and validation**, in this strand, the concepts and new technologies are assessed, tested and validated in simulations or real-time operation environments, in other words, solutions are taken from the laboratories and put into the real world. This stage strives to develop the readiness level of solutions to enable their following deployment and transformation into tangible solutions. [40,41]
- **Very large scale demonstrations**, in this stage, stakeholders test solutions readiness level in very large scale demonstrations trials in real traffic and operations. Furthermore, it demonstrates the highest maturity level of solutions that are ready for utilisation by industries and ATM stakeholders and which deliver performance benefits for the ATM system. [40,41]

Furthermore, as can be seen in the Figure 3.1, European ATM Master plan categorises SESAR Solutions and its R&D activities into four key areas namely:

- **Optimised ATM network services** - ATM is a highly interconnected system which must operate seamlessly and efficiently. The solutions below this research category produce a network that is robust and resilient, solving unanticipated circumstances and situations in a safe manner. All will be done due to more reliable information provision within all stakeholders, and solutions will further secure more effective flight planning resulting in higher capacity and enhanced use of airspace. This category involves solutions concerning dynamic, collaborative tools to manage ATC airspace configuration (sectors) and civil-military collaboration for greater predictability and management of operations&airspace use. [40,41]
- **High-performing airport operations** - The future European ATM system depends on the complete integration of airports as centres within the network. This means enhancing the operation of airports, assuring a continuous process through collaborative decision-making, under normal circumstances, and through the further progress of joint recovery procedures under unfavourable conditions. In this context, solutions in this category address, in particular, the need to increase airport capacity by increasing runway throughput, remote towers integrated surface management, overall airport management and airport safety alerts for controllers and pilots. [40,41]

- **Advanced traffic services** - The future European ATM system will be defined by exceptional service delivery, supported by the advancement of automation tools to assist controllers in regular tasks to properly react to traffic demand with extended en-route available capacity. This category shows a shift towards more automation with actions focused on improved arrivals and departures, separation management, enhanced air and ground safety networks and trajectory as well as performance-based free routing. [40,41]

- **Enabling aviation infrastructure** - The improvements outlined in the primary three key functions will be supported by a cutting edge, united and reasoned aviation infrastructure that produces the necessary technical abilities in a resource-efficient way. This category will depend on better integration and interconnection among aircraft and ground systems, including ATC and other stakeholder systems, for instance, flight operations and military mission management systems. CNS, SWIM, trajectory management and emerging human positions will be recognised in a coordinated manner for application in the ATM system in a globally interoperable and harmonised way. [40,41]

The end-stage of the Innovation Pipeline process belongs to the fully developed SESAR solution that is ready to be implemented by various stakeholders benefiting to the entire ATM system. SESAR Solutions relate to brand-new or upgraded operational procedures or technologies that are invented to fit the specified business needs classified in the European ATM Master plan. They are additionally developed in complete accordance with the Global Air Navigation Plan and thus suitable to global ATM environments. [12]

SESAR 2020 solutions served as the fundamental resource for the making of the mind map. Mainly because SESAR 2020 concentrates on the most advanced research&development carried out in the European ATM environment and develops solutions to improve the entire ATM system operation and effectiveness. This mind map was created to reveal the complexity of solutions by showing the technological enablers and operational improvement steps of each solution which is being developed. More importantly, mind map was created as a tool which would enable the identification of R&D sections that might be close in their research activities to research undertaken by the Department of Air Transport, thus could be potentially explored further at the Department.

All Solutions, which are used for the mind map, are available at the European ATM Master plan website www.atmmasterplan.eu. At this website, each solution can be found under the Research&Development View in the Planning section. There the solutions developed by SESAR 2020 programme are put in context and show related elements complemented by their description to explain their precise role.

With the use of the resources outlined earlier, the mind map of SESAR 2020 Solutions was put together by using the XMind mapping software. Mind map SESAR 2020 is displayed in the following section, together with an explanation of its elements.

### 3.1.3. SESAR 2020 Solutions mind map

The map of SESAR 2020 Solutions was developed according to the main four key research areas of SESAR described in section 3.1.2 above. Each area contains solutions that were developed under the SESAR 2020 programme and serve as possible technological improvements of the current ATM system. The following Figure 3.2 shows delivered solutions of SESAR 2020 classified into the key research areas. It should be noted, however, that not every single aspect of the solution was included in the first displayed mind map as this would make the mind map very large. Instead, the cells are collapsed displaying only solutions to comprehensively present sections that are being currently researched and developed.

"*SESAR Solutions are the outputs from the SESAR Programme R&I activities which relate to an Operational Improvement (OI)*[1] *step or a small group of OI steps and its/their associated enablers (EN)*[2]*, which have been designed, developed and validated in response to validation targets that, when implemented, will deliver business benefits to the European ATM*". [42] Solutions provided in the map contain these operational improvement steps and associated enablers so a reader can easily get the notion of what is needed to enable the operation of such a solution. To demonstrate, the following Figure 3.3 shows the extended branch of CNS environment evolution solution where enablers are linked to operational improvement steps that they support. Implementing a set of enablers allows for completing operational steps, moreover, the enablers are the means to make a difference in the ATM operational environment. [43] Due to the immense size of the map, the whole map is attached in its electronic form as an interactive document that can be instrumental as a comprehensive tool to the further exploration of selected topics.

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[1] "*OI-Operational improvements are not necessarily related exclusively to the effect of a change in technology, they can relate to procedures, working methods or routines and human factor aspects. Operational improvement is always associated with an operational benefit. Operational improvement is associated with one or more strategic objectives and is part of one or more directions of change. Operational improvement could also mean the improvement of an existing capability and/or the introduction of a new capability*" [43].

[2] "*EN-New or modified technical system/infrastructure, human factors element, procedure, standard or regulation necessary to make (or enhance) an operational improvement*" [43].

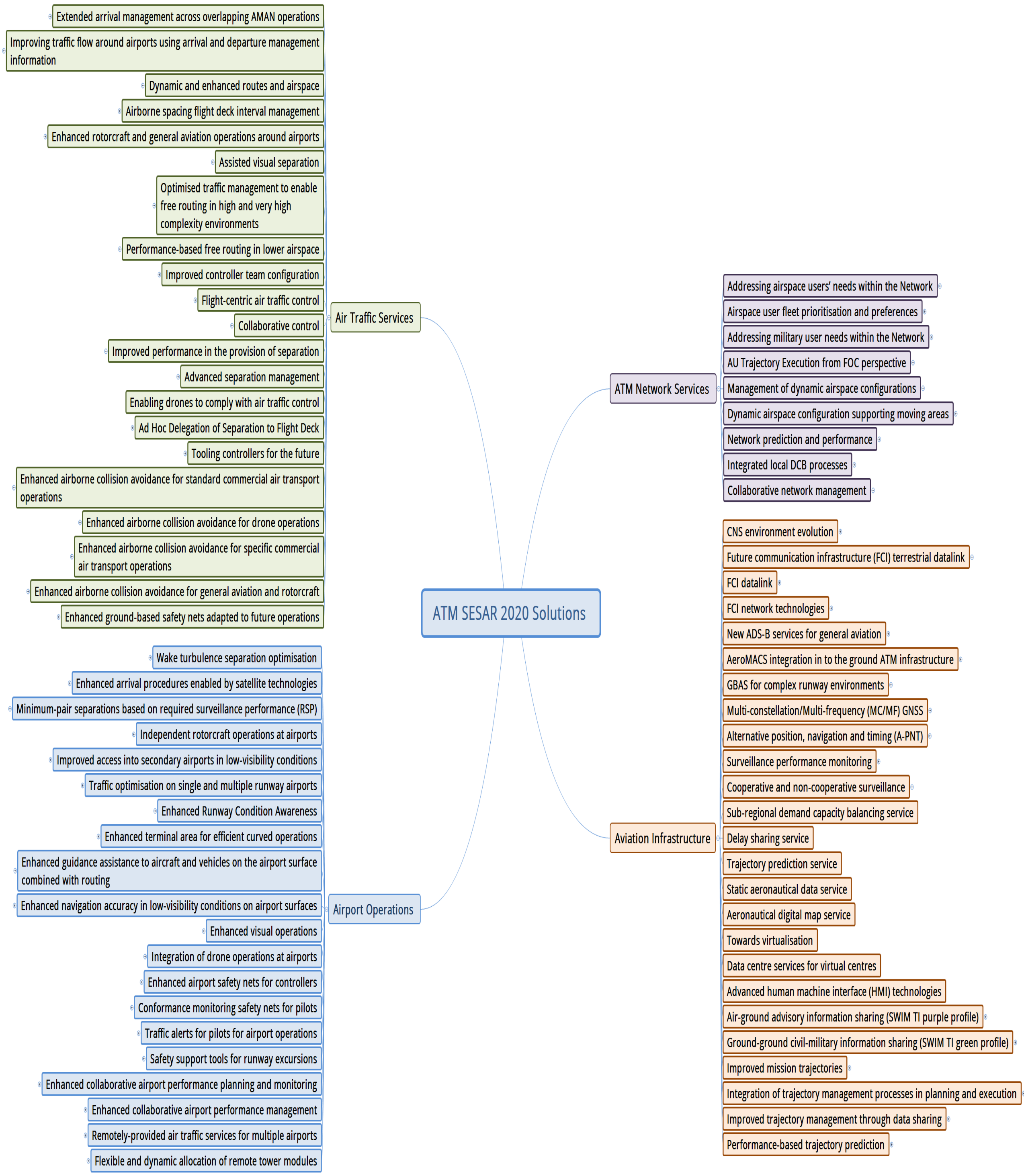


Figure 3.2: SESAR 2020 Solutions mind map.

## 3.2. Identification of the scientific research sections for years 2019–2022

The main goal of this thesis is to identify the most up-to-date research areas. The two methods of identification are described in this section, as first, the quantitative approach based on the

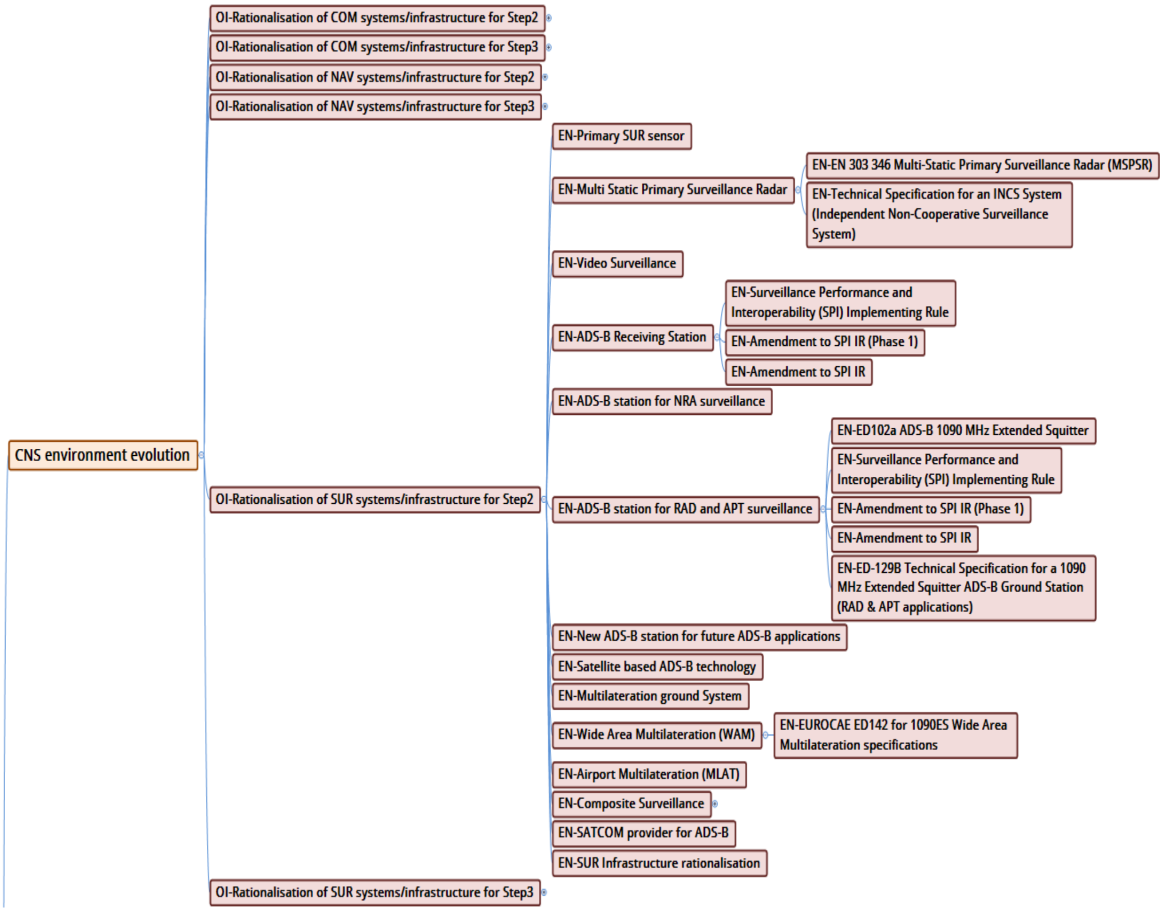


Figure 3.3: Detailed CNS environment evolution solution.

data obtained from the mind map. Subsequently, the qualitative method in the form of further research of the strategic documents chosen to provide more results based on the upcoming plans of SESAR.

### 3.2.1. Quantitative approach

An intention behind the creation of the mind map was the subsequent identification of possible research areas. As the map was being developed and become very large, it was genuinely challenging to propose which areas might need to be further researched. To determine the areas of focus, the quantitative approach was selected. As was mentioned in the section above, all solutions consist of the essential elements-the enablers which allow the operational improvement step to complete. The chosen approach intended to assess the number of enablers which occurred in the mind map repeatedly assuming that the enablers which would occur in the map the most frequently could be considered as the potential enablers for further exploration.

The quantitative approach progressed subsequently. All enablers of the SESAR 2020 Solutions map were extracted from the map into an Excel sheet. Such extracted enablers resulted in the number of 2373 cells. The Matlab software was used to quantify the number of recurrent enablers, and the following Matlab code (Fig. 3.4) enabled the quantification of the recurrent enablers by producing the Excel sheet with results. Matlab identified 269 results that appeared in the mind

```
clear all;close all;clc;
num,txt, raw]=xlsread('SESAR 2020 Solutions Statistics');
rows, cols]=size(txt);
%%
clearvars -except num txt raw rows cols;
List={};
for i = 4:rows
if isempty(List)
List{i-3,1}=txt{i,1};
else
rList, cList]=size(List);
buff=txt{i,1};
checker=0;
for j = 1:rList
if strcmp(List{j,1},buff)==1
checker=checker+1;
end
end
if checker==0
List{i-3,1}=txt{i,1};
end
end
end
List = List(~cellfun('isempty', List));
clearvars i j;
[rList, cList]=size(List);
count=[];
for i=1:rList
counter=0;
for j = 4:rows
if strcmp(List{i,1},txt{j,1})
counter=counter+1;
end
end
count(i,1)=counter;
end
List(any(count==1,2),:) = [];
count(any(count==1,2),:) = [];
%%
plot(1:length(count),count,'b');
countmax=max(count);
disp(countmax)
title('Maximum EN occurance','FontSize',12,'FontWeight','bold','Color','k');
xlabel('Enablers','FontSize',12,'FontWeight','bold','Color','k');
ylabel('Number of EN
occurance','FontSize',12,'FontWeight','bold','Color','k');
%%
C = num2cell(count); DatatoExp(:,1)=List;
DatatoExp(:,2)=C;
xlswrite('DataToGo',DatatoExp);
helpdlg('Check out DataToGo in Excel ;)!','Results');
```

Figure 3.4: Matlab code used for the quantification of recurrent enablers.

map more than once. To determine the number of enablers that will be later compared with the capabilities of DAT, the obtained data were sorted by the number of occurrences into the three intervals to assess the percentage ratio of the extracted data. Following the assumption that the enablers which would occur in the map the most of the time could be considered as showing the highest potential for further exploration, the data were sorted by the number of occurrences, in particular, into intervals (2-9); (10-19); (20 and more). The percentage ratio representing data classified by intervals is depicted in the pie chart in Figure 3.5. The interval of the highest number of occurrences to be exact (20 and more) equals to the 5% sample of all data that occurred in the mind map more than once. This 5% sample represents the following 13 enablers ordered in Table 3.1. Identified enablers serve for subsequent comparison with the research capabilities of DAT. As can be seen from Table 3.1, 10 of the provided results belong to

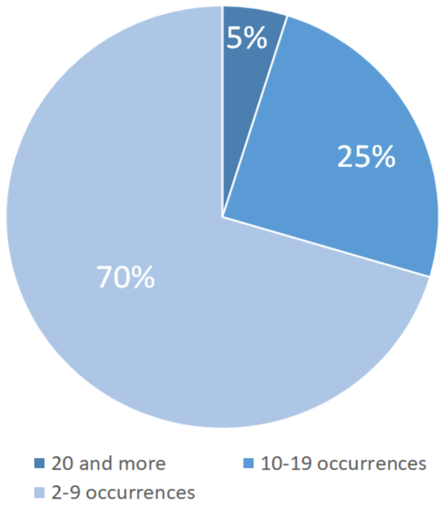


Figure 3.5: The ratio of data sorted by the number of occurrences.

category Standard or Regulation, and the rest stand for the category Systems. The description of enablers can be found at the European ATM Master plan website: www.atmmasterplan.eu where the future steps for the particular enablers are highlighted in a roadmap form. The number of occurrences was the highest for the mentioned enablers standing for legislation which is needed to implement the new operational improvement step. On the other hand, the rest of enablers belong to the category of systems and their brief description of the systems from Table 3.1 is provided below:

Table 3.1: The 13 most repeated enablers of the mind map SESAR 2020 Solutions.

| **Enabler** | **Number of occurrences** |
|---|---|
| EN-Regulatory Provisions for Datalink Extension (DLS II), (Regulation) | 70 |
| EN-Means of Compliance for DLS II, (Regulation) | 70 |
| EN-CS in support of PCP AF3-Free Routes, (Regulation) | 65 |
| EN-New ICAO Standard for ATN/IPS, (Standard) | 45 |
| EN-Flight Information Exchange Model v4 incl. ICAO FPL 2012, Extended Flight Plan and Flight Objects elements, in accordance with SESAR FIXM Strategy, (Standard) | 30 |
| EN-MASPS and MOPS for AMS(R)S Class B, (Standard) | 28 |
| EN-MASPS and MOPS for AMS(R)S Class A, (Standard) | 28 |
| EN-Amendment to DLS IR (Phase 1), (Regulation) | 23 |
| EN-Surveillance Performance and Interoperability (SPI) Implementing Rule | 23 |
| EN-Amendment to SPI IR (Phase 1), (Regulation) | 23 |
| EN-Generate and provide MET information relevant for Airport and approach related operations, Step 2, (System) | 22 |
| EN-Provision and monitoring of real-time airport weather information, Step 2, (System) | 21 |
| EN-New remote sensing technologies supporting MET-ATM Systems for LVP Operations, (System) | 21 |

- **EN-Generate and provide MET information relevant for Airport and approach related operations, Step 2** - "*The ATM-MET system is acquiring, generating, assembling and providing Meteorological (MET) information to the SWIM network in a SWIM compliant manner to support all actors in Airport and approach related operations, including rotorcraft and RPAS operations. The provided information for these types of operations is made consistent with information relevant for other operational user environments such as En-route and Network operations. Dedicated ATM-MET system capabilities will introduce new or improved meteorological observation, nowcast and forecast capabilities to support enhanced decision making. When a high level of consistency and consolidation with MET information for other operational user environments is required, the information will be made available through a system that provides this capability to consolidate and* *make the MET information consistent. This includes the ability to acquire, assemble and provide the relevant, ground, aircraft and space-based MET observation information.*" [42]

- **EN-Provision and monitoring of real time airport weather information, Step 2** - "*ATM-MET ground based sub-system dedicated to acquire, collect, combine, provide and monitor Meteorological (MET) information from real time sensors relevant for the Airport/TMA operational environment including advanced wake turbulence applications, low visibility operations and advanced operations that are more sensitive for wind such as time-based separation and curved approaches. This ATM-MET ground based sub-system enables ATM-MET systems or ATM systems directly by providing real time MET sensor information in a SWIM compliant manner or via direct provision of the legacy/native sensor data feed.*" [42]

- **EN-New remote sensing technologies supporting MET-ATM Systems for LVP Operations** - "*Novel ground based 3D-scanning sensors offer new and improved Information on low visibility conditions at the aerodrome. MET products on visibility conditions (e.g. cloud amount) representative for the aerodrome area can be derived in support of LVP Operations due to long range scanning observations.*" [42]

Introduced enablers are related to the development of meteorological systems and the provision of information for the SWIM network and are further compared with the capabilities of DAT. The quantitative approach was one of the methods for identification of the actual R&D sections. The 13 enablers were identified according to their most frequent occurrences in the map SESAR 2020 Solutions, and this set of data serves for later discussion. Even though for this thesis the sample of 5% enablers was chosen, the SESAR 2020 Solutions map is attached as a comprehensive interactive document intending to serve as a foundation tool for future students and researchers to be aware of the problems that are solved in the framework of SESAR 2020 programme.

### 3.2.2. Qualitative approach

Qualitative method was added to provide another set of R&D sections complementing the quantitative approach. Particularly a method which builds on further research of the newest SESAR strategic and planning documents especially: SJU Single Programming Document 2019-2021, SESAR Solutions Catalogue 2019, European ATM Master plan and for farther future SESAR Exploratory Research document. All of these documents include information about the direction of future R&D sections that need to be addressed. For this chapter the SJU Single Programming

Document provided valuable information about SESAR's plan of the projects for 2019–2022. With this in mind, this section introduces the actual Industrial research topics according to the named strategic document of SESAR. Together with the current Industrial research plan for 2019–2022, the overview also involves fundamental and applied research exploring new concepts beyond those identified in the European ATM Master plan. Exploratory Research section due to its genuinely innovative ideas could be significant for the definition of future research of DAT. Lastly, this section introduces the new European project called ENGAGE which is the SESAR's Knowledge Transfer Network. Project Engage is managed by a consortium of academia and industry to promote and facilitate the development of air traffic management research in Europe. To resume, SESAR addresses its R&D sections in main four key features Optimised ATM Network Services, Advanced Air Traffic Services, High-Performing Airport Operations, Enabling Aviation Infrastructure and the overview is structured in the same way below.

**Industrial research projects for 2019–2022 according to SJU programming document [41]:**

1. **Optimised ATM Network Services**
   **Optimised airspace users operations**
   - Enhanced integration of AU trajectory definition and network management processes
   - Mission trajectories management with integrated Dynamic Mobile Areas Type 1, 2
   - Collaborative framework managing delay constraints on arrivals

   **Digital Network Management Services**
   - Dynamic Airspace Configurations (DAC)
   - Enhanced Network Traffic Prediction and shared complexity representation
   - Network optimisation of multiple ATFCM time based measures
   - Digital Integrated Network Management and ATC Planning (INAP)
   - Collaborative Network Performance Management [41]

2. **Advanced Air Traffic Services**
   **Enhanced Arrival and Departures**
   - Dynamic E-TMA for advanced continuous climb and descent operations and improved arrival and departure operations
   - Next generation AMAN for 4D environment

- Advanced rotorcraft operations in the TMA

**4D skyways**

- Improved Ground Trajectory Predictions enabling future automation tools
- Improved vertical profiles through enhanced vertical clearances
- RBT revision supported by datalink and increased automation
- Trajectory Prediction Service

**Separation Management and Controller Tools**

- Flight-centric ATC and Improved Distribution of Separation Responsibility in ATC
- Delegation of airspace amongst ATSUs
- HMI Interaction modes for ATC centre
- Collaborative control and Multi sector planner (MSP) in en-route

**IFR RPAS**

- Collision avoidance for IFR RPAS
- IFR RPAS accommodation in Airspace Class A to C
- IFR RPAS integration in Airspace Class A to C [41]

3. **High Performing Airport Operations**

**Airport airside and runway throughput**

- Evolution of separation minima for increased runway throughput
- Digital evolution of integrated surface management
- Advanced geometric GNSS based procedures in the TMA
- Improved access to secondary airports
- Safety support tools for avoiding runway excursions

**Total airport management**

- Enhanced Collaborative Airport Performance Planning and Monitoring
- Digital Collaborative Airport Performance Management

**Digital technologies for Tower**

- Multiple Remote Tower and Remote Tower centre
- HMI Interaction modes for Airport Tower [41]

4. **Enabling Aviation Infrastructure**

   **Integrated CNSS**

   - Integrated CNS and Spectrum
   - FCI Services
   - Future Satellite Communications Data link
   - FCI Terrestrial Data Link and A-PNT enabler (L-DACS)
   - Long-term alternative Position, Navigation and Timing (A-PNT)
   - Dual Frequency/Multi Constellation DFMC GNSS/SBAS and GBAS
   - Hyper Connected ATM
   - Aircraft as an AIM/MET sensor and consumer
   - Surveillance Performance Monitoring
   - New use and evolution of Cooperative and Non-Cooperative Surveillance

   **SWIM infrastructure**

   - SWIM TI Purple Profile for Air/Ground Safety-Critical Information Sharing
   - SWIM TI Green profile for G/G Civil Military Information Sharing [41]

The SESAR Exploratory Research has been briefly described in section 3.1.2. All projects that has been covered during the period 2016-2018 are ordered in Tables 3.2 and 3.3, added websites can be instrumental for a deeper insight into details and results of each project. Projects are divided in two main groups. The first group (see Table 3.2) called ATM excellent science&outreach is focused on the fundamental research in four domains, particularly: Automation, robotics and autonomy; Complexity, data science and information management covered wide, Environment and meteorology for ATM; Economics, legal and regulation. The second group (see Table 3.3) ATM application-oriented research also addressed four main areas exactly: High-performing airport operations; Advanced air traffic services; Enabling aviation infrastructure; ATM operations, architecture, performance and validation.

Table 3.2: ATM excellent science&outreach [44].

| **ATM excellent science&outreach** | |
|---|---|
| **AGENT** | Adaptive self-governed aerial ecosystem by negotiated traffic (www.agent-aero.eu) |
| **AUTOPACE** | Facilitating the automation pace (www.autopace.eu) |
| **MINIMA** | Mitigating negative impacts of monitoring high levels of automation (www.minima-project.eu) |
| **TaCo** | Take control (www.tacoproject.eu) |
| **STRESS** | Human performance neurometrics toolbox for highly automated systems design (www.stressproject.eu) |
| **BigData4ATM** | Passenger-centric big data sources for socio-economic and behavioural research in ATM (www.bigdata4atm.eu) |
| **DART** | Data driven aircraft trajectory prediction research (http://dart-research.eu) |
| **MALORCA** | Machine learning of speech recognition models for controller assistance (www.malorca-project.de) |
| **ATM4E** | Air traffic management for environment (www.atm4e.eu) |
| **BEST** | Achieving the benefits of SWIM by making smart use of semantic technologies (http://project-best.eu) |
| **PNOWWA** | Probabilistic Nowcasting of Winter Weather for Airports (http://pnowwa.fmi.fi) |
| **TBO-Met** | Meteorological uncertainty management for trajectory-based operations (https://tbomet-h2020.com) |
| **COCTA** | Coordinated capacity ordering and trajectory pricing for better performing ATM (www.cocta-project.eu) |
| **COMPAIR** | Competition for Air Traffic Management (www.compair-project.eu) |
| **Vista** | Market forces trade-offs impacting European ATM performance (www.vista-eu.com) |

The projects are exemplary of what can be achieved by going beyond the current horizon of knowledge in ATM and aviation by bringing scientists and industries together. Outcomes of the activities proved as the ATM is becoming more and more interdisciplinary, the current and future aviation challenges can be addressed with the application of modern tools and methodologies

Table 3.3: ATM application oriented research [44].

| **ATM application oriented research** | |
|---|---|
| **MOTO** | The embodied remote tower (www.moto-project.eu ) |
| **RETINA** | Resilient synthetic vision for advanced control tower air navigation service provision (www.retina-atm.eu) |
| **COPTRA** | Combining probable trajectories (www.coptra.eu) |
| **OptiFrame** | An optimisation framework for trajectory based operations (wp.lancs.ac.uk/optiframe) |
| **PARTAKE** | Cooperative departures for competitive ATM network service (www.partake-aero.eu) |
| **R-WAKE** | Wake vortex simulation and analysis to enhance en-route separation management in Europe (www.rwake-sesar2020.eu) |
| **SALSA** | Satellite ADS-B for lower separation minima application (www.airbus.com/salsa.html) |
| **NAVISAS** | Navigation of airborne vehicle with integrated space and atomic signals (https://navisas.tekever.com) |
| **SAPIENT** | Satellite and terrestrial architectures improving performance, security and safety in ATM |
| **APACHE** | Assessment of performance in current ATM operations and of new concepts of operations for its holistic enhancement (https://apache-sesar.barcelonatech-upc.eu) |
| **AURORA** | Advanced user-centric efficiency metrics for air traffic performance analytics (http://aurora-er.eu) |
| **INTUIT** | Interactive toolset for understanding trade-offs in ATM performance (www.intuit-sesar.eu) |
| **PACAS** | Participatory Architectural Change Management in ATM Systems (www.pacasproject.eu) |

from other industries. The tables of projects can be instrumental to a reader for having an awareness of the real challenges as well as innovative approaches to face such obstacles. Even though some of the listed projects have been already completed the outcomes and connected ideas can serve for further potential exploration. Subsequently, it is needed to pay attention to the eight ongoing Exploratory Research activities which are described in full details below:

- **Engage**: This project strives to encourage the shift of exploratory research outcomes towards the direction of ATM applications research. The knowledge hub, which will serve as single access to up to date research information in European ATM including information on R&D themes, theories, future priorities and challenges. Engage will be a platform where members of the entire research community are constantly connected and will be able to share their research ideas and work on them collectively. Monitoring, recognising and examining novel possibilities for innovative ATM research related to the evolution of the European ATM system are paramount efforts in the knowledge hub framework. Action strategies and suggestions will be determined and executed with the guidance of interactive roadmap striving to provide an innovative and interdisciplinary set of ATM ideas across the SESAR 2020 timespan. [44,45]

- **EVOAtm-Evolutionary ATM. A modelling framework to assess the impact of ATM evolutions**: This project will simulate the ATM system in a Free Route situation by combining (agent-based modelling, evolutionary agent-based optimisation problem, statistical analysis) with evolutionary computation. The aim is to develop a framework to better recognize and model how architectural and design choices affect the ATM system and its functionality, and vice versa how the anticipated overall ATM performance influence design selection. It will test the framework using familiar situations and quantitative indicators to test its effectiveness in terms of impact assessment, support for design and support for strategic thinking. [44,46]

- **ENVISION-Enhanced situational awareness through video integration with ADS-B surveillance infrastructure on airport**: This project goal is to use modern technologies such as LIDAR (Light Detecting and Ranging), CCTV cameras, sophisticated image processing in the complement of ADS-B to replace more cost demanding systems managing the surface movements reliant on sensors from various kind of surveillance systems SMR, MLAT and ADS-B. This project will benefit to smaller local and regional airports to decrease the equipment expenses, furthermore, to improve their capacity and safety levels through this innovative approach, controlling the surface movement abilities on airports in support A-SMGCS and A-CDM services. [44,47]

- **ADAPT-Advanced prediction models for flexible trajectory based operations**: This project focuses on creating strategic and tactical models to forecast the volume, flexibility and complexity of traffic demand across Europe with the help of the data-based approach. This project not only recognises specific flights but also the network infrastructure. Besides, it aims to develop data-based models to forecast traffic demand across Europe, at the strategic level, will determine the possible bottlenecks and the degree of flexibility of flights. The tactical level will evaluate and mitigate actual network congestions for example by speed corrections of the aircraft. The principal aim of ADAPT project is to advance the strategic planning that would provide benefits in flexibility and decreased costs to all airspace users. [44,48]

- **GATEMAN-GNSS navigation threats management**: This project deals with an innovative approach to navigation threats management because GNSS signals are susceptible to threats, especially jamming and spoofing, which can cause total loss of navigation. GATEMAN is an innovative project aiming to utilise integrated GNSS RFI for air navigation threats management, detection, localisation and finally their mitigation. It will allow keeping the navigation operative in case of a complete signal outage. Furthermore, this new threats management concept will use alternative positioning systems, that are independent of ground systems and can manage the GNSS based approaches as well. The management of those GNSS threats would rely on existing aircraft avionics (with minor adjustments), including an arbitrary operational mode in which ground equipment would be required. Overall, these innovations of this concept will address the combination of existing onboard and ground equipment to open unexpected opportunities for the ANSPs and resulting in cost reduction for airspace users. [49]

- **COTTON-Capacity optimisation in trajectory-based operations**: COTTON's primary goal is to maximize the efficiency of capacity management processes in TBO and make full use of the available trajectory data. [44] This project joins two SESAR 2020 solutions concerning capacity management to be precise the dynamic airspace configurations focusing on sector configurations, ATC controllers workload and the second, Flight Centric ATC solution. Combination of these two solutions will result in enhanced flexibility in unexpected capacity demand fluctuations. [44,50]

- **EMPHASIS-Empowering heterogeneous aviation through cellular signals**: "*The project strives to improve safety, reliability and interoperability of General Aviation/Rotorcraft (GA/R) operations with both commercial aviation and emerging drones operations. These aspects are viewed as critical factors for ensuring and enhancing access to airspace for*

*GA/R users in the future airspace environment and for increasing the operational safety of their operations.*" [44,51]

- **Domino-Novel tools to evaluate ATM systems coupling under future deployment scenarios**: *"The project will develop a toolkit, methodology and a platform for assessing the interconnection of ATM systems from a flight and passenger viewpoint. This platform will enable ATM system designers to gain insight into the impact of the use of new mechanisms. Moreover, it will provide an insight into the impact of deploying solutions in a variety of ways, such as local/independent deployment and information about criticality elements in the system and how they can vary for different stakeholders.*" [44,52]

In response to the current ER activities, the Engage project seems to be a very helpful source for defining future research since at the core of the Engage is the definition of various thematic challenges, above all new ideas suggested by the research community, that are not yet included within the scope of an existing SESAR project. The Engage project enables participation in research by inspiring new researchers to work on the challenges within their PhD programmes or their theses. The first four thematic challenges that have been recently formulated by the research community are stated below.

- **Vulnerabilities and global security of the CNS/ATM system**: The first thematic challenge brought by the scientific community in the framework of Engage project put a strong emphasis on vulnerabilities of the current CNS/ATM systems (e.g. ADS-B, SWIM) which could become victims of so-called cyber-attacks. This thematic challenge revealed the obstacles considering the cybersecurity and cyber-resilience of the present and future ATM systems. [45] ATM is moving toward the more interconnected, digital and automated industry; therefore, it is essential to consider future threats thoroughly. "*The future design security of the systems is crucial: a new generation of system and application architectures should be explored to ensure confidentiality, cybersecurity, fault tolerance, scalability, efficiency, flexibility and trust among data owners. Cooperation and exchange of safety information are essential for all aviation actors; however, it can be especially challenging in ATM context, which is multiple stakeholders, in a multi-system environment and where confidentiality and trust are crucial.*" [45]

- **Data-driven trajectory prediction**: "*This challenge acknowledges the need for precise and reliable trajectory prediction (TP), which is a necessity to support trajectory-based operations. The lack of prior information and inconsistencies between planned and flown* *trajectories due to airport operational uncertainties, ATC interventions and "hidden" flight plan data (e.g. cost indexes, take off weights) are significant weaknesses of the existing pre-tactical and tactical prediction technologies. The challenge presented areas of possible research directions, including machine learning techniques, aggregation of probabilistic predictions, and the development of tools to identify flow control hotspots. These could be integrated into network planning and trajectory tools, leading to upgraded TP.*" [45]

- **Efficient provision and use of meteorological information in ATM**: The third theme of ENGAGE is the weather. The climate has been changing in recent years, and new weather phenomena, such as hail, severe icing, droughts and floods have occurred. Weather plays an essential role in flight planning, and ATM system has to face to weather constraints daily. "*About 20-30% of total ATFM delay has been caused by weather in recent years.*" [45] This thematic challenge is intending to deepen research activities considering so-called "MET" systems and components to prevent constraints and limitations caused by adverse weather conditions. The weather forecasting has improved significantly recently; however, few improvements have reached the ATM environment so far. This challenge aims to bring together the scientific community and jointly proceed in the definition of further research and operational requirements regarding the application of weather information for more effective ATM. [45]

- **Novel and more effective allocation markets in ATM**: Air traffic management is a unique system where demand usually exceeds capacity whether in case of en-route flights, where the number of controllers manages the sector is insufficient or in case of airports, lacking the capacity to receive flight. This undesired situation usually results in costly delays. This fourth challenge investigates economic models to design new market mechanisms which would appropriately address trajectories, routes and slots reallocation to airlines at the tactical level. Aforementioned "market mechanism" does not necessarily mean using money as a means of transactions. The challenge also explores better ways to predict the real behaviour of stakeholders (especially airspace users) compared to the behaviour predicted by classical models, and also to consider the fact that decisions are usually made in the circumstances of uncertainty. [45]

To summarise, this section aimed to provide an insight into the most current challenges and problems that need to be solved in the near future together with the definition of challenges for a distant future. The comprehensive list of themes in this section is intended as a foundation document for the DAT research community.

# 4. Comparison of identified research parts with DAT capabilities

The Department of Air Transport has currently five laboratories at its disposal, in particular: ATM Systems Laboratory, Laboratory of Aviation Simulations, Laboratory of Human Factor and Automation in Aviation, Non-Destructive Testing (NDT) Laboratory and Aviation Safety and Security Laboratory. [53] It has to be noted that this thesis mainly focuses on the identification of the research sections concerning the modernisation of the ATM system. Therefore it is focused primarily on the ATM systems laboratory. To compare the capabilities as well as to propose which areas might be suitable for research in the Department of Air Transport, it is first necessary to present the current research capabilities of the ATM systems laboratory. This chapter includes the introduction of ATM systems laboratory, projects and grants where DAT is involved and the structured interview with the researchers working in the ATM systems area. Subsequently, the comparison and intersection with identified parts for research are provided and the research proposals for identified areas together with final theses suggestions and roadmaps with a view to the year 2025 are proposed.

## 4.1. ATM systems laboratory

The laboratory of ATM systems was established as a part of the Department of Air Transport at the Faculty of Transportation at Czech Technical University in Prague. Its establishing was motivated by the necessity to create a comprehensive platform where it will be possible to use and develop tools for solving specific problems related to the domains of CNS/ATM. The laboratory is expected to carry out research and development activities and also support student projects in the sphere of CNS/ATM systems. The laboratory primarily focuses on analyses, processing of various types and formats of surveillance information data provided by cooperative surveillance systems (SSR mode S, MLAT, ADS-B, etc.) and potential methods of applying this data in Air Navigation Service Providers systems. Adequate software tools are necessary for such research activities mostly tailored to address specific requirements. The laboratory possesses its own network of ADS-B receivers located within the Czech Republic. Cooperation is primarily established with Air Navigation Services of the Czech Republic, ERA a.s., CS SOFT a.s., which enables to utilise and work with provided data from real systems and the real air traffic operations. [53]

The main research domains in which the laboratory participates and directions in which develops its portfolio of activities are: Modelling the load of RF band utilised by cooperative surveillance systems in aviation (1030/1090 MHz), "Quality position indicators" analyses in ADS-B messages, Advanced applications for S radar mode such as (Clustering, Dataflash Application,...), Possibilities for using low-cost ADS-B receivers for non-critical applications, Surveillance data provision for project dealing with the effect of condensation trails on Earth radiation balance. [53]

## 4.2. Projects and grants

This section provides the tables of the projects in which the DAT has been involved since the year 2015, as well as currently ongoing projects. Projects undertaken on a European and National scale are ordered in Table 4.1. The mentioned European projects were both undertaken as part of the H2020 call, and National projects were all engaged in the frame of Technology Agency of the Czech Republic. Table 4.2 shows the Czech Technical University projects in from of Students Grant Competition (SGS).

Table 4.1: European projects and National projects of DAT [53].

| **European projects** | **Period** |
|---|---|
| Capacity building for aviation stakeholders, inside and outside the EU | 2015–2017 |
| Promoting Excellence and Recognition Seal of European Aerospace Universities | 2014–2016 |
| **National projects** | |
| The Psychophysiological Condition of the Pilots and Its Influence on the Final Stage of Landing at the Airport | 2019–2021 |
| Design of Standard Scenarios for Safe Operation of Unmanned Systems | 2019–2021 |
| The value of air transport in the Czech Republic | 2018–2021 |
| Research of intelligent components of systems for collecting and evaluating safety data | 2017–2019 |
| Strategic infrastructure protective system detecting illegal acts intentionally affecting GNSS signals | 2017–2019 |
| Development of effective pilot teaching tools and methodology with an emphasis on increasing flying safety | 2016–2017 |
| Instrument Flight Procedures for Rotary Wing Aircraft | 2014–2017 |
| Research and Development of Progressive Methods for Measuring Aviation Organisations Safety Performance | 2014–2017 |
| The Utilisation of Crisis Management, Risk Management, System Engineering Tools and Modern Technologies to Improve Security at International Airports in the Czech Republic | 2013–2015 |

Table 4.2: CTU projects of DAT [53].

| **CTU SGS projects** | **Period** |
|---|---|
| Evaluation of Pilot´s Psychophysiological State in Real Time | 2019–2020 |
| Study of Fatigue Influence on Pilot's Performance | 2019–2020 |
| Augmented Reality as a form of Pilot's Support during the Flight | 2019–2020 |
| Alternative Navigation Methods for GNSS Signal Unavailability in Aviation | 2019–2020 |
| Optimisation of the Commuter Aircraft Operation Based on the Engine Monitoring System | 2019–2020 |
| Use of ADS-B Messages as a GNSS Interference Indicator | 2019–2020 |
| Conceptual Model of Integration of Safety Studies Knowledge with Safety Data from Operation | 2019–2020 |
| Model of Fatigue for Fatigue Risk Management System of Air Operator | 2019 |
| Method of calculating security performance for system-based security analysis models | 2018–2019 |
| Concept of assessing the operational efficiency of centralised security control posts at airports | 2018 |
| Evaluation of risks caused by unmanned resources in clash with man | 2017–2018 |
| Evaluation of psychophysiological state of pilots based on physiological parameters | 2017–2018 |
| Contrails in Czech airspace | 2017–2018 |
| Optimal aircraft stands configuration for international airports | 2017–2018 |
| Tool for RF Channels 1030/1090 MHz Loading Analysis | 2017–2018 |
| The Use of Sensor Networks for Passenger Security Check | 2017–2018 |
| Development of methods for implementation of evidence based training into initial professional pilot training programme | 2017–2018 |
| Safety Performance Time Series Analysis and Evaluation Model at Air Navigation Service Providers | 2016–2017 |
| The Use of Thermal Imaging Cameras During the Approach | 2015–2016 |
| Design and Testing of New Approach to Land Using GNSS for Small Uncontrolled Aerodromes | 2014–2016 |
| A Study of the Impact of Contrails on the Earth Radiative Balance | 2014–2016 |
| The Development of a Low-Cost Surveillance Solution for Noncritical Applications in the Field of General Aviation | 2014–2015 |

## 4.3. Structured interview

The participants for this study were university experts and researchers working on the challenges of ATM at DAT, and structured interviews with each collected the data. The interview was chosen as a method to get a more in-depth insight into the Department's research areas as well as to get a personal opinion of researchers on the future direction of DAT research.
The questions to university researchers were sent via e-mail. After the interview was accepted the time and date of the meeting was established. All 6 interviews were recorded after the consent of the interviewee. On average, the interviews lasted about 20 min and subsequently the digital soundtrack was analysed. The interviews consisted of a total of 5 questions, and the flow of the interview proceeded from questions regarding the areas of the research at Department to more specific questions about suggested topics for future research and funding. The interview questions and the summarised outcomes are as follows:

1. **What are the main research areas at the ATM systems laboratory?**
   All interviewees responded to a question almost unanimously. The first broad area of research is the Modelling a load of RF (1030/1090) MHz band used by cooperative surveillance systems in the aviation. Specifically, the aim is to invent a tool for prediction of such SSR receivers loading. This topic is being solved in the framework of the SGS (Students Grant Competition) project called Tool for RF Channels (1030/1090) MHz Loading Analysis. As a matter of fact, by the year 2020, all states must comply with new EU legislation ensuring that 1090 MHz receivers are not overloaded. Thus this area of research is very required.
   The other mostly described topic is being solved in the scope of the national project and focuses on developing a strategic infrastructure protective system detecting illegal acts intentionally affecting GNSS signals. This project is being handled in cooperation with the Ministry of the Interior, Faculty of Electrical Engineering and GNSS Centre of Excellence. The Faculty of Electrical Engineering focuses on developing detectors, and an intensive modelling of an optimal location of such detectors is executed on the DAT. Regarding to GNSS interference, one SGS project follows this area of research by using the ADS-B Messages as a GNSS Interference Indicator.
   Another significant area of research that was mentioned by all interviewees was the development of a low-cost surveillance solution for non-critical applications in the field of general aviation based on possibilities of using low-cost ADS-B receivers and Multilateration. Similarly, the question of using the low-cost surveillance information to increase the

safety of AFIS Service has been explored in the framework of the SGS project.

Next area considering the impact of aviation on the environment was utilising the surveillance data for a project dealing with the effect of condensation trails on Earth radiation balance. This research is based on surveillance data provision accompanied by CCTV cameras so the environmental impact can be evaluated. This unique research was supported by two SGS projects dealing with this issue.

Main areas of research concerning the surveillance data utilisation were mentioned. However, the interviewee admitted there might be much more to discover. Therefore the analysis of ADS-B messages shows great potential for further operational applications.

Further topics that were mentioned during the interview and which are being dealt with at the Department regarding the GNSS utilisation for navigation purposes especially the design and testing of a new approach to land using GNSS for small uncontrolled aerodromes or instrument flight procedures for rotary wing aircraft using GNNS navigation. On the other hand, the opposite problem is also being solved the case of signal unavailability in the scope of the SGS project particularly: Alternative Navigation Methods for GNSS Signal Unavailability in Aviation.

Lastly discussed topic also being solved at DAT was the issue of UTM (Unmanned Traffic Management). This new and rapidly growing area opens many possibilities for future research at the Department.

2. **Are the research areas suitable for current R&D and do the areas show potential for future exploration?**

   As it has been already indicated in the first question, some of the areas explored at the Department show truly high potential for future research. All interviewees stressed the most, topics concerning the GNSS interference and load of RF band used by cooperative surveillance systems in the aviation (1030/1090) MHz. One of the respondents even suggested that the topic of GNSS interference might have potential not only for aviation but also in other areas, for instance, the road transport where the GNSS technology can be used by companies to track their drivers or to be used for collecting the toll on motorways. In such cases, the GNSS interference detecting tool could be beneficial to prevent possible illegal acts from happening. Another interviewee also emphasised the area of GNSS interference with providing an idea of the model creation supported by proper data integration which could result even in the global detection of the GNSS interference.

   As a matter of fact, air traffic is constantly growing, and the continuous development of new messages and data transmitted by aircraft is increasing, the load of (1030/1090) MHz RF channel issue becomes more and more critical. So critical that the Department currently cooperates with ANS of the Czech Republic which demands a new strategic tool to model a prediction of the loading (1030/1090) MHz RF channel in future. Even though the interviewees considered these two areas as the most important and the most critical for the near future, all areas which were mentioned in the first question show at least some potential for further exploration, that is to say, all areas explored at Department are suitable for current R&D.

3. **In your opinion, what is the potential of the ATM laboratory in the future, or what topics should be addressed and not, which are interesting and have high potential?**
   The question regarding the potential of the ATM laboratory in the future was again answered almost equally saying that expertise and potential of DAT are genuinely significant. However, currently, there is a big issue with the lack of long term personnel at the Department who could work on research projects, saying that it is the main reason that keeps the advancement of DAT stagnated. The rest of the question provided a variety of answers. For instance, one respondent suggested that DAT should address areas concerning ATM procedures more, as well as to focus more on developing new strategies and procedures to improve the capacity of airspace, e.g. Sectorless ATM concept. In interviewee's opinion proposed procedural areas fit more into the concept of Faculty of Transport Sciences and DAT. There has been too much attention paid to the technical aspects of ATM. However, the primary domain of DAT should be focused more on the data analyses, the efficiency of air traffic controllers, new concepts and procedures in ATM and also operational issues. Relating to the mentioned possibilities, another significant area of concern stressed by more respondents was the use of artificial intelligence (AI), machine learning (ML) for ATM purposes. Due to the increasing digitalisation and automation in aviation, the DAT should keep up with the utilisation of the modern technologies, as well as should be able to find new ways to apply these technologies to improve the efficiency of ATM. The demand for the applications supported by sophisticated technologies is increasing, due to the enormous amount of data needed to keep everything connected. Bringing the new areas like AI and machine learning to DAT could not only help with modelling and prediction of various scenarios but also open new possibilities for future research and strengthen the profiles of graduate students so they would be able to compete on global job markets.

Moving to the areas that are exciting and high potential in the interviewees view omitting the previous AI and machine learning another frequently mentioned topic was the dilemma of drones, their integration in the airspace as well as using drones for surveillance purposes. This area shows significant potential, and due to its current expansion, the solutions concerning drones have to be brought. Said by one respondent: "*This area is so new that the starting point is the same for every organisation. Therefore, we can compete and get involved in solving the UAS dilemma.*"

Further topic showing great potential for future exploration and was mentioned often was the Higher airspace or the area above FL 600 which is becoming a new frontier for flight. The emergence of new airspace users and operations with highly connected and automated vehicles in this higher airspace and of new commercial and state space operations will create new business and social benefits. For example, the Czech company STRATOSYST intending to send their prototypes fully functional observatories which will stay in the stratosphere and maintain the position over an extended period. Those operations, however, bring also new challenges that will have to be addressed, in particular for the aviation sector and air traffic management below FL 600 but also managing the traffic above FL 600.

Last but not least interviewees alluded to the new air traffic control simulators from Eurocontrol called ESCAPE (EUROCONTROL Simulation Capabilities and Platform for Experimentation) that will be installed at DAT in the near future. This simulator will open other possibilities for research by providing the necessary operational data. The ESCAPE simulator could also enable the simulations of the previous topic of air traffic management above FL 600 where for example the situation of getting the observatory station up to the stratosphere could be simulated, and the impact on the air traffic could be studied in depth.

4. **In your opinion, what are the financial requirements of the proposed topics and does the DAT (or FTS) have the ability to cover them?**

   Generally, the respondents stated that almost every high-quality research is financially challenging. However, DAT can solve problems more efficiently regarding finance. Research is typically founded by the public interest in the form of grants and calls ranging from the SGS to European projects. In the Czech Republic exists many opportunities for funding research concerning transportation especially the air transport. The separated question though is to consider the possible partnerships in such calls and grants for example with ANS of the Czech Republic or other even international universities. Respondents agreed that there is not a problem relating to finance; more important is the maturity of the idea and expertise coverage at the DAT followed by the proper formulation of the ideas when asking for such grants.

5. **How do you think the DAT could participate in European projects in ATM (SESAR and others)?**

   In spite of the previous answers indicating that there is a potential of some sections even on a global scale, the last question was almost unanimously followed with the negative answer. Respondents agreed there is a little chance to take part in large European projects as SESAR for the following reasons. For example, one respondent stated that DAT lacks cooperation with more prominent European universities. The universities are not aware of the research conducted in ATM systems laboratory, nor the Department has an awareness of the research in foreign universities either. Thus the necessary intersection of research that could lead to cooperation is missing. Even if the DAT could participate in European projects such as H2020, there is a lack of competence for being a leading organisation that conducts the project; hence, the partnership either with other universities or companies is inevitable.

   Even though there is a negligible chance that DAT could be a leading organisation in large European innovation projects, the same respondent also emphasised that main research areas load of RF (1030/1090) MHz channel, as well as GNSS Interference, have a high level of expertise. Therefore the DAT could offer the possible solutions to tackle the future challenges in these areas and could contribute to the European R&D.

   The topic of the effect of condensation trails on Earth's environment could be potentially the framework worth European project. Therefore the DAT intensively looks for a suitable partnership to explore the area even more.

   All interviewees cautioned about the shortage of long term personnel at the Department, seeing that as the main reason why it might be challenging to be part of such advanced projects like SESAR. Concerning the lack of workforce, another respondent suggested that due to the personnel shortage, DAT could function only as a subcontractor to the more significant organisations, for example, Air Navigation Services of the Czech Republic which is a member of B4 Consortium and taking an active part in SESAR 2020 innovation programme. Given these points, the DAT currently does not have the competence to become a full-fledged member of the SESAR 2020 innovation programme. However, DAT could participate as a member of some consortium or more likely as a possible subcontractor of a consortium member, e.g. ANS CR.

## 4.4. Comparison of research capabilities of DAT with identified areas

This section provides the comparison of research capabilities of DAT, in particular, the ATM systems laboratory with identified areas. The comparison is based on the results obtained from a quantitative approach and the in-depth qualitative research of current SESAR programming documents as well as documents reaching behind the scope of the newest ATM Master plan-SESAR Exploratory Research activities. Results were compared to the description of ATM systems laboratory capabilities, projects and grants in which DAT has been involved and eventually the essential information obtained after interviews with the experts working at ATM systems laboratory.

Regarding the identified topics this section aims at the possible intersection with research areas of ATM systems laboratory furthermore acknowledges the potential exploration in future.

With this in mind, each topic is presented in details, as stated in the strategic documents of SESAR. Description and steps for accomplishing the objectives are then compared with the areas of research at ATM systems laboratory supported by outcomes of the interviews which mostly enabled the evaluation of the possible intersection.

Regarding the quantitative approach, it has to be noted, that the chosen approach intended to assess the number of enablers which occurred in the mind map repeatedly-assuming that the enablers which would occur in the map the most of the time could also be considered as showing the highest potential for further exploration and the highest number of the mentioned enablers stand for legislation or standard (see Table 3.1) which are needed to implement the new operational improvement step. Even though the standards and legislative could also be potentially devised at the DAT, regulations and standardisation do not seem to be the subject for the long term evolving research concerning the modernisation of ATM systems or new operational procedures. Therefore the 10 enablers in the form of regulation and standard were found to be unsuitable for the comparison. On the other hand, the category of systems seemed to be more compelling concerning the potential for the research, nevertheless, the three enablers in form of systems namely:*EN-Generate and provide MET information relevant for Airport and* *approach related operations, Step 2; EN-Provision and monitoring of real-time airport weather information, Step 2; EN-New remote sensing technologies supporting MET-ATM Systems for LVP Operations* described in details in subsection 3.2.1 were found not intersecting any area of research conducted at ATM Laboratory. After comparing the outcomes of the interview as well as the projects where DAT has been involved, there was not found any similarity between these enablers and areas of research performed at ATM laboratory.

In the same way the Industrial research projects for 2019-2022 according to SJU programming document listed in subsection 3.2.2 were taken for consideration of possible intersections where the ATM systems laboratory could add expertise. Starting with the key area called Enabling Infrastructure which focuses more on the technical development of CNS systems; hence this area is the closest in terms of research in the ATM laboratory.

Under this category were considered following topics possibly intersecting the research capabilities at DAT:

- **Long-term alternative Position, Navigation and Timing (A-PNT)**-"*The solution aims at developing A-PNT systems capable of providing better performances in comparison to the short-term solution (based on DME-DME) and support PBN/RNP operations in case of a GNSS degradation or outage. Long term A-PNT airborne solution is expected to support: RNP 1 for the Standard Instrument Departure Route (SID) or Standard Terminal Arrival Route (STAR) developed upon RNP 1 navigation specification, the airways defined with RNP 0.3 or RNP 1 constraints, and preferably RNP-APCH operations down to LNAV/VNAV minima supposing appropriate ground infrastructure.*" [41]

- **Surveillance Performance Monitoring**-"*The solution aims at enabling an improved performance monitoring of surveillance systems and ensuring the correct functioning of the ATM surveillance function. This applies both at the individual sensor level and ATC end-to-end level (input to the controller working position), e.g. spotting degradation trends early in the process. The solution shall consider both current and emergent surveillance techniques: WAM, ground-based and space-based ADS-B, independent non-cooperative surveillance sensors, MLAT, SMR, etc.*" [41]

- **New use and evolution of Cooperative and Non-Cooperative Surveillance**-"*The solution covers major improvements of cooperative and non-cooperative surveillance systems in areas such as composite surveillance (ADS-B/WAM), multi-sensor data fusion, new non-cooperative surveillance systems, secured surveillance systems and future ADS-B communications link.*" [41]

All three topics were considered intersecting the research capabilities of DAT mainly for the reason that the ATM systems laboratory solves similar problems. Concerning the topic Developing A-PNT systems that aim at supporting PBN/RNP operations in case of a GNSS degradation or outage, currently, ongoing SGS project Alternative Navigation Methods for GNSS Signal Unavailability in Aviation is being solved in the Department and addressing the similar issue of GNSS degradation or outage as well.

Other mentioned topics comprise the problems connected with new use and evolution of surveillance systems. In this case, ATM laboratory which deals mainly with analyses, various types and formats of surveillance data provided by cooperative surveillance systems (SSR mode S, MLAT, ADS-B) could contribute into possible evolution and modernisation of such systems.

Further topics considered as the possible intersection belong to the category of Advanced Air Traffic Services:

- **Advanced rotorcraft operations in the TMA** - "*IFR Rotorcraft operations are constrained to use same approach/departure procedures as fixed-wing aircraft, and due to their lower speed profiles, runway throughput is very often negatively impacted at busy airports. Specific rotorcraft procedures need to be defined in particular in adverse weather conditions to assist rotorcraft pilots by extending landing to degraded visual conditions. As well the development of new cost-efficient traffic surveillance systems enhancing the pilot's situation awareness and rotorcraft interoperability with GA, drones and RPAS.*" [41]
- **IFR RPAS accommodation in Airspace Class A to C** - "*The objective is to enable IFR RPAS operating from dedicated airfields to routinely operate in airspace classes A-C as GAT without a chase plane escort. The solution includes the development of ATC procedures, adaptations to the flight planning processes, contingency.*" [41]
- **IFR RPAS integration in Airspace Class A to C** - "*Solution aims at providing the technical capabilities and procedural means to allow IFR RPAS to comply with ATC instructions and the development of new procedures and tools to allow ATC to handle IFR RPAS in a cooperative environment in full integration with manned aviation.*" [41]

The first suggestion regarding the Advanced rotorcraft operations in the TMA was chosen due to the recent research conducted at DAT in the scope of a national project called Instrument Flight Procedures for Rotary Wing Aircraft. Purpose of this project was HEMS operation to hospital heliports in adverse meteorological conditions. In the project framework, arrival, approach, missed approach, and departure procedures using points in space based on GNSS were constructed. As well as descend gradients, and lateral guidance was designed. [54] Gained expertise from solving the national project could be applied for R&D needs stated in the description of the Advanced rotorcraft operations in the TMA dilemma.

The number of remotely piloted aircraft systems is continuously increasing, and this will imply higher interactions with the broader ATM system. The problem of UTM was mentioned many times by respondents during the structural interview, and the integration of RPAS into the ATM is a challenge that needs to be addressed as soon as possible. Because DAT is already involved in projects regarding unmanned systems to be exact the national project Design of Standard Scenarios for Safe Operation of Unmanned Systems, the IFR RPAS topics could be taken as a proposal for further exploration at Department.

After comparing the industrial research projects planned for the years 2019-2022 the possible intersections with projects listed in Tables 3.2 and 3.3 are next to be addressed. ATM excellent science&outreach covers the fundamental research in four domains: Automation, robotics and autonomy; Complexity, data science and information management covered wide, Environment and meteorology for ATM; Economics, legal and regulation. The potential intersection was considered with projects dealing with Human Factor, specifically AUTOPACE, MINIMA, STRESS. The main interest of research of all three projects was to study the impact of automation levels on the ATCOs. For example, 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*" [44]. Currently the Laboratory of Human Factor works on fundamental research focused mainly on pilots, especially in the framework of SGS projects: Evaluation of Pilot's Psychophysiological State in Real Time; Study of Fatigue Influence on Pilots' Performance; Augmented Reality as a form of Pilots' Support during the flight and the national project The Psychophysiological Condition of the Pilots and Its Influence on the Final Stage of Landing at the Airport. Nevertheless, by potential instalment of the new ESCAPE simulators at DAT, there might be a possibility to transition the research from the pilots also to the ATCOs. Even though this thesis is focused on the ATM systems laboratory, there is a clear intersection with the Laboratory of Human Factor research. Therefore, it has to be noted, that Human Factor research also plays a vital role for future ATM.

The rest of the projects were dealing with improving the ATM through modern approaches as artificial intelligence, robotics, autonomy, automation, machine learning, big data science and information management. The other ATM application-oriented research also explored new technologies, for instance, virtual reality for towers, augmented reality for controllers and again, machine learning as well as data processing. Any of ATM application-oriented research was not found intersecting the areas of research at DAT. Project NAVISAS seemed to be close to the research areas of ATM systems laboratory especially the Alternative Navigation Methods for GNSS Signal Unavailability in Aviation; however, their focus was primarily on developing atomic clock and atomic gyro for navigating the airborne vehicle with integrated space and atomic signals.

An increasing trend of digitalisation and automation in ATM is relevant. Coming back to the structural interview, the researchers at the DAT are aware of this new direction. However, according to the actual areas that are being solved at DAT there is not any other possible intersection with ER projects, reason being, these new technologies are not yet used at DAT for research purposes.

Next identified R&D areas that have been presented in subsection 3.2.2 are ongoing Exploratory research activities. Out of the eight introduced projects, two can be considered as intersecting the similar problems as solved at Department. For instance the Project GATEMAN (see 3.2.2) focused on proving a novel concept for integrated GNSS interferences air navigation threats management, aiming at, on the one hand, their detection and localisation and, on the other, their mitigation, either to keep GNSS navigation operative or, if that is not possible, to revert to a cost-effective alternative technology that is able to support GNSS-based approaches [49]. This project deals with a very similar issue as the national project Strategic infrastructure protective system detecting illegal acts intentionally affecting GNSS signals. By getting a more in-depth insight into the GATEMAN project can inspire further steps of research or vice versa DAT could offer its expertise in GNSS interference domain.

On the other hand project EMPHASIS (see 3.2.2) aims to increase safety and reliability of General Aviation/Rotorcrafts (GA/R) operations at low altitude as well as their interoperability with other airspace users such as commercial aviation or emerging drone operations. It is planned to achieve this through affordable CNS capabilities benefiting, among others, from existing and future mobile RF network infrastructure. The project EMPHASIS aims to develop and test the concept of such surveillance building on the ADS-B concept while addressing specific needs of low altitude airspace and GA/R community and taking into account interoperability with new users. [51] Not only the project deals with ADS-B systems, integration with drones in airspace class G, and innovative approach to certification and airworthiness, but also two participants of the project are from the Czech Republic, namely Honeywell International and Evektor. Compared to the areas of research at DAT, the project EMPHASIS intersects the areas where DAT could add its expertise and possibly establish cooperation with mentioned companies in future projects.

Lastly compared were the thematic challenges (see 3.2.2) that have been formulated by the research community within the frame of project Engage. All four themes represent the most upcoming challenges that are not included within the scope of an existing SESAR project. The thematic challenge: Vulnerabilities and global security of the CNS/ATM system are critical because CNS/ATM components (e.g., ADS-B, SWIM, datalink, Asterix) of the current and future air transport system present vulnerabilities that could be used to perform an 'attack'. As it has been mention many times during this section, DAT actively participates in addressing the issues of detecting illegal acts intentionally affecting GNSS signals, therefore, could also add its expertise and be involved in this thematic challenge.

Even though the project Engage is yet to be fully developed, regular attention should be paid for potential active participation in the next thematic challenges. Project Engage might serve for future PhD students as a platform providing calls and inspiration for the most up-to-date research in ATM.

## 4.5. Research proposals and roadmaps

In the section dealing with comparison, several areas of research currently being undertaken in SESAR 2020 and which are planned to be done by the year 2022, were suggested. The purpose of this section is to provide R&D needs of identified themes defined by SESAR, moreover, based on the needs, suggest the final theses themes/topics for future students. These suggestions could also be resolved in the scope of future students' projects in the ATM/CNS field or modified for the specific requirements of ATM system laboratory and the research activities of DAT in general. Furthermore, in this section, roadmaps with a view to 2025 were presented, taking into account the identified intersected areas of research and including proposals for potential cooperation with organisations working on similar problems as DAT in the domain of ATM.

The ATM is truly complex system full of potential for future modernisation. The objective of this thesis is not to solve severe technical problems, though to identify the present areas of research in the ATM domain and find potential intersections with the research capabilities of DAT. Mainly, this work aims to provide an insight into the possibilities for research in ATM that can motivate future researches and students in choosing their research area or writing their final theses. Complex ATM system can offer many directions for cutting edge research as the aviation and ATM has to stay continuously on the top of the technological development to ensure safe and efficient air travel.

One of the tools which can serve as inspiration or at least provision of insight into the current research is the created mind map SESAR 2020 that is attached in its electronic format to this thesis and can be opened by XMind free mapping software. This mindmap contains every operational step and technical enabler of each developed solution in the framework of SESAR 2020, therefore, can be beneficial while looking for a potential topic for final theses or inspiration for further research.

Proposals presented below are research and development needs for topics which were found meeting the area of research at DAT. Each area is subsequently followed by the final thesis theme proposal, together with a brief introduction of objectives for successful elaboration. Topics can be eventually extended or slightly modified by the particular master's or bachelor's thesis supervisors to fit their area of expertise, research requirements or current needs to be as beneficial for the DAT as possible.

### 4.5.1. Advanced rotorcraft operations in the TMA

Advanced rotorcraft operations intend to enhance the integration of rotorcraft in TMA operations. The rotorcraft possesses unique capabilities of tight turns, steep climb and descent, which in combination with GNSS-based IFR procedures and RNP navigation specification enabling flights in low-level IFR routes not only prevent the rotorcraft from interacting with fixed-wing aircraft but also optimise operations in rich urban environments obstacles and noise-sensitive areas. The solution can address the development of several advanced procedures and technologies for rotorcraft, allowing IFR flights and landings in adverse weather conditions. Technologies such as a head-up display (HUD) or other related helmet-mounted systems for enhancing the pilot's situation awareness or approaches using Point in Space (PinS). [55]

Under this area of research, certain R&D needs in the document H2020-SESAR-2019-1 IR VLD WAVE 2 Call Technical Specifications were considered relevant and further specified as follows: [55]

- "*Research should consider possibilities of using enhanced vision systems (EVS) and combined vision systems (CVS) capabilities for rotorcraft flight operations.*
- *Research should consider the exploration of using SBAS/EGNOS technology to support low RNP flight procedures (e.g. RNP 0.1).*

- *Research should consider flight management and guidance for improved lateral navigation in approach via RNP 0.1.*
- *Research on alternative technologies for rotorcraft to meet PBN specifications.*
- *Research on efficient integration of the rotorcraft into the ATM environment by new cost-effective traffic surveillance systems. These systems would increase pilot's awareness and would improve interoperability with GA, drones and RPAS.*
- *Research on the development of operational concepts based on new technologies to support integrated rotorcraft and drones/RPAS flight operations.*
- *Research on developing the TMA interface to control real-time CNS status awareness and submission of relevant ATC information and development of all required ATC procedures for the safe management in case of GNSS unavailability.*" [55]

In this research area, based on R&D needs, the following topic for final thesis elaboration was suggested:
***RNP approach and departure procedures specifically for HEMS using PinS approaches based on augmented GNSS procedures for Vinohrady Hospital Heliport.***
As a foundation, a student shall consider outcomes of the master's thesis of Ing. Tomas Kominek: "*PinS approach usability for HEMS flight*" providing an evaluation of the current situation for HEMS operations in the Czech Republic. The study should consider the precise progress in implementation of PinS for Vinohrady Heliport. A student should consider if approach and departure paths can connect with the low-level IFR route network, if present, and can include initial, intermediate, and missed approach segments. Furthermore, evaluate costs for implementation, operational costs, benefits, problems and potential regulation allowing for PinS.

### 4.5.2. IFR RPAS integration and accommodation in controlled airspace

RPAS belong to the new entrants demanding the accommodation and integration into the ATM system. This problem has been emerging rapidly in recent years; therefore, it is crucial to undertake this issue consistently and focus on the attainable procedures and concepts fit for IFR RPAS operation. RPAS vary significantly in their flight characteristics, e.g. speed, operation altitude, manoeuvrability and all of these have to be taken into account while developing the new procedures and concepts that will facilitate safe air traffic in controlled airspace for all airspace users.

It is required to address the RPAS aircraft in the same manner as to conventional aircraft in terms of their transparency to ATC and other airspace users to achieve successful integration of new IFR RPAS technologies into the ATM system. By the same token, the ATC is responsible for providing separation for RPAS in the same way as it is in case of standard aircraft. [55]
Under this area of research, certain R&D needs in the document H2020-SESAR-2019-1 IR VLD WAVE 2 Call Technical Specifications were considered relevant and further specified as follows: [55]

- Research should consider Detect and Avoid (DAA) systems for IFR RPAS, which serves as a safety net in case of prior to the ATC clearance similar to TCAS and ACAS for crewed aircraft preventing collision with other traffic. DAA should include two functions (collision avoidance (CA) and remain very clear (RVC)). DAA system development is crucial for IFR RPAS operations and overall integration to a controlled environment.
- Research shall identify the initial demand for RPAS between years 2021-2025 intended in European airspace and clearly identify specific needs for IFR RPAS operations (e.g. research on planned military/civil missions, type of operations, future planned commercial activities).
- Research shall also consider the military IFR RPAS flights and missions performed in non-segregated controlled airspace and successfully performed to this date. Subsequently, identify the issues that occurred during past operations and evaluate lessons learned as a foundation for subsequent research.
- Research shall consider the methods of potential communications between a controller and pilot/commander of RPAS based either on the same communication means as for regular pilot-controller or on alternative ways of communications.
- Research should consider the definition of navigation performance and separation minima (among IFR RPAS as well as between RPAS and manned aircraft). [55]

In this research area, the following topics for final theses elaboration were suggested:
***Overview of past military IFR RPAS missions in controlled European airspace and appraisal of its impact on future practise (positives and negatives).***
A student shall elaborate a study of past military IFR RPAS missions performed in controlled European airspace and evaluate issues that occurred during past operations. The comprehensive study should serve as a foundation for future IFR RPAS operations research.

***Identification of initial IFR RPAS demand in controlled European airspace for years 2021-2025.***

A student shall identify the demand for IFR RPAS operations in 2021-2025, including commercial plans as well as military operations. A student shall determine specific needs that will enable accommodation of controlled airspace, based on flight characteristics and type of operations.

***Safety nets and Communications techniques for IFR RPAS.***

A student shall elaborate a study on possibilities of using similar collision avoidance technologies as ACAS and TCAS for IFR RPAS operations and consider the options for communications between controller and pilot/commander. A student shall propose the most promising techniques enabling safe IFR RPAS operation.

### 4.5.3. Higher airspace operations FL 600+

New highly automated technologies will expand the boundaries of current flight operations towards the new limits. Lately, the demand for higher airspace operations (FL 600+) has been increasing and brought new potential for businesses and commercial use, mainly in domains such as telecommunication and meteorology. It is expected that the market for this new kind of operations will grow in the near future. However, this new interest causes different challenges in the ATM system in terms of controlling very diverse traffic in currently unlimited airspace above FL 600, but also in terms of integration with the air traffic while RPAS is climbing or descending through controlled airspace. The diversity of systems striving for higher airspace operations is extensive. RPAS vary either in the type of aircraft, e.g. fixed-wing systems or rotary-wing systems. [56]

Moreover, in their flight characteristics, e.g. "*High-altitude pseudo-satellites (HAPS) are unmanned aircraft which hover for long periods at high altitudes. However, high altitude long endurance (HALE) aircraft are long-range unmanned aircraft operating at a high altitude, carrying out missions that can last over 30 hours*" [57]. This new market for higher airspace operations have been recent; therefore, it opens many possibilities on how to approach higher airspace environment concerning the R&D activities. Higher airspace operations have great potential in innovation, unlike the current ATM system; conventional procedures do not constrain and limit the emergence of new innovative ideas and concepts considering ATM. Thus, it is possible to approach ATM procedures from the absolute beginning and so avoiding bias.

The R&D needs to be stated below are based on the recent European higher airspace operations symposium, which was organised by EUROCONTROL.

- Research shall consider the distinction between very diverse FL 600+ operations, in particular, differentiate the space operations (including launch, re-entry), from other higher airspace operations.
- Research shall consider in the longer term, dynamic management of airspace adapted to the systems performance, reliability, safety, manoeuvrability, predictability and flight profile.
- Research shall study the impact of higher airspace operations on ANSP and other lower and upper airspace stakeholders.
- Research should consider regulation & certification for the aircraft, operation, crew licensing.
- Research shall consider the position reporting and surveillance possibilities and also the way of communication between pilot/commander and ATCo. [56]

In this research area, the following topics for final theses elaboration were suggested:

***Overview of potential higher airspace operations FL 600+.***

A student shall identify the initial commercial/military demand for very diverse higher airspace operations and review the type of operations in terms of the type of aircraft, flight characteristics, flight profiles. Based on the investigated demand, suggest the possibilities in managing traffic above FL 600+.

***Impact of high-altitude pseudo-satellite (HAPS) launch on ANS CR.***

A student shall assess the potential impact of HAPS on Air Navigation Services of the Czech Republic with the help of ESCAPE simulator installed at DAT. Based on real traffic data determine the feasibility of launching HAPS into the stratosphere within the Czech airspace and evaluate the potential issues that can be caused by such launch.

### 4.5.4. Long-term Alternative Position, Navigation and Timing (A-PNT)

Alternative Positioning, Navigation and Timing (A-PNT) will ensure airspace users with a higher precision back up for GNSS procedures based on position, navigation and timing services. A-PNT are the enablers of performance-based operations (RNP and RNAV) due to its reliable provision of navigation performance even in the event of GNSS services degradation or absence, while maintaining capacity and operational safety. It will also decrease the workload of ATCO who would otherwise, in cases of GNSS outage, had to rely on conventional ground infrastructure systems such as DME, VOR and NDB. Besides, it will prevent flight re-routings

and cancellations, which would cause delays and higher costs for airspace users in case of GNSS services unavailability. [55]
Under this area of research, certain R&D needs in the document H2020-SESAR-2019-1 IR VLD WAVE 2 Call Technical Specifications were considered relevant and further specified as follows: [55]

- Research shall study the A-PNT requirements for all phases of flight including navigation reversion modes and increased autonomy aspects.
- Research shall consider the following technologies for A-PNT, which include Multi-DME and RAIM, enhanced DME, L-DACS-NAV, N mode, inertial, including data fusion of these different sources concerning the required navigation performance and integrity.
- Research shall review the long-term A-PNT possibilities that will be based on a new system or technology that has not yet been defined or standardised by ICAO.
- Research should consider that the synergies of the CNS should be exploited as far as possible. [55]

In this research area, the following topic for final thesis elaboration was suggested:
***Alternative Navigation Methods for GNSS service outage in Aviation.***
A student shall evaluate the potential APNT candidates in the aviation and provide a qualitative comparison of all the potential options in terms of navigation performance and integrity. Eventually, the student shall recommend the most promising candidate solutions for APNT.

### 4.5.5. Surveillance performance monitoring

The surveillance performance monitoring considers monitoring of the functionality of surveillance systems. The solution for systems monitoring performance would enable controllers to detect the system degradation instantly resulting in increased safety.
Under this area of research, certain R&D needs in the document H2020-SESAR-2019-1 IR VLD WAVE 2 Call Technical Specifications were considered relevant and further specified as follows: [55]

- Research shall examine the current and upcoming surveillance technologies such as wide area multilateration, ADS-B ground and space-based sensors, independent non-cooperative surveillance sensors MLAT, SMR and others.

- Research shall focus on possibilities to provide the early detection of degradation trends via real-time monitoring for systems above. [55]

In this research area, the following topics for final theses elaboration were suggested:

***RF (1030/1090MHz) Loading Analysis.***

A student shall evaluate the progress that has been done to this date in the ATM systems laboratory. Actively participate in developing a tool for predicting RF (1030/1090 MHz) Band loading analysis.

***Monitoring methods for detecting ADS-B service degradation.***

A student shall analyse the potential methods for real-time ADS-B service outage detection. The student should consider the performance of ground infrastructure antennas, avionics performance and possibilities of detecting service degradation by analysing ADS-B report data.

### 4.5.6. Evolution of cooperative and non-cooperative surveillance

This area of research includes new uses and innovations of non-cooperative and cooperative surveillance. New surveillance systems emerge from combining two different systems together that combination produces particular benefits. Such combined systems are termed composite surveillance systems providing adequate surveillance performance while reducing the operational and implementation costs. That cost efficiency can be beneficial in case of small regional airports or remote tower environments. [55]

Few examples of new developments are in areas, e.g. composite surveillance, multi-sensor data fusion, new non-cooperative surveillance systems, secured surveillance systems and future ADS-B communications link. [55]

Following R&D according to the document H2020-SESAR-2019-1 IR VLD WAVE 2 Call Technical Specifications can be addressed to advance surveillance services forward.

- "*Research should consider adding new capabilities, in case of cooperative sensors, for instance, security screening and reporting methods, into the existing systems such as multi-sensor trackers, ADS-B systems, WAM/MLAT systems, video tracking.*

- *Research should study the progression of ADS-B datalink and information interchange among sensors and composite surveillance to improve sensor uncertainty resolution performance; range (via active interrogation)and range difference (via passive interrogation) measurements from Mode-S (without azimuth measurements) to update the track state such as (position, velocity).*

- *Research should examine the security aspects of alleviating threats by concentrating on RF signals and RF content and producing alarming methods together with more reliable performance.*" [55]

In this research area, the following topic for final thesis elaboration was suggested:

***Modern tracking methods on low-cost surveillance sensors.***

A student shall follow up on the research done by Ing. Petr Lukes in his master's Thesis: "*Design and Development of a Tracker for Requirements of the ATM laboratory.*" A student shall extend the research in the area of tracking algorithms by using low-cost sensors.

### 4.5.7. Vulnerabilities and global security of the CNS/ATM system

The first thematic challenge brought by the scientific community in the framework of Engage project put a strong emphasis on vulnerabilities of the current CNS/ATM systems (e.g. ADS-B, SWIM) which could become victims of so-called cyber-attacks. This thematic challenge revealed the obstacles considering the cybersecurity and cyber-resilience of the present and future ATM systems. The current R&D areas, determined by the scientific community in the scope of the ENGAGE project, are as follows: [45]

- Research shall conduct an initial safety evaluation of the elements supporting air navigation and their relationships to identify vulnerabilities and provide adequate protection against future potential attacks and current global threats.
- Use controls on existing aviation and air traffic systems to detect attacks and make them cyber secure without the need for replacement or reinstallment. Issues relating to certification, liability and accountability should also be considered.
- Research should study different ATM systems (e.g. ADS-B, data link, SWIM, Asterix) that are prone to specific attacks (some of which might still be unknown), such as: corrupting, through false instructions or information, aeronautical communications broadcast in known frequencies or incorrect ADS-B aircraft transmissions called false data injection attacks. [45]

In this research area, the following topics for final theses elaboration were suggested:

***Cyber-secure ADS-B.***

A student shall provide an overview of research activities that have been done in the domain of security of ADS-B to this date. Student shall propose potential solutions for enhancing security and robustness of ADS-B services, for instance, using data comparison from different sources to detect the possible cyber threats.

***Strategic infrastructure protective system detecting illegal acts intentionally affecting GNSS signals in the Czech Republic.***

Follow up on outcomes of research projects Strategic infrastructure protective system detecting illegal acts intentionally affecting GNSS signals being solved by DAT and project GATEMAN described in this thesis. A student should evaluate the current outcomes and issues related to the dilemma of GNNS RFI. A student should consider the potential solutions and methods for identification of GNSS RFI based on existing aircraft equipment (with minor modifications) such as using the ADS-B Messages as a GNSS interference indicator.

### 4.5.8. Roadmaps

Based on the identification that has been done in the scope of this thesis, Roadmaps with a view to 2025 with identified areas for research that can be carried out at DAT specifically in ATM systems laboratory are proposed. The first roadmap regards the new areas for future exploration and suggests the milestones years for particular tasks. Suggested tasks presented in this roadmap shall serve as a possible guide for determining headings of the future research that are relevant to DAT and steps that might be undertaken or at least to be a subject of careful observation in order to be in accordance with the trends of the most significant worldwide plans and therefore use the laboratories' potential as fully as possible.

The second roadmap suggests establishing cooperation with organisations working on ATM modernisation, mainly establishing a partnership with European universities working on similar research areas to advance the current research undertaken at the Department forward. If some of these collaborations were realised, it might significantly increase the engagement of academics and students in researching the most current research topics, bringing the dialogue about modernisation closer to the Department and enable easier participation in these areas if desired.

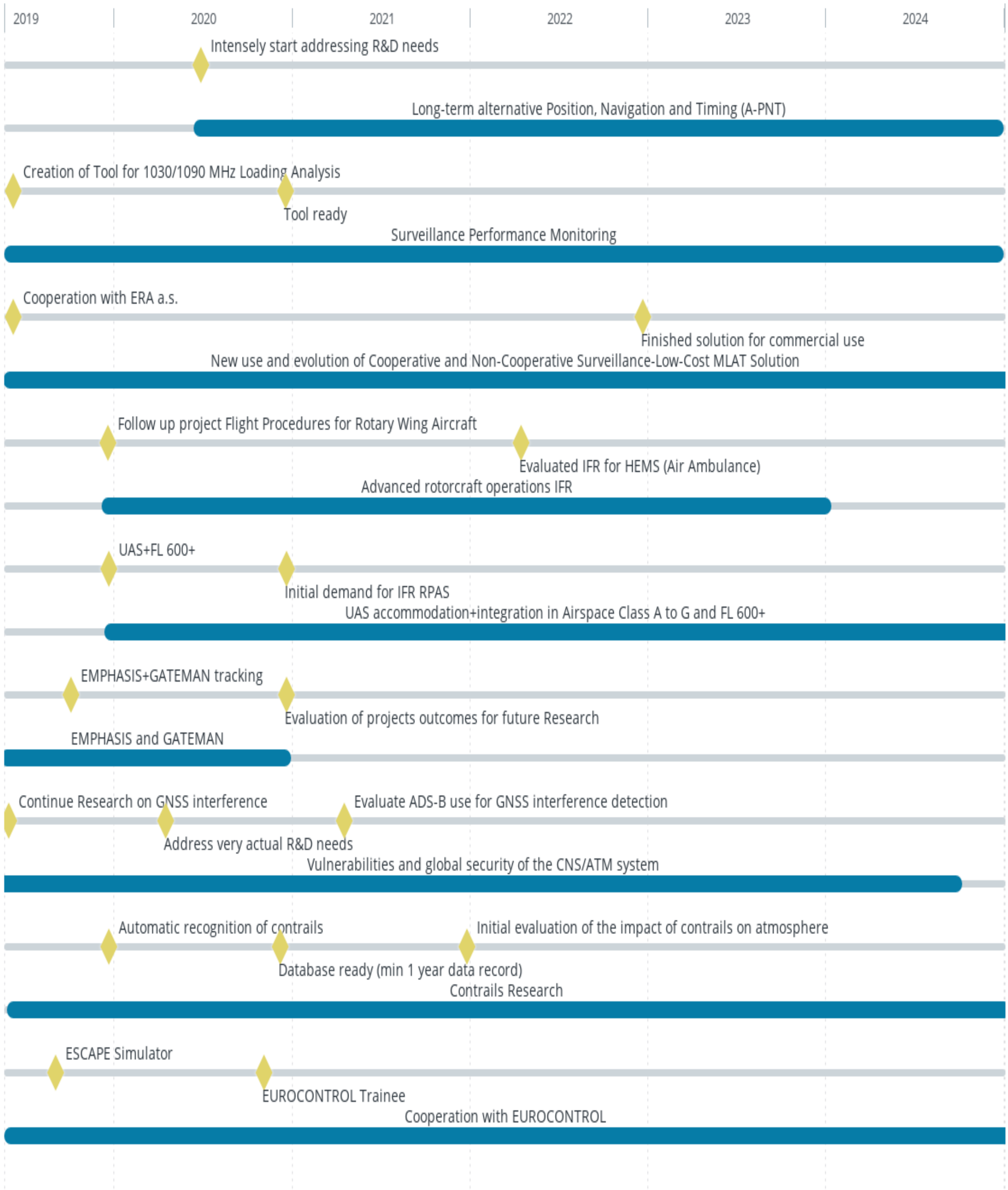


Figure 4.1: Roadmap of new areas for future exploration.

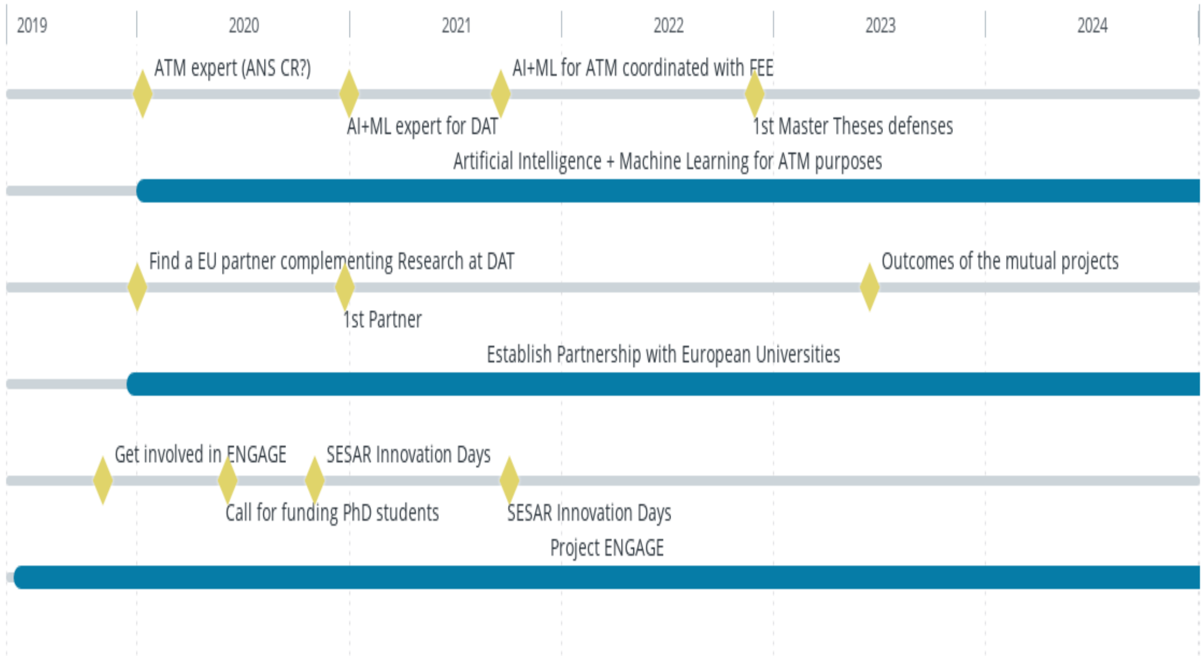


Figure 4.2: Roadmap for future cooperation with organisations.

# 5. Summary and recommendations

The principal purpose of this thesis has been to identify the most current R&D areas concerning the modernisation of ATM and compare them with the research capabilities of DAT, particularly with the ATM systems laboratory focusing on research in CNS/ATM domain.

The first part of the thesis was dedicated to the precisely structured overview of modernisation of ATM systems worldwide and the programmes of leading global organisations working on solving future challenges in ATM. The main emphasis was put on the modernisation process undertaken in Europe, where SESAR can be considered as a leader in the innovation of ATM systems. Accordingly, SESAR 2020 programme, which is the most recent version of the SESAR programme, served as a foundation for identifying the actual research areas due to its cutting edge research & development progress.

For identification of the current R&D areas, the detailed mind map of SESAR 2020 Solutions was created and served as a basis for subsequent quantitative method. The qualitative method was based on in-depth research of the SJU strategic planning documents. Results from both methods were consequently critically analysed and compared to the research capabilities of DAT. Such comparison was supported by a structured interview conducted with academics and experts working at ATM systems laboratory at DAT.

The quantitative methodology was conducted by extracting the data from the mind map. It was then followed by evaluation assuming that the highest number of technological enablers which occurred in the mind map most frequently could also be considered as showing the highest potential for further exploration. This method provided the list of the topics that were later compared; however, similarities with research areas carried out at Department were not found whatsoever.

The second, qualitative approach, provided another list of topics and projects considered to be the primary research areas for years 2019–2022 and the new areas of exploratory research that aim at further future challenges. After comparing the qualitative results, themes that were found related to the research conducted at DAT were determined. Areas and projects found meeting the research areas of DAT are listed in section 4.4.

Additionally, the thesis provided a structured interview conducted with experts working on the modernisation of ATM at DAT. This part not only served as support allowing for the critical comparison but was also another valuable source of information regarding the future potential areas for research. Based on the interviewees' expertise, the following areas were proposed as a possible direction for future exploration:

- Artificial intelligence and Machine learning to further advancement of current research areas,
- New strategies and procedures improving the capacity of airspace, e.g. Flight-centric ATM concept,
- Unmanned Traffic Management and Drones integration, as well as Higher airspace operations above FL 600.

These areas are currently discussed by the aviation stakeholders and international organisations involved in ATM modernisation. They, therefore, show high potential for long term research where the DAT can contribute by its participation.
In conclusion, it can be assuredly said that the research conducted at DAT show considerable potential for the future. In particular, the area dealing with GNSS interference detection. Detecting and mitigating GNSS interference is becoming more and more critical in order to prevent possible cyber-attacks while navigating aircraft. The second area showing high potential for further exploration is a load of (1030/1090) MHz RF channel issue. As the air traffic is continuously growing, and the continuous development of new messages and data transmitted by aircraft is increasing, a load of (1030/1090) MHz RF channel problem becomes severe. These two areas being solved at Department correspond with research themes that are very actual and being addressed on the European scale. Hence, DAT could get involved with its high level of expertise in more notable European projects.
Besides the mentioned areas, the new ESCAPE simulator that is going to be installed at the DAT will offer new possibilities and significantly expand the areas for research at the DAT.
Taking all the research mentioned in the thesis into account, the following recommendations for DAT are proposed:

- The Department of Air Transport should focus more on research in areas concerning ATM procedures, on developing new concepts and procedures to improve the capacity of airspace, e.g. Flight-centric ATM concept, a delegation of airspace amongst ATSUs etc., as well as on addressing the operational issues.
- The DAT should be able to react to the increasing digitalisation and automation in aviation and put more emphasis on computer sciences. Bringing the new areas like AI and Machine learning to DAT could not only help with modelling and prediction of various scenarios but also open new possibilities for future research.

- The DAT could consider cooperation with the Faculty of Electrical Engineering (FEE) in terms of coordination of the project-oriented study so that the new concepts and operational procedures could be suggested at DAT and the technical aspects enabling the new concepts could be carried out by FEE.
- The DAT should deepen cooperation with companies actively working on SESAR projects (e.g. Air Navigation Services of the Czech Republic, ERA a.s, CS SOFT a.s., Honeywell International) so the DAT could add its expertise as a possible subcontractor. DAT should also aim to find partnerships among European universities conducting related research.
- The DAT should actively follow the project ENGAGE, which defines new thematic challenges that are not yet included in the scope of any SESAR project and are defined by the research community. ENGAGE will also become the knowledge hub a single European point of entry for ATM knowledge. Thus, it can be used as a source of information about the most current research as well as the possibility for PhD to participate in European ATM projects.

Complementary to the recommendations, in the final part of the section dealing with comparison, the R&D needs of identified areas that are related to the research at DAT were proposed. Furthermore, twelve theme proposals for final theses elaboration were suggested. For pointing out the spheres deserving increased future focus, two roadmaps including identified areas of research and particular steps attempted to propose a view to the year 2025 were created (Figures 4.1 and 4.2).

The thesis outcomes might serve as the foundation of themes intended for the next potential research activities for the ATM systems laboratory and the Department of Air Transport at the Czech Technical University in Prague. Lastly, the outcomes might serve well as a source of inspiration for future students who might explore the topics provided in the thesis either in terms of their final theses or as a framework of their Student's projects.

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# 6. List of abbreviations

| | |
|---|---|
| ACARE | Advisory Council for Aeronautics Research in Europe |
| ACAS | Airborne collision automatic system |
| A-CDM | Airport collaborative decision-making |
| ADS-B | Automatic dependent surveillance-broadcast |
| AFIS | Aerodrome flight information service |
| AI | Artificial intelligence |
| AIM | Aeronautical information management |
| AMAN | Arrival manager |
| AMS(R)S | Aeronautical mobile-satellite (R) service |
| ANS | Air navigation services |
| ANSP | Air navigation services provider |
| A-PNT | Long-term alternative position, navigation and timing |
| ASBU | Aviation system block upgrades |
| A-SMGCS | Advanced surface movement guidance & control system |
| ATC | Air traffic control |
| ATCO | Air traffic controller |
| ATFCM | Air traffic flow and capacity management |
| ATFM | Air traffic flow management |
| ATM | Air traffic management |
| ATN | Aeronautical telecommunication network |
| ATSU | Air traffic services unit |
| AU | Airspace user |
| BBB | Basic building block |

| | |
|---|---|
| CA | Collision avoidance |
| CAAMS | China's Civil Aviation ATM Modernization Strategy |
| CARATS | Collaborative actions for renovation of air traffic systems |
| CMATS | Civil and military air traffic system |
| CNS | Communication, navigation and surveillance |
| CTU | Czech Technical University |
| CVS | Combined vision system |
| DAA | Detect and avoid system |
| DAC | Dynamic airspace configurations |
| DAT | Department of Air Transport |
| DataComm | Data communications |
| DCB | Dynamic capacity balancing |
| DFMC | Dual frequency/multi constellation |
| DLS | Datalink services |
| DME | Distance measuring equipment |
| DSS | Decision support systems |
| EASA | European Union Aviation Safety Agency |
| EATMA | European ATM architecture framework |
| EGNOS | European Geostationary Navigation Overlay Service |
| EN | Technological enabler |
| ER | Exploratory research |
| ERAM | En-Route automation modernisation |
| ESCAPE | EUROCONTROL simulation capabilities and platform for experimentation |
| EU | European Union |

| | |
|---|---|
| EUIR | European upper information region |
| EVS | Enhanced vision system |
| FAA | Federal Aviation Administration |
| FAB | Functional airspace block |
| FANS | Future air navigation system |
| FEE | Faculty of Electrical Engineering |
| FF-ICE | Flight and flow information for a collaborative environment |
| FIR | Flight information region |
| FIXM | Flight information exchange model |
| FTS | Faculty of Transportation Sciences |
| FUA | Flexible use of airspace |
| GA | General aviation |
| GA/R | General aviation/rotorcraft |
| GANP | Global air navigation plan |
| GAT | General air traffic |
| GATMOC | Global air traffic management operational concept |
| GBAS | Ground based augmentation system |
| GNSS | Global navigation satellite system |
| GPIs | Global plan initiatives |
| GPS | Global positioning system |
| HALE | High altitude endurance |
| HAPS | High altitude pseudo-satellite |
| HEMS | Helicopter emergency medical services |
| HGL | High level group |

| | |
|---|---|
| HMI | Human machine interface |
| HUD | Head-up display |
| ICAO | International Civil Aviation Organization |
| IFR | Instrument flight rules |
| ILS | Instrument landing system |
| INAP | Integrated network management and ATC planning |
| IPS | Internet protocol suite |
| KPA | Key performance ambition |
| KPI | Key performance indicator |
| LDACS | L-band digital aeronautical communications system |
| LIDAR | Light detection and ranging technology |
| LNAV | Lateral navigation |
| LVP | Low visibility procedures |
| MASPS | Minimum aviation system performance standards |
| MET | Meteorological information |
| ML | Machine learning |
| MLAT | Multilateration |
| MOPS | Minimum operational performance standards |
| MSP | Multi sector planner |
| NAS | National airspace system |
| NDB | Non-directional beacon |
| NDT | Non-destructive testing |
| NextGen | Next Generation Air Transportation System |
| NM | Network Manager |

| | |
|---|---|
| NNEW | Next generation network enabled weather |
| NSA | National supervisory authorities |
| OI | Operational improvements |
| PBN | Performance based navigation |
| PCP | Pilot common project |
| PinS | Point-in-space |
| PRB | Performance Review Body |
| R&D | Research and development |
| R&I | Research and industrialisation |
| RAIM | Receiver autonomous integrity monitoring |
| RBT | Reference business trajectories |
| RF | Radio frequency |
| RNAV | aRea NAVigation |
| RNP | Required navigation performance |
| RPAS | Remotely piloted aircraft systems |
| RVC | Remain very clear |
| SARPs | Standard and recommended practices |
| SBAS | Satellite based augmentation system |
| SES | Single European Sky |
| SESAR | Single European Sky ATM Research |
| SESAR DM | Single European Sky ATM Research Deployment Manager |
| SESAR JU | Single European Sky ATM Research Joint Undertaking |
| SGS | Students grant competition |
| SID | Standard instrument departure route |

| | |
|---|---|
| SJU | SESAR Joint Undertaking |
| SMART | Specific, measurable, achievable, relevant and time-bounded |
| SMR | Surface movement radar |
| SPI | Surveillance performance and interoperability |
| SRIA | Strategic Research and Innovation Agenda |
| SSR | Secondary surveillance radar |
| STAR | Standard terminal arrival route |
| STARS | Standard terminal automation replacement system |
| SWIM | System wide information management |
| TBO | Trajectory based operations |
| TCAS | Traffic collision avoidance system |
| TMA | Terminal control area |
| TP | Trajectory prediction |
| UAS | Unmanned aircraft systems |
| UTM | Unmanned traffic management |
| VNAV | Vertical navigation |
| VOR | VHF-omnidirectional range |
| WAM | Wide area multilateration |