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Preface

The general requirement of the Task 3.1 of the WP3 is to specify the main characteristics of the expected Air Traffic Management (ATM) system, in order to accommodate the added European Personal Air Transportation System (EPATS) traffic.

This document has been prepared with the assistance of REA Tech Engineering and Architect Ltd, Daniel Rohács.

Abstract

According to the WP2, EPATS would represent from 42 924 291 to 44 179 030 movements a year by 2020, and call for 99 000 and 89 000 aircraft, respectively for the Case A and Case B estimations. Using the EUROCONTROL and the European Commission findings, this investigation distinguished EPATS IFR and EPATS VFR flights.

The EPATS IFR flights are found to grow from less than 1 million (as in 2007) to 2 944 105 or 2 860 539, respectively for the Case A and Case B projections. Knowing the targets of SESAR, it is clear that these personal IFR flights fit in the envisioned ATM capacity. Results also indicate that the maximum EPATS IFR traffic that could be handled by SESAR in 2020 is 12.59 and 12.56 million flights respectively for the Case A and Case B estimations. This is about 3.5 more than the predicted personal IFR traffic. The found capacity gap appeared in the results of the COSAAC simulation, which showed that the impact of the EPATS IFR flights on the traditional movements is limited, and therefore the personal IFR movements are not leading to congestions at the airports or waypoints. On the other hand, EPATS IFR might generate further traffic complexities, if the aircraft performances/characteristics are different from the traditional flights, and therefore horizontal/veridical interactions or even wake vortex problems are faced.

On the other hand, the EPATS VFR segment is expected to grow from about 15 million flights a year (as in 2007) to 41.2 million for the Case A and 40 million with respect to the B prediction. The impact of the personal VFR flights on the ATM is an unknown problem, since these movements are not clearly addressed in the targets of the coming ATM. Nevertheless, this investigation showed that personal VFR movements flying at low altitude will meet the arrival / departure flows of the traditional traffic at the airport vicinities. Therefore, EPATS VFR will affect these regions, and call for advanced methods to cope with the two classes of traffic together (EPATS and traditional). If not feasible, the deviation or the separation of the flights will be needed.

With respect to the total EPATS traffic, this investigation showed the evidence for the fact that the geographical distribution of the envisioned EPATS flights is different from those of the rest of the airspace users. More particularly, the results indicate that generally personal movements keep off the most crowded regions of the traditional flights. However, EPATS will influence the rest of the airspace users in Italy; Greece; Portugal; Spain; the Southern regions of France, England; the South-Eastern areas of Poland and the North-Western locations of Germany. With respect to the impact of EPATS on the most preferred airports of the traditional flights, Athens, Rome, Madrid Barcelona, Warsaw, London are found to be the most influenced, while the most congested locations such as Frankfurt, Amsterdam or Paris are indicated to be less concerned. The cruising altitude distribution showed that 60 % of the personal movements take place in the airspace below FL 100, in which only 2 % of the traditional flights are present.

Major findings of the analysis suggested that future decisions concerning the airspace organization should take into consideration that (in 2020) about 40 million personal flights would rely on the see-and-avoid concept, from which a significant percentage would take place below FL 100. Beside, a particular focus on the terminal area management is also proposed to cope with the EPATS and the traditional flights at the airport vicinities. Finally, it is also suggested to address the business model of EPATS in order to clarify whether the flights will take place by scheduling or by request, and how these will fit in the SESAR business trajectory process.

1. INTRODUCTION

In 2006, there were about 9.6 million flights in Europe [1], which relative to the past values represents an annual growth rate of 4.1 %. If this were to continue, the traffic would be approximately doubled [2, 3] over the timescale of 2007-2020.

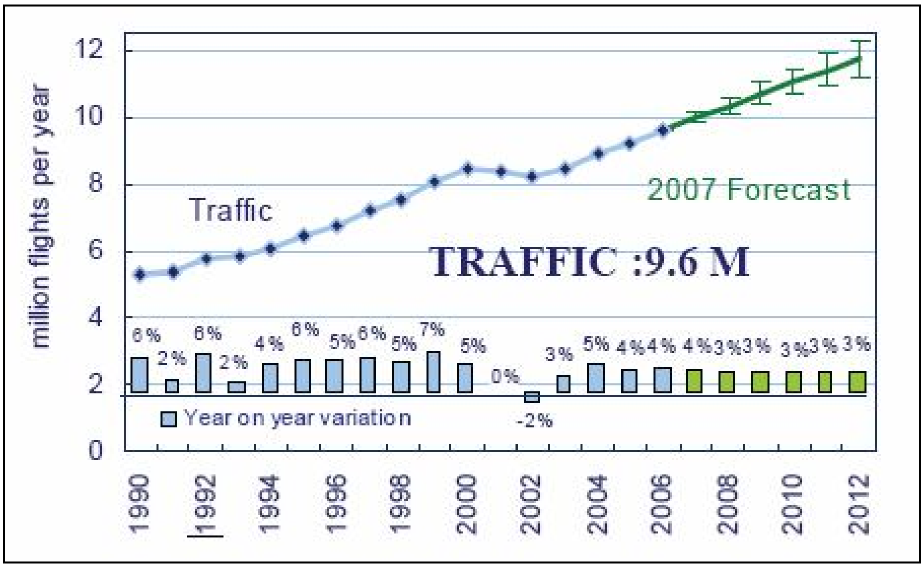

Figure 1. Yearly traffic growth (source: EUROCONTROL).

In addition to this, the air traffic composition might change. The recent years have seen the coming out of numerous novel classes of aircraft. For example the Unmanned Aerial Vehicles (UAV), which initially developed for military purposes, now is finding civil applications [2]. On the other hand, Europe is currently facing with small aircraft initiatives ranging from small start-up point-to-point air taxi services (e.g. the London based JetSet Air [4] or the Swiss JetBird [5]) to personal operations, such as the European Personal Air Transportation System. Besides being a potential source of additional growth in air traffic, these might even call for different system requirements (e.g. level of responsibility), especially if the aircraft characteristics (e.g. rate of climb, speed) would be different from those of the traditional.

Although the capacity of the European Air Traffic Management System is increased by 50 % over 1999 and 2007 [6], there is a risk that with further traffic growth, the Air Traffic Management System could not provide Air Navigation Services in line with the targeted level of safety or without imposing considerable operational, economic or environmental penalties, such as delays, or non-optimal flight routes (see Figure 2.) [7]. Therefore, to safely accommodate the European personal flights with the expected air traffic growth and seeing that the current system is already reaching its limits of capacity, there is a clear need to analyze the ATM with respect to EPATS. This task might be seamless to the past and current investigations, including (i) the improved capacity planning processes at the network and the local level, (ii) the coordinated efforts of Air Navigation Service Providers (ANSPs), (iii) aircraft operators, and (iv) the implementation of pan-European programs such as Reduced Vertical Separation Minima (RVSM), improvements to the airspace structure, route network, Air Traffic Control systems and procedures.

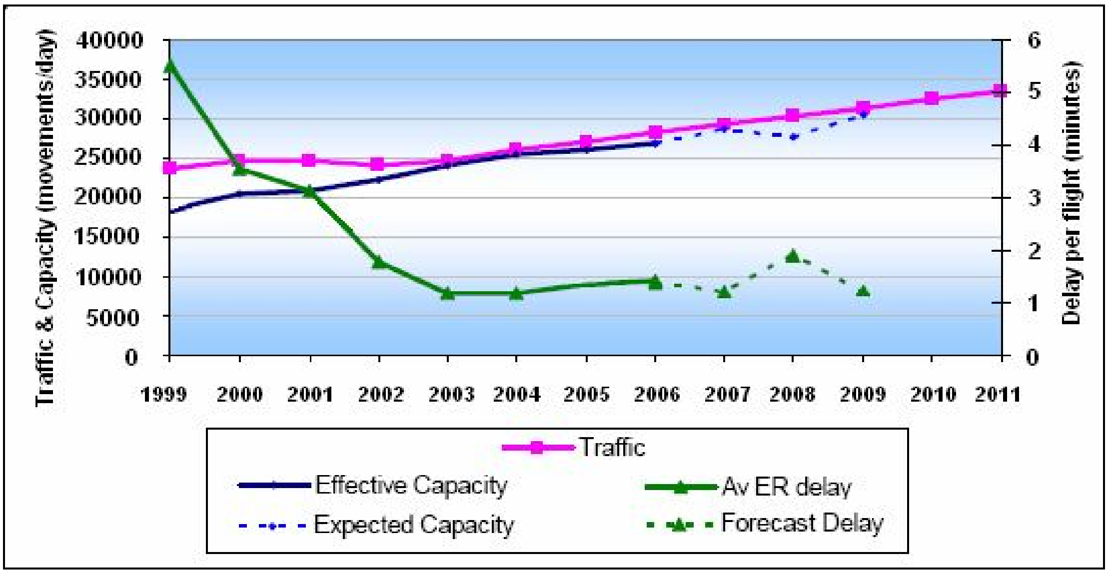

Figure 2. En-route capacity versus demand (source: EUROCONTROL).

The major objective of this analysis is to specify the main characteristics of the expected Air Traffic Management (ATM) system, in order to accommodate the added European Personal Air Transportation System (EPATS) traffic. As defined in the official EPATS proposal, this task covers the following main issues:

- defining the major Air Traffic Control (ATC) / ATM parameters and its constraints in 2007,
- assessing the impact of small aircraft load on the ATM parameters,
- proposing perspectives and visions (or recommendations and proposals) to support the EPATS traffic.

To meet this requirement, the analyst planned to identify and investigate numerous ATM-related issues, which are further discussed.

This document is structured such as follows. It starts with an introduction to provide the reasoning, and the key objectives of the investigation. The chapter two introduces the state-of-the-art, which seeing the requirements of this fist delivery is also the core part of the analysis. Essentially, this identifies the current ATM (as in 2007), the definitions of its base parameters, their constraints and also their future perspectives. The main purpose of doing so is to understand the system as a whole, and to detect the areas which are already constrained. Therefore, it does not necessarily means that the issues listed are calling for a change or adaptation with respect to the EPATS traffic, but rather the assistance to locate the domains within the upcoming ATM – in general – might require further analysis.

2. AIR TRAFFIC MANAGEMENT IN 2007

2.1. Definitions and general characteristics

In order to analyze the impact of EPATS on ATM, the first action was to baseline the Air Traffic Management in 2007, by identifying its key features and defining the constraints which should be considered when giving proposals and recommendations.

In the literature, several definitions are offered for the ATM / ATM System [8,9,10,11]. According to those of EUROCONTROL and ICAO, the Air Traffic Management is defined such as follows:

- "the aggregation of ground based (comprising variously ATS, ASM, ATFM) and airborne functions required to ensure the safe and efficient movement of aircraft during all appropriate phases of operations" [8],
- "the dynamic, integrated management of air traffic and airspace - safely, economically, and efficiently - through the provision of facilities and seamless services in collaboration with all parties" [9],

while the Air Traffic Management System is given as:

- "a part of ANS system composed of a ground based ATM component and an airborne ATM component." [8],
- "a system that provides ATM through the collaborative integration of humans, information, technology, facilities and services, supported by air, ground and/or space-based communications, navigation and surveillance" [9].

These definitions are consistent to each other; however those of EUROCONTROL comprise the added information on the notions of efficiency and safety. Seeing the above, the ATM system consists of functionally integrated ground and airborne components, as shown in the Figure 3. [12]. Accordingly, the ATM distinguishes numerous domains (e.g. terminal or en-route), within it consists of the Air Traffic Flow Management, the Air Traffic Services, the Airspace Management and the airborne functions. With respect to EPATS, the author suggests the use of the above introduced ATM definitions, since both EUROCONTROL and ICAO are major organizations in aviation. However, these should be applied to the specific task of this project, since for example the oceanic domain is irrelevant in the context of EPATS. Additionally, the SESAR concept extends the ATM definitions to include airports, since their capacities should also be addressed in the view whole system's traffic management (see chapter 2.2.) [13].

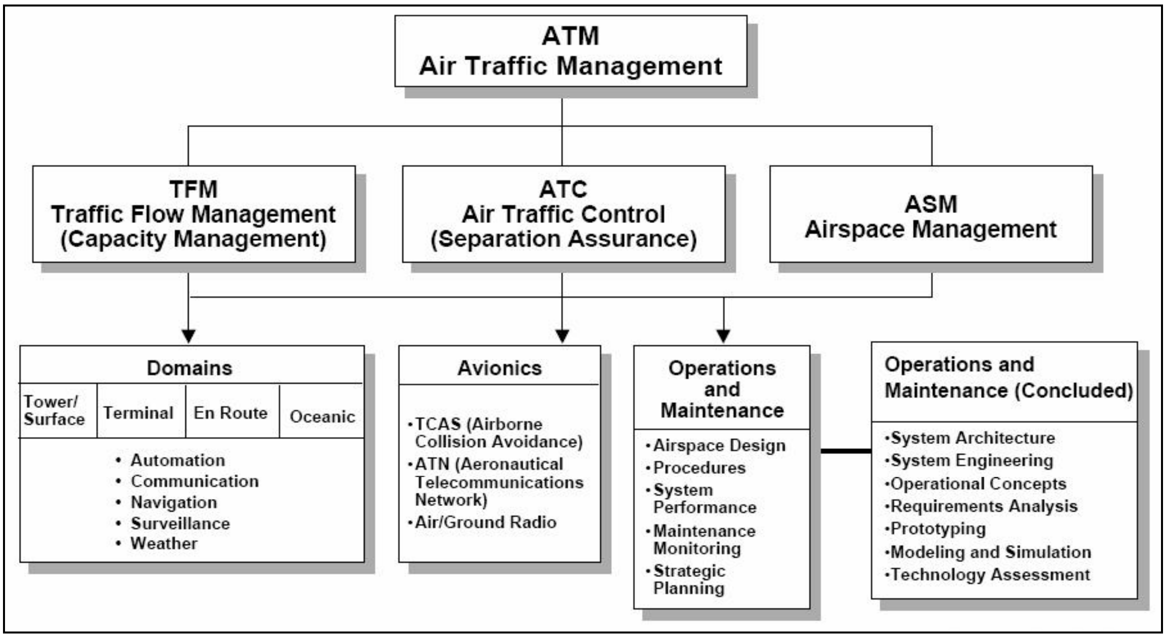

Figure 3. ICAO ATM definition (concluded form definitions and [11]).

At the dawn of civil aviation, conflicts were solved by the pilots, since they flew in good weather conditions with relatively low speed aircraft and in a low traffic density environment. On the other hand, with the appearance of modern aircraft with its higher speeds and the ability to fly in low visibility conditions, pilots were not able to solve conflict as previously. Consequently, they must either have to call for an enhanced avionics (e.g. TCAS) or for an Air Traffic Control (ATC) to be helped to solve conflicts and obtain an adequate situational awareness [14].

In 2007, ATC is a service provided by ground-based Air Traffic Controllers (ATCOs), with the objective of providing and maintaining a safe and efficient flow of air traffic within the areas where air traffic control is obligatory [15, 16,17]. The primary task is to:

- prevent collisions between aircraft, and to
- prevent collisions on maneuvering areas between aircraft and obstacles on the ground.

Secondary tasks include ensuring the orderly and expeditious flow of traffic and providing information to pilots, such as weather, navigation. However, such ATC service is not provided through all the airspace. Controlled airspace is in which the controllers are responsible for separating the aircraft, in contrast to the uncontrolled airspace, where aircraft fly without beeing controlled by an ATCO [17]. As a result, depending on the type of the flight (VFR or IFR) and the airspace classifications, the ATC service might range form instructions to flight informations or advisories to assist the operations of the flight in the airspace. In the controlled airspace however, the responsibility is distributed among several controllers. The tower control is charged for situations when the aircraft is still on runway, just after it made the take-off, or before it completed the landing [16]. The next is the departure and approach control, within the controllers are responsible for each aircraft that is flying in a given area around the airport, to ensure a safely separated sequencing to land, or to climb. Besides, the area control center is distinguished, which depending on the authority over the airspace, further divides the whole

structure into smaller regions to safely and efficiently control the flow of the en-route traffic. These centers split the airspace into one or more adjacent volumes, so called sectors, across the control of aircraft are distributed. Each of these is then managed by a team of Air Traffic Controllers [15]. According to EUROCONTROL, this translates to a decomposition of the problem, since sectors serve a subset of aircraft, which being a smaller entity is generally easier to control. As a result, these sectors and centers lead to the fact that the current system is neither fully centralized, neither fully distributed. It is rather an example of “distributed centralization” [18].

The purpose of dividing the airspace into sectors or more generally to manage the airspace organization, is to establish the airspace structure that enables to accommodate the different types of activity, volume of traffic and different levels of service. Airspace Management (ASM) is therefore the process that maximizes the use of the available airspace by selecting and applying different options to meet the needs of the ATM community [9, 11].

Since ATM might not meet excessive maximum air traffic demands, the air traffic flow has to be planned [11]. The function of this sub-system called Air Traffic Flow Management (ATFM) is to balance traffic demand and capacity, in order to ensure the efficient use of the airspace and other system capabilities (e.g. airports). To do so, mainly three following phases are distinguished [19]:

- First is the strategic Air Traffic Flow Management (ATFM), which occurs from two months to 7 days before the flight. This forecast is based on the expected number of flights and the available routes
- The second stage is the pre-tactical flow management, which takes place in the last 6 days before the flight. It prepares an air traffic flow management notification message to ATC units and aircraft operators about the planned operation, in the aim to optimize the capacity, resulting in an efficient usage of airspace, and minimized delays.
- The last phase [19] is the tactical air traffic flow management, which is accomplished in the same day as the flight itself. That handles the allocation of the departure times (so called SLOTs), and ad-hoc re-routings to prevent congestions and maximize efficiency.

2.2. Current technical and operational constraints of the ATM (as in 2007)

The objective of this chapter is to discover the technical and operational constraints of the ATM in 2007, since this facilitates to locate the areas that should be addressed in the coming years, and therefore assists for elaborating a relevant state-of-the-art on the current system.

Depending on the focus, the baseline and the geographical region of the investigations, this literature review found numerous ATM bottlenecks [13, 20, 24, 26, 27]. Firstly, being a major European concept, those of the SESAR [13, 20] were considered which secondly was completed by other relevant sources. Accordingly, the following major issues were pointed out:

- Airspace organization and management,
- Limitations of the current tools, procedures and operational aspects,
- Capacity of airports,
- Uncertainties,
- Unexploited aircraft capabilities,
- Limited information exchange,
- Pilots' limited situational awareness,
- Novel systems' affordability.

2.2.1. Airspace organization and management

According to SESAR [13], the "European airspace is, in the main, organised around the use of fixed volumes and rigid route structures which are organised and managed in a fragmented manner. This results in aircraft being unable to fly their most efficient trajectory and creates unnecessary additional workload for air traffic control". This statement is in line with the most recent EUROCONTROL Performance Review Reports [1, 21], which identifies flight-efficiency as a "major contribution to ATM performance". Within these documents, flight-efficiency is defined as a route extension, measured in the actual flight length between the TMA entry / exit points (*A*) and the great circle distance (*D*) (see Figure 4). According to the results, the European average en-route flight extension is found to be 5.9 %, which translates to about 48.6 km and a 2 230 M€ per annum of estimated cost to airspace users [1]. Flight extension or at least the impact on it might therefore be investigated with respect to EPATS, since presently it is unclear how the results introduced above might vary due to the additional small aircraft load.

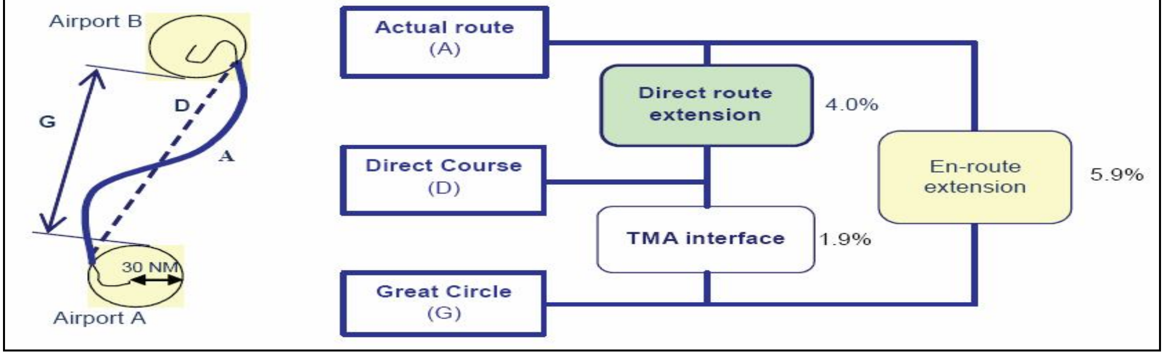

Figure 4. En-route efficiency (source: EUROCONTROL)

Besides, the sector-oriented ATC is characterized by tactical controller actions protecting separate regions of airspace. As for the individual flights, this results in the loss of efficiencies, since ATCOs might not always be aware of the impact of their actions on downstream sectors [22, 23]. In addition, in high aircraft density areas, controllers should issue multiple instructions, which – causing ATC workload and radio frequency congestions – limits the number of aircraft that can be safely managed in a sector at a given time [23]. To reduce the ATCOs' workload and traffic congestions, the airspace has to be divided into smaller sectors. However the sectorisation is done by experts applying rules and experiments learned from the past, further re-sectorisation into smaller sectors for long-term solution is no longer reasonable [24]. It would probably raise the number of the so-called hand-off procedures, which finally might lead to increased workload and congestions in the sectors.

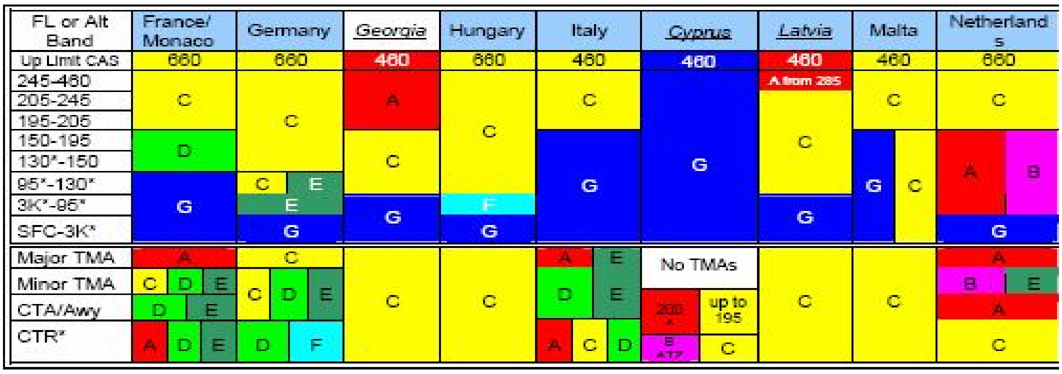

Figure 5. Lack of a harmonized European airspace classification (source: EUROCONTROL).

Moreover, in accordance with certain characteristics, such as the type of flight, the service provided or the radio communication requirement [25], the airspace could be divided into several vertical classifications. Depending on the dissimilar regulations set by the countries, this leads to various airspace classifications across Europe (see Figure 5.) [26]. Instead of a single continuum of airspace, the users therefore should now face with the lack of a harmonized system, which at the national boundaries translates to an additional pilot workload [26].

2.2.2. Limitations of the current tools, procedures and operational aspects:

A high level description of these issues is given in SESAR [13], pointing out that "with the tools and procedures in use today the increase of capacity will be fundamentally limited and is reaching its limits". More explicitly in the literature, this is covered by numerous technical operational constraints [24]. With respect to communication, it is clear the aviation uses radio signals to carry the data. On the other hand, with the traffic growth, the use of such data links is increasing day after day. The problem with communication is that all messages have to be transmitted and acknowledged by the recipient, even if these were briefs [24]. On the other hand, once the reception conditions are poor, the messages require being repeated. In addition, since en-route controllers cannot handle simultaneously an infinite number of aircraft, sectors are designed, with at least one radio channel for each of them [24]. Although, one single channel could be used by several sectors if they are far enough from each other, aviation radio communications are limited to a number of dedicated channels in their allocated part of the radio spectrum [24]. While ICAO introduced an 8.33 kHz spacing to increase the available number of channels, experts proved [27] that further channel splitting is technically not

possible, and around 2012 a communication jam is possible to happen. In addition, it is questionable, whether general aviation and small airlines would equip their fleet with novel and most probable more expensive radio transceivers [28].

Other constraint is the use of waypoints. There are still waypoints and airways, despite the fact that within the coverage of the flight navigational aids or other instruments such as GPS, an aircraft can currently fly along nearly any desired flight path (except re-routings to prevent congestions or restricted/segregated airspaces). These in the same time are crossing points of converging aircraft trajectories, and therefore a potential source of conflicts or collisions [24].

Besides, an operational limitation is the presently used see and avoid concept to provide aircraft with separation [24]. However TCAS could be implemented as a technical support for the same goal, according to ONERA [24], the equipage of all aircraft with it will probably never happen due to its high cost, especially for cost sensitive small aircraft [29 – EPATS WP4].

Last but not least, as the ATCOs' workload is limited, humans could also be considered as an operational constraint [24]. If future re-sectorisation is no longer be reasonable, this issue would call for a re-oganisation or steps towards a system within controllers are supported with for example automation (see chapter 2.3.).

2.2.3. Capacity of airports

According to SESAR [13] the "capacity of airports (due to e.g. their infrastructure, environmental and political constraints) together with the terminal airspace around them is primarily the limiting factor of overall capacity". This is reasonable, since each airport uses one or several runways with a finite capacity, given in a finite number of aircraft that the runway can handle safely. This happens because only one aircraft can depart or land on the same runway at the same time, and because aircraft must be separated by certain time to avoid conflicts or wake vortices [30]. Therefore, airport capacity is driven by numerous factors, for example the number of runways, the rapid exit taxiways and the meteorological conditions. Especially, this last might lower the capacity of an airport, since strong wings could limit the available number of runways, while lower visibility could necessitate higher separations between the aircraft [31]. In Europe, the problem is that some major airports are to saturate. Wake vortices determine minimum safe separations on approach, and it is often not possible to build new runways, due to environmental considerations, or lack of available space (see Napoli) [18]. Over the timescale of the past years (from 2007) this translates to a growing proportion in the amount of ATFM delays (see Figure 6). In addition, with respect to the length of delays, the airport role becomes more and more important over the one of the en-route. In addition, staff shortages, radar maintenance or equipment faults can further lower the capacity of a unit, which besides the airports also affects ATC [31]. However, the growth of air traffic is not influenced by the congestions at the major airports, since it is rather the traffic that is growing at some, for example regional airports [32, 18]. On the other hand, depending on the EPATS demand and more explicitly the city pair analysis, the congestion of airports might not be relevant for small aircraft, if for example more flights were to happen to smaller or regional airports. Since presently this is uncertain, the airport preference requires further investigations.

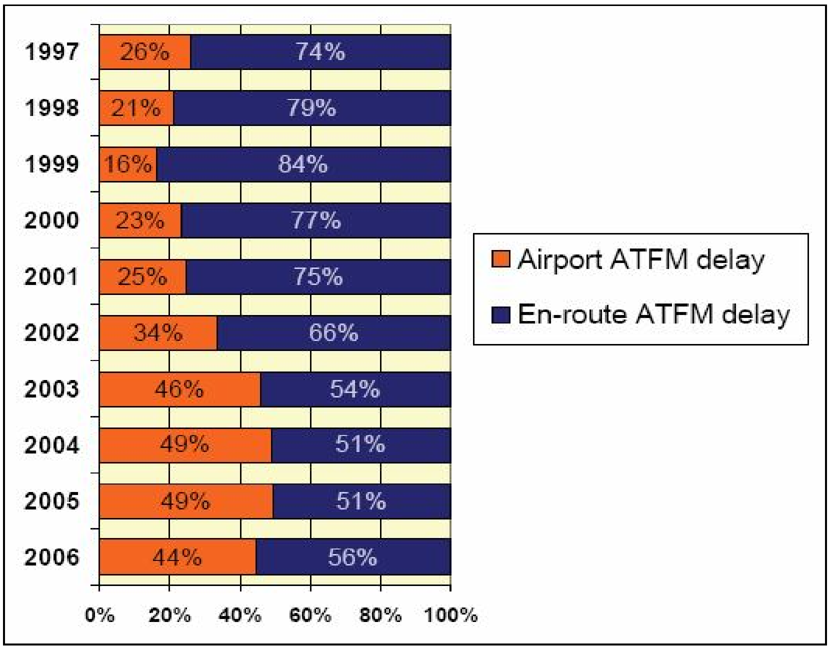

Figure 6. ATFM delay distribution by delay reason (source: EUROCONTROL).

2.2.4. Uncertainties

According to ONERA [24], the global management of the air transportation system requires the exact position of all aircraft movements. To obtain these, numerous data should be available. Firstly, the aircraft current and future state, expressed for example in 4-D profiles along all phases of flight, as this might address the differences or the potential deviations between the planned and real positions. Secondly, the pilots and controllers intent, since these give the added information on what exactly they are going to carry out in the future (e.g. follow or issue instructions). When considering an ATCO point of view, technical supports are accessible to decrease the uncertainties (see chapter 2.3), except those related to pilots' intents. Human behaviors are more difficult to foresee, since man does not behave as an automatic system, and might follow procedures or deviate from them for various reasons [33]. This results in uncertainties, which therefore is an operational bottleneck of the ATS. Other problem that comes with the uncertainties in the human decision making is the fatal accidents. Relevant analyses show that presently the main cause in many circumstances is the human or the flight crew. This leads to Controlled Flight Into Terrain (CFIT) or loss of control, which alone are the two major accident reasons over the timescale of 1992 and 2001 [34]. Human, as a primary cause for accidents appears again in the analysis of the primary causes of hull-loss accidents. This indicates that in 66 % of all cases [34], the flight crew is the responsible due to inadequate or wrong decision making. Therefore the uncertainty in the human decision making is an issue to be addressed with respect to EPATS, especially if the flights would take place at higher aircraft density regions or at lower altitudes, where the ground proximity might play a role.

According to SESAR [20], uncertainties also play a major role in forecasting the traffic demand. It results from numerous drawbacks, for example in the limited prediction accuracy, the inability to exchange relevant data with the airspace users on expected demand, or in the lack of dynamic traffic forecast.

2.2.5. Unexploited aircraft capabilities

SESAR's position is that "most aircraft operating today have the capability to fly with much greater precision in terms of position and time than is accommodated in the design of, and supported by, many of the systems in operational service to manage and control air traffic" [13]. Accordingly, this capability (in 2007) is not fully exploited and therefore could be addressed in the future to enhance the system capacity. With respect to EPATS it is questionable whether the aircraft characteristics would allow to fully exploit this present constraint. Seeing that the concept focuses on all propulsion systems (piston, turboprop and jet) the problem might only be relevant for certain cases (e.g. jets).

2.2.6. Limited information exchange

SESAR points out [13] that "throughout the processes, procedures and systems used by the stakeholders involved in planning, managing and executing flights today, decisions are often taken in isolation by some on matters which have an impact on others. This leads to fragmentation and inefficient flight profiles. However, a large amount of information exists, within the stakeholders, which is currently not fully exploited". Seeing that the characteristics and the expectations of EPATS flights might be different from those of the traditional air carriers, the limited information exchange requires to be focused on. One potential solution for the problem is the Collaborative Decision Making (CDM) process supported by the System Wide Information Management System (SWIM), in which diverging expectations and interests of all members are balanced, and therefore resulting in a better understanding of the network effects on the decisions [13]. This might be reasonable for EPATS, since otherwise, common interests would not be addressed in the recommendations and proposals for supporting small aircraft.

2.2.7. Pilots' limited situational awareness

According to SESAR [13], "today pilots have a limited situational awareness of the traffic, which can potentially affect them and this restricts them from taking a more pro-active role in the ATM process". Depending on the traffic complexity, as a function of the traffic density and the number of climbing, cruising and descending aircraft [1], the pilots might required enhanced situational awareness, especially if EPATS flights would take place in high aircraft density regions (e.g. airport surroundings). Hopefully, in 2007, numerous concepts address this limitation, which is discussed in the chapter 2.3.

2.2.8. Novel systems' affordability

Last but not least, it is believed [24, 35] that the system in 2007 does not fully take the advantages of the latest technological achievements. This is mainly due to the fact that the airspace is shared between a number of different actors, with different characteristics (e.g. sensitiveness to cost) and that the flight safety could only remain on at least its present state if novel systems would be fitted in all aircraft from the same class (e.g. commercial) [24]. No doubt that while the safety is the primary objective, cost still plays a major role, once choosing a technology to be applied. In line with this, ONERA [24] expects that the equipage of all aircraft with for example the TCAS II will probably never happen due to its relatively high acquisition cost. Therefore to allow the latest technological achievements, this approach and therefore the weight of the transition cost has to be reviewed.

2.3. Future perspectives in ATM

As predictions generally comprise numerous uncertainties (e.g. GDP, fuel price), the impact of air transportation growth on the ATM might influence a range of different parameters and domains. In view of this, several options are developed in the literature to consider different scenarios, and for addressing the present capacity limitations, for example those introduced in the previous chapter. EUROCONTROL [36] defines the capacity of the Air Traffic Management System as the "ability to provide Air Navigation Services to a certain volume of air traffic, in line with the targeted high level of safety and without imposing significant operational, economic or environmental penalties under normal circumstances". To respond to the present capacity bottlenecks, and therefore address a novel ATM, the literature comprises numerous ATM programs, including for example the Single European ATM Research (SESAR) [13], the US Next Generation of Air Transport System (NGATS), the ICAO Global ATM Operational Concept [37] and the IATA Global Roadmap [38]. These are supported with several ATM concepts, which are further discussed in the sections introduced below.

The ICAO Global ATM Operational Concept was developed from 1999 to 2002, and was endorsed by the major aviation representative organizations at both the 11th Air Navigation Conference (in 2003) and the 35th ICAO Assembly (in 2004). It provides the framework, and guidance material for planning, implementation and related development work. According to the document, a performance-based approach is needed, within the expectations of the members of the ATM community might be better satisfied, once they are quantified into a set of agreed performance targets. These might even be periodically adjusted. According to ICAO, the expectations could be classified into eleven categories, called the Key Performance Areas (KPA). While recognizing that safety is the highest priority, the expectations are shown in alphabetical order [37]:

- Access and Equity: The global ATM system should ensure equity for all users that have access to a given airspace or service.
- Capacity: The global ATM system should exploit the inherent capacity to meet airspace user demands at peak times and locations while minimizing restrictions on traffic flow. To respond to future growth, capacity must increase, along with corresponding increases in efficiency, flexibility and predictability, while ensuring that there are no adverse impacts on safety and giving due consideration to the environment
- Cost Effectiveness: The ATM system should be cost-effective, while balancing the varied interests of the ATM community
- Efficiency: Efficiency addresses the operational and economic cost-effectiveness of gate-to-gate flight operations from a single-flight perspective
- Environment: The ATM system should contribute to the protection of the environment by considering noise, gaseous emissions and other environmental issues in the implementation and operation of the global ATM system
- Flexibility: Flexibility addresses the ability of all airspace users to modify flight trajectories dynamically and adjust departure and arrival times, thereby permitting them to exploit operational opportunities as they occur
- Global Interoperability: The ATM system should be based on global standards and uniform principles to ensure the technical and operational interoperability of ATM systems and facilitate homogeneous and non-discriminatory global and regional traffic flows

- Participation by the ATM community: The ATM community should have a continuous involvement in the planning, implementation and operation of the system to ensure that the evolution of the global ATM system meets the expectations of the community
- Predictability: Predictability (the ability of airspace users and ATM service providers to provide consistent and dependable levels of performance) is essential to airspace users as they develop and operate their schedules
- Safety: Safety is the highest priority in aviation, and ATM plays an important part in ensuring overall aviation safety. In implementing elements of the global aviation system, safety needs to be assessed against appropriate criteria
- Security: Security risk management should balance the needs of the members of the ATM community that require access to the system, with the need to protect the ATM system

Although these elements were being developed to assist in describing the ATM community expectations, any change to the ATM system should be assessed against the following criteria [38]:

- Safety: any change to the ATM system should not increase the rate of serious risk bearing incidents or accidents;
- Capacity: any change to the ATM system should be aimed at providing the capacity that meets the current and predicted traffic growth, and/or reducing the average per-unit delay. Seeing that the traffic is composed of numerous actors, the system should be designed collaboratively – in particular through demand and capacity balancing – to limit system disruption during abnormal operations;
- Efficiency: any change to the ATM system should be aimed at ensuring that user operating efficiency requirements are met, and therefore the actors have access to preferred trajectories;
- Predictability: any change to the ATM system should be aimed at increasing the levels of predictability.

Seeing that EPATS covers different classes of aircraft with numerous propulsion systems (e.g. piston, turboprop, jet) efficiency should play a major role, especially once these flights should be accommodated with those of the traditional and novel ATM perspectives and visions are investigated.

To meet the expectations defined above, ICAO defines the ATM Operational Concept elements such as follows [37]:

- Airspace organization and management,
- Aerodrome operations,
- Demand and capacity balancing,
- Traffic synchronization,
- Airspace user operations,
- Conflict management,
- ATM service delivery management.

These key findings are incorporated in other relevant investigations, for example the IATA Global Roadmap [38]. Whilst published by IATA, this work presents the combined views of the respective organizations on a common action plan, detailing directions that need to be taken to achieve the goal of a Global Seamless ATM system. The high level objectives of this document are distinguished on the short-, mid- and long-term evolutions [38]. The first aims to fully exploit a number of pragmatic measures, within the majority have already been agreed or about to be implemented [37]. These include the followings:

- enhanced airspace organization, and resource management,
- implementation of existing standards for capacity and efficiency enhancement,
- increased levels of automation support for pilots and air traffic management personnel where required,
- increased use of existing aircraft interactive and self-contained capabilities,
- improving and preparing existing ground and airborne systems for further integration.

On the other hand, the mid-term evolutions might include:

- better use of the available capacity at airports,
- increased, integration of information systems,
- improved information exchange between systems,
- more accurate information about aircraft positions,
- enhanced computer support tools for pilots and air traffic management personnel,
- enhanced conflict predictions,
- shift of separation responsibilities in certain circumstances from the controllers to the pilots.

Finally, the long-term evolution could incorporate the followings:

- improve the levels of productivity by re-distributing the tasks between people and machines and between controllers and pilots,
- application of integrated air and ground data communications in the air traffic control centers and at major airports,
- exploit of advanced computer tools.

Similarly to IATA, SESAR also incorporates a series of aspects, thought the eleven Key Performance Areas (KPAs) of the ICAO Global ATM Operational Concept. According to them [13, 20], using the achievements of ICAO as a reference to develop the ATM system is reasonable, since in the timeframe covered by the program, the ATM network could significantly benefit form an improved, integrated approach to pan-European planning and coordination between all stakeholders. One approach to support this is to take the benefits of the already agreed and endorsed view of the ICAO ATM Operational Concept. SESAR is the Single European Sky ATM Research. In short, Single European Sky (SES) [39] is a European Commission initiative to reform the management of European airspace in order to meet future capacity and safety needs via legislation. Its objectives include the (i) improvement and reinforcement of safety, (ii) the reconstruction of the European airspace to accommodate air traffic flow, (iii) the creation of additional capacity and (iv) the enhancement of the overall

efficiency of the air traffic management system. Seeing these from the perspective of SESAR [39], the problem is that (i) the European airspace is fragmented, which with further traffic growth is predicted to become congested, (ii) and that the Air navigation services including their systems that support them are not sufficiently integrated. SESAR answers to these with the objective of "eliminating the fragmented approach to ATM, transforming the European ATM system, and synchronizing the plans / actions of different partners or federate resources" [39]. It is therefore a European ATM modernization program that combines technological, economical, regulatory aspects and aims to bring into play the Single European Sky legislation to synchronize the plans and actions of the different stakeholders and federate resources for the development and implementation of the required improvements throughout Europe, in both airborne and ground systems [40]. It will deliver a European ATM Master Plan, for which the first time in the European ATM history, SESAR brought together the major European aviation actors / stakeholders (including e.g. airport operators, airspace users, air navigation service providers, research centers and a number of other different partners, ranging from military organizations to safety regulators). This is dissimilar with the present approach within some increase in the short and mid term is achieved, but the success rate is rather limited, since the projects are not necessarily been fully coordinated with others, especially in terms of implementing the end product [20]. Bottlenecks are shifted rather than to be solved, which clearly comes from the lack of a framework, an ATM target concept, within collective and not "individual" benefits are addressed. Using this approach, SESAR also aims to meet "a more adaptable system that could dynamically respond to changes in traffic performance and capabilities" [20]. This characteristic is essential with respect to EPATS, if for example "traditional" flights would face with piston small aircraft in the same airspace (e.g. airport surroundings).

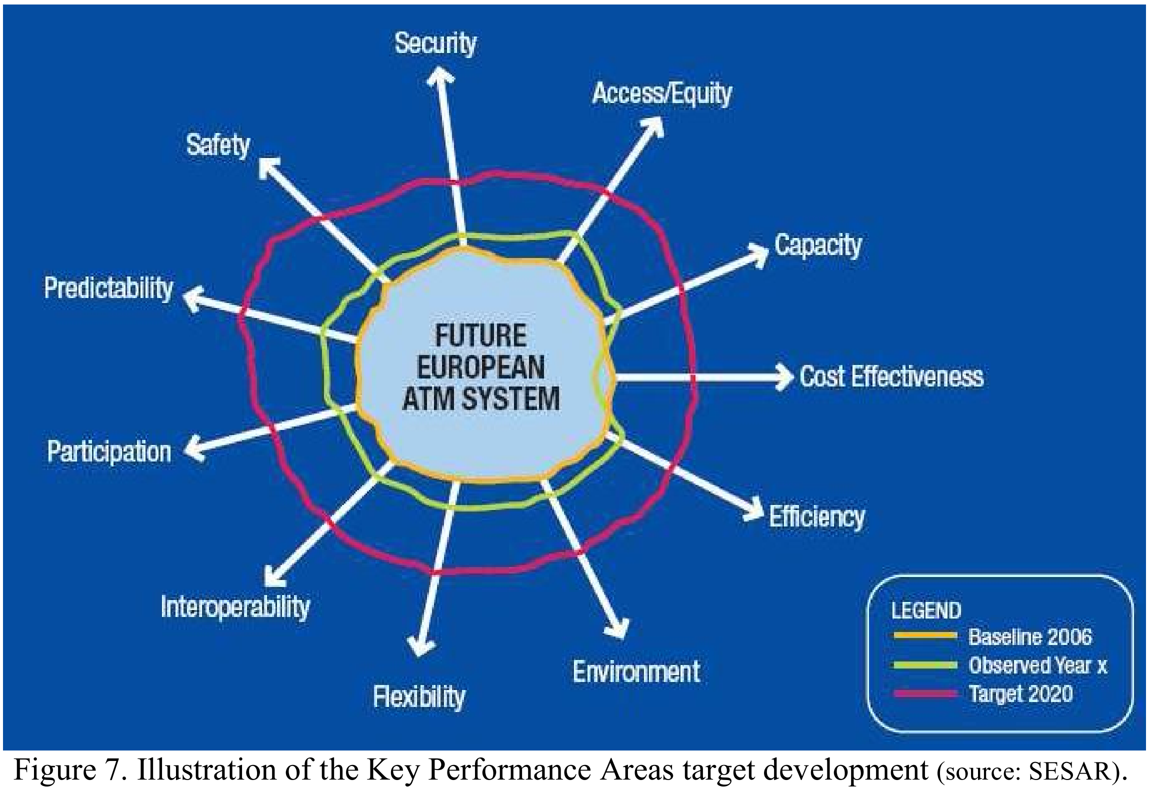

Figure 7. Illustration of the Key Performance Areas target development (source: SESAR).

As already mentioned, the initial set of targets to develop the ATM Target Concept of SESAR incorporates the eleven KPAs of the ICAO Global ATM Operational Concept. These represent initial working assumptions that might call for further analysis and validation (see Figure 7.). All of them are interdependent and might be the basis for impact assessment and consequent trade-off analysis for decision-making in further investigations developed by the program. In the summary of the documents, SESAR points out four of them [40], since they are directly linked to the EC objectives and the achievement of the vision. These are described below [40]:

- capacity: To be able to manage the predicted traffic growth even beyond 2020, the vision is to enable a “three-fold increase” in the overall capacity, which – as expected – could reduce the delays at both, the airport and air side. This capacity should be based on the idea that by 2020, the ATM System should accommodate a 73% of increase in the traffic volume, while also meeting the objective of the rest of Key Performance Areas;
- safety: The safety performance objective of SESAR incorporates the ATM2000+ objective: “To improve safety levels by ensuring that the numbers of ATM induced accidents and serious or risk bearing incidents (includes those with direct and indirect ATM contribution) do not increase and, where possible, decrease”. More explicitly SESAR’s safety objective is based on the assumption the safety needs to gradually improve with the square of the traffic volume evolution. This, on the long term (from 2005) results to a safety level increase by a factor of 10, so that to meet the forecasted three-fold increase in the traffic;
- environment: The initial political objective is to meet a 10 % of reduction on the environmental loads per aircraft that the European air transportation has. While the minimization of noise emissions and the reduction of gate-to-gate excess fuel consumption are addressed, presently the objectives to decrease the atmospheric emissions are yet to be developed. Generally, the aim is that “all proposed environmentally related ATM constraints would be subject to a transparent assessment with an environment and socio-economic scope; and, following this assessment the best alternative solutions from a European sustainability perspective are seen to be adopted”, while fully respecting local environmental rules affecting ATM (e.g. aircraft type restrictions);
- cost-effectiveness: SESAR defines the assumption for the cost effectiveness as the shift of the total direct European gate-to-gate ATM cost from the present 800 EUR / flight (as indicated in the EUROCONTROL PRR 2005 [21]) to 400 EUR / flight. This diminution is planned to be progressive along the timescale of 2005 and 2020.

According to SESAR [20], it is clear that targets defined in the documents will be met by a series of different developments and implementations in novel technologies or operational procedures. In 2007, it is considered that numerous investigations are in development, which has varying capabilities and various degrees of complexity. To provide the future perspectives, this investigation takes only a limited example of them, and especially those, which are in line with SESAR. This is reasonable, since being a European program, it addresses the same market than EPATS, and which according to EUROCONTROL “will lead the way for the modernization of the Air Traffic Management system in Europe” [38]. The key foundlings of this investigation are classified into the areas introduced below.

2.3.1. Airspace organization and management

According to SESAR [13], the European airspace will be organized in a service-oriented approach that divides the airspace into two categories:

- managed: where information on all traffic is shared between the actors, and certain separation responsibilities might be delegated to the pilots within the context of predefined rules,
- un-managed: within the separation is managed by the airspace users.

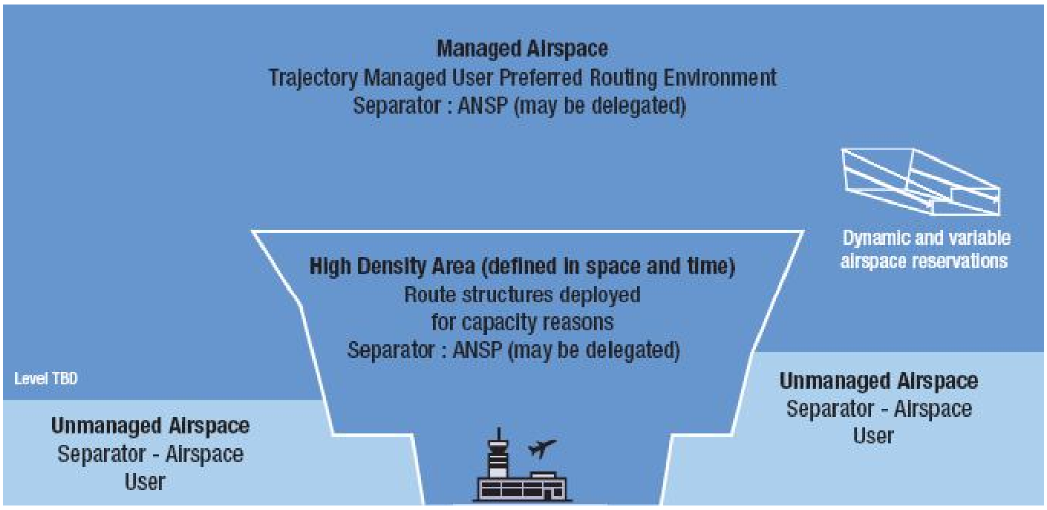

Figure 8. Airspace structure (source: SESAR).

In the first, and especially at the cruising phase, user preferred routing will be applied and the fixed route structures will only remain for those flights that require such support, or at congested regions, within capacity will overrule flight efficiency [13]. In the vicinity of major airports (Hubs) an extended terminal area will be used, covering therefore the lower part of the en-route airspace to manage the climbing and descending flows (see Figure 8.). If needed, the airspace might temporary and partially be reserved, but only when required and to meet the needs of specific missions. Depending on for example the level of automation or cockpit instruments applied in the upcoming years, one might imagine that at high aircraft density areas EPATS flights are led through by a particular airspace or tunnel. This would pierce the crowded region reserved for the rest of the airspace users, in the objective of avoid conflicts. However, it is not mentioned in this high-level description, the classification introduced above will most probable take place gradually. According to the position of IATA on the ICAO Global ATM Operational Concept, this could be only managed, if first the current system was simplified [38]. An initial step towards a harmonized and a single continuum of airspace might be the adaptation of ICAO classifications [38] by all national authorities, and even the global implementation of the RVSM to ensure a consistent application of the vertical separation standards. At the mid or long-term, Europe could reduce the number of airspace categories. A good example for this approach is the presently ongoing EUROCONTROL Airspace Strategy (see Figure 9.) that adapts certain classifications to those of ICAO through the Member States' airspace [26]. Further, its objective is to reduce the number of airspace categories to only three types by 2010 and to two by 2015 [26].

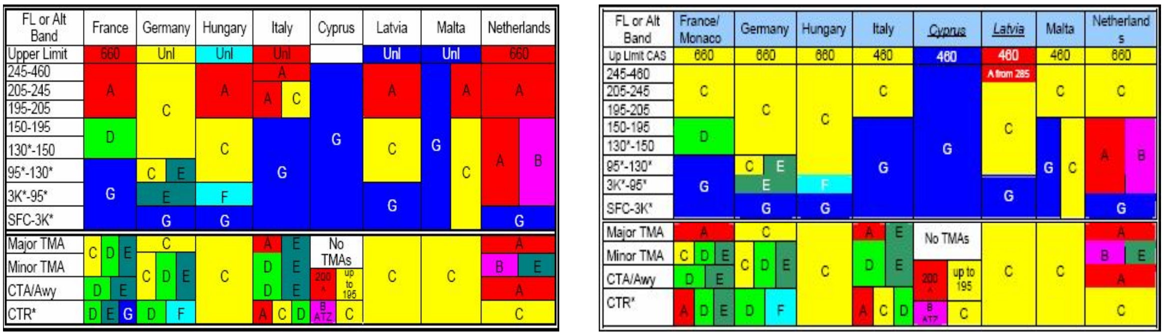

Figure 9. European airspace classifications in 2003 (on the left) and 2007 (on the right) (source: EUROCONTROL).

Similarly to the most relevant investigations (e.g. ICAO [9]), the target concept of SESAR is addressing a dynamic and flexible use of airspace capabilities, rather than to be based on strict segregations as presently. Therefore, the airspace will be treated as a single continuum, minimizing the need for traffic segregation, achieved by a more accurate planning, time management and procedures that can flexibly handle real-time changes to volumes and times. It is envisioned by SESAR that the Advanced Flexible Use of Airspace concepts (AFUA) [13] will play a major role in increasing the capacity for all airspace users and improving the civil-military cooperation. The objective is to replace the fixed airspace structures with volumes of airspace that responds dynamically to particular traffic flows (or meteorological conditions) and which is available to all users. This might be beneficial with respect to EPATS, since that class of aircraft might increase the traffic volume in particular regions, and therefore similarly to the civil-military case, it could call for civil-EPATS cooperation. If needed, the restricted airspace for EPATS flights in the vicinity of "crowded" regions might even reply dynamically for particular traffic flows.

In the literature, and more particularly at EUROCONTROL, numerous investigations aim to enhance the performance of the ATC capacity that exists within the current European airspace organization. One major is the Dynamic Management of the European Airspace (DMEAN) Framework Programme [7] that – while being consistent with SESAR mandates – brings together a number of important EUROCONTROL initiatives, e.g. airspace design, collaborative decision-making (CDM), Flexible Use of Airspace (FUA), and Air Traffic Flow & Capacity Management (ATFCM) improvements. Other studies in the domain include for example the Tube Advanced Lane Control (TALC) [41], the Dual Airspace [42], the SuperHighway [43], or the Full Aircraft Separation Transfer (FAST) [44]. With respect to the first two, both define a reserved area called respectively highway and tube. While these are in line with the previously mentioned scenarios, within EPATS could fly in a special airspace, the concepts are at their development phase with only high-level of descriptions. On the other hand, started in 2006, the SuperHigway [43] is an ongoing EU 6th Framework Program, which defines layers of parallel tracks on a European-size regular lattice (see Figure 10.) to eliminate crossing conflicts between cruising aircraft. One of the major benefits is that the airspace capacity is expected to be improved with respect to the classical sectorised method. Unfortunately the outcomes of the benefit assessment is not yet available to compare the key performance area indicators (e.g. efficiency, capacity) with those of conventional and direct route structures. Even so the approach might not be fully in line with SESAR, once certain routes are only available for a specific traffic (e.g. small aircraft); this program might enable to manage for example the traffic flow of the EPATS and traditional flights. On the other hand, in the FAST [44] study of the Freer Flight Project (focusing on the "autonomous aircraft" mode) a Free Flight AirSpace (FFAS) is proposed, situated at specific altitudes. Key finding of the investigation shows that in terms of autonomous separation tasks, the concept is valuable at low density areas. The analysis of "autonomous aircraft" and free flight with respect to EPATS is discussed later.

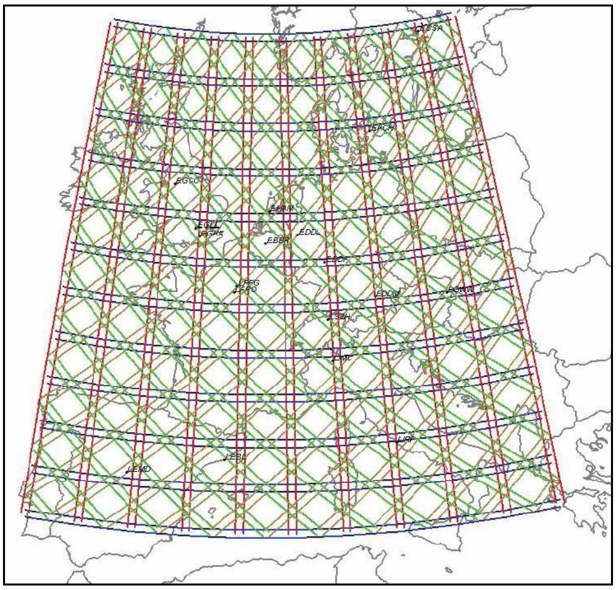

Figure 10. The regular lattice of the SuperHighway Project.

2.3.2. Collaborative planning and decision making

The demand and capacity balancing is predicted to minimize certain effects of the ATM system-wide limitations and allow the airspace users to optimize their participation in the system [37]. It will strategically evaluate the traffic flows to implement necessary actions, and therefore manage the dissimilar needs of airspace and airport capacity. ICAO foresees a more efficient use of the air traffic flow, in balancing the demand and capacity in a collaborative process, within system-wide information on air traffic flows, weather and assets are used. According to the Global ATM Operational Concept [37], the collaborative decision making will cover the strategic, pre-tactical and tactical stages, such as follows:

- the strategic stage: to respond to the fluctuations in schedules and demands. At this stage, assets will be optimized to maximize the throughput, and therefore enabling a more predictable allocation and scheduling;
- the pre-tactical stage: to make adjustments (if possible) to the system parameters, for example the airspace organization, projected trajectories, or the entry/exit time intervals for the airports or the airspace regions to cope with any unbalance;
- the tactical stage: to make dynamic actions to the system in order to adjust unbalances caused for example by weather conditions, infrastructure status, resource allocations or other disruptions in schedules.

The collaborative layered planning is also considered in SESAR, since this last took the ICAO Global ATM Operational Concept as the guiding material for its ATM related research. Although, SESAR undertook this planning approach at all, the local, sub-regional and the European level to balance the capacity and the demand. Using collaborative planning and decision making, the decisions are made on the basis of common situational awareness, which by assisting to better understand the network effects, leads to more accurately achieve the desired results [13]. In addition, SESAR foresees a Network Management functions to link the partners in a transparent and collaborative manner, at the European, regional and local levels. This will ensure that the network has an achievable operational performance that remains stable and efficient, even if unexpected changes happen. The result of such planning is foreseen to be reflected in a continuously updated Network Operations Plan (NOP) [13], which aims to reach agreement on demand and capacity balancing and therefore ensure a degree of strategic de-conflicting whilst minimizing holding and ground queues. In its initial phase, the NOP is planned to enable the collaborative demand and capacity balancing through an integrated airspace / airport organization and management in accordance with the traffic complexity that should be managed. In case of capacity limitation, the Network Management might facilitate the negotiations to meet the demand with the capacity in a collaborative manner. Nevertheless, capacity might be adjusted by applying for example the airspace in a highly flexible manner, decisions made by an airspace organization or other resource management unit [13]. Once all possible measures are taken, the Network Management could link the airspace users, airports and other actors together to decide if the predicted level of delay is acceptable. If the delay is not acceptable, SESAR foresees the possibility of solving the problem by defining certain priority rules between the airspace users, in the objective of enabling the affected flights to meet their planning.

To favor information exchange and tailored sharing of information and to support the collaborative decision making processes, the technical architecture proposed in the SESAR D3 is the System Wide Information Management (SWIM) [13]. This is based on the interconnection of various actors – including flight crew, airline operators, airport operators and controllers – and their sub-systems for example surveillance, or flight control (see Figure 11). The architecture aims to provide a specific information management service, called SWIM service, in the following objectives [13]:

- support flexible and modular sharing of information;
- establish a transparent access to Air Traffic Management services;
  - ensure the overall consistency.

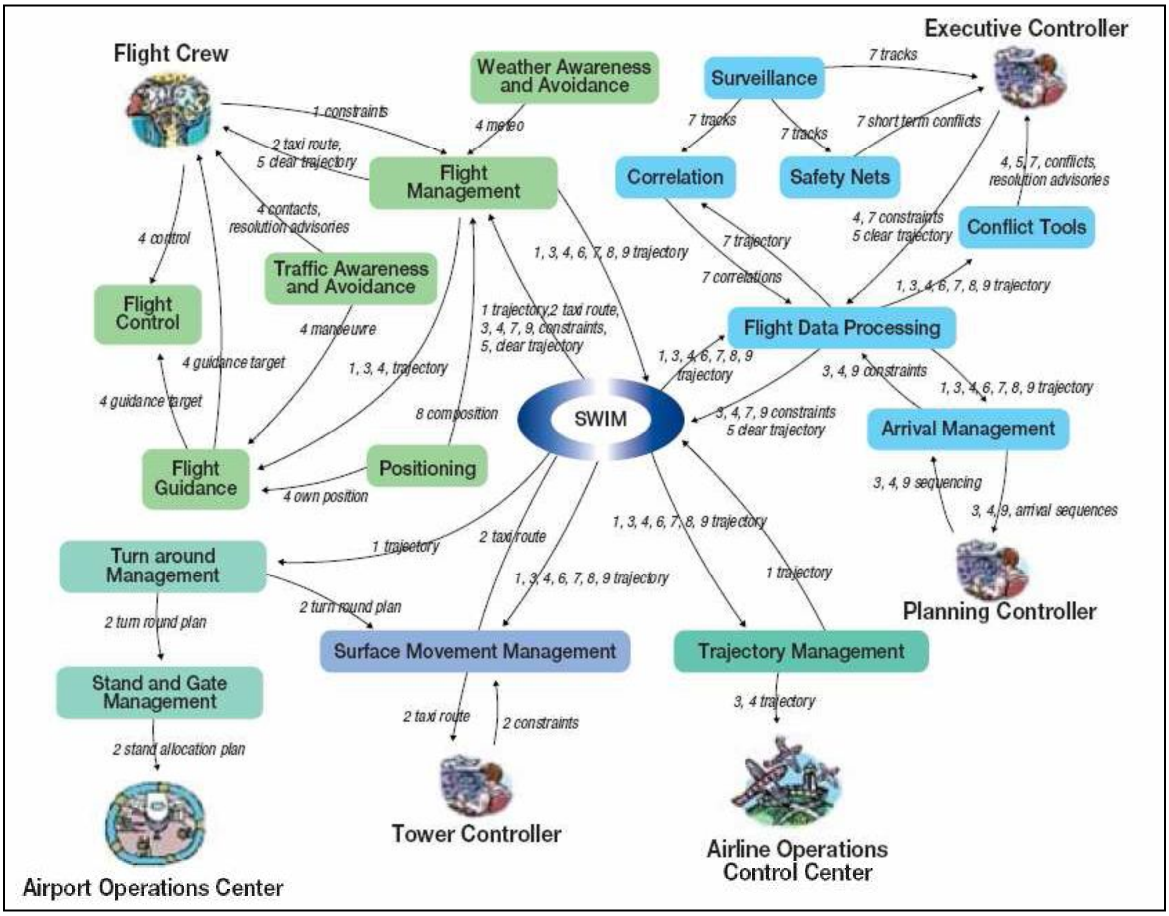

Figure 11. The SWIM architecture of SESAR (source: SESAR).

Collaborative decision making and its supporting architecture such as the SWIM of the SESAR program might be beneficial for EPATS, since this might enable to share the information between the different actors, which is especially valuable once the flight characteristics of the small and the traditional aircraft are different. In addition, EPATS foresees different propulsion systems, and therefore dissimilar aircraft characteristics, which once again might call (for example) for SWIM to handle the EPATS information exchange. Otherwise the different actors might not always be fully aware of the small aircraft traffic, and therefore might not be able to flexibly use the airspace and airport capacities. For that reason, the analysis of the impact of EPATS on ATM might ideally consider whether small aircraft uses the same regions of airspaces, including the analysis of the most preferred city pairs, constraining points (see chapter 3).

Air Traffic Control

This section reviews the relevant investigations and concepts dealing with air traffic control. Upon the conflict management and separation assurance methods, these might be classified into the following three approaches:

- trajectory oriented approach;
- airborne separation assurance approach;
- combined trajectory-orientation and airborne separation assurance approach.

According to the NASA [23], the first aims to shift the air traffic control paradigm from the tactical sector-based operation towards a strategic execution of flight trajectories that cover numerous sectors. Major investigations having this approach in mind include the (i) Programme for Harmonized Air traffic Management (PHARE) [45], (ii) the Distributed Air / Ground - Traffic Management (DAG-TM) [46, 47], (iii) the Innovative Future Air Transportation System (IFATS) [14], (iv) the Boeing ATM concept [48], (V) the Tube Advanced Lane Control (TALC) [41] and other investigations at the EEC, for example the Airborne conflict-free trajectory re-planning [2]. Generally, these investigations propose a "contract" negotiated between the air and ground to fly 3D trajectories at a given timeframe and within a predefined tolerance. The principle of these 4D (3D+time) trajectories is to know where the rest of the traffic or other limiting factors are to avoid [14]. This could be an aircraft flying at the same place and at the same time, or a specific meteorological circumstance, such as a thunderstorm. This approach is also often referred as "4D tubes" in the sky, which is therefore a reserved conflict free airspace like in the TALC concept. At the tactical planning these are generated with accordance to the aircraft characteristics, the traffic complexity, the meteorological conditions and the flight operators' demand. For managing, modifying and communicating the trajectories, numerous investigations trying to focus on advanced tools and certain procedures. For example Boeing [48] aims to apply a system of CNS satellites to share real-time aircraft trajectory-based information through the use of the so-called Common Information Network (see Figure 12). By doing so, the controllers and the airspace users' look ahead time is expected to increase, to reduce the buffer of the heading vectors while managing conflicts.

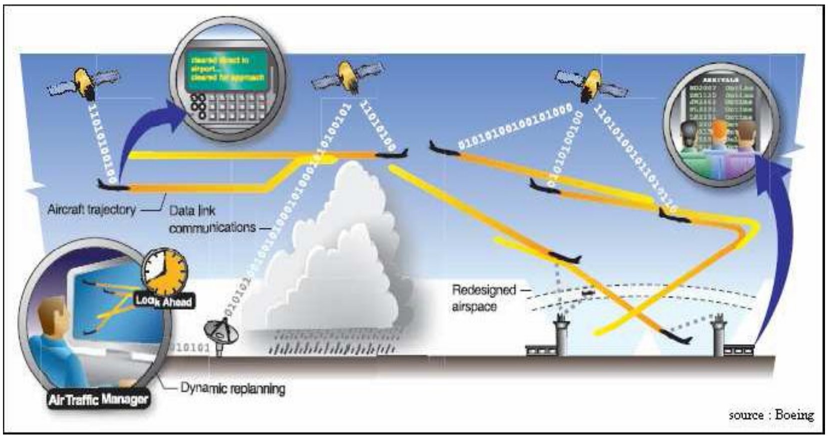

Figure 12. the use of a system of CNS satellite to share real-time information on aircraft trajectories (source: Boeing).

Although with further traffic increase the concept might only be beneficial in the short or mid term. On the other hand, the EEC [**2**] proposes an airborne trajectory-based approach; in which aircraft broadcast trajectory messages periodically that provide the basis for the airspace users to detect conflicts. As a consequence, no pilot, sectors or air traffic controllers are needed. This last is partially considered in the EUFP 6 IFATS project [14], in which short to mid term tasks are proposed to be performed by the onboard autonomous flight control system to keep the aircraft on its 4D trajectory, called "freedom bubble". According to the investigation, this is reasonable, since automation is assumed to find a solution for a conflict much faster than human being. On the other hand, the human being is suggested to be kept in the loop and to be able to act from the ground, since human being is considered to be advantageous in handling unexpected events, to solve problems and emergency situations that cannot be managed by the onboard automatism. (Note that a more specific analysis of human vs. automation is introduced in the chapter 4.)

In summary, the 4D trajectory-based operations might provide the following benefits [23]:

- more efficient flight path enabling to remain longer at higher altitudes,

- reduction in the variance of the inter-arrival spacing;
- reduced sector controller workload;

While the trajectory-oriented approach could be promising, it is envisioned that small aircraft pilots would demand enhanced situational awareness if complex traffic regions come into existence. In addition, caused by the system uncertainties (e.g. wind, speed, delays) this approach and more particularly the 4D contract is considered to require a relatively large buffer around the aircraft, which in the same time limits its capabilities [23]. Therefore, further analysis is required to address the above and to evaluate, whether it is reasonable to combine the approach with for example the Airborne Separation Assurance Systems (ASAS) [23].

ASAS differs from the trajectory-oriented investigations. ASAS aims to improve the flight crew situational awareness and achieve lower air traffic controller workload. According to the Co-operative Actions of R&D in EUROCONTROL in the context of ASAS (CARE-ASAS) [49], the Airborne Separation Assurance System is defined as "an aircraft system that enables the flight crew to maintain separation of their aircraft from one or more aircraft, and provides flight information concerning surrounding traffic". By taking onto account the operational procedures, human factors, aircraft instrumentation and system implementation, the ASAS applications include the following categories:

- "Airborne Traffic Situational Awareness": situational awareness is enhanced both in the air and on the airport surface, in which no changes in separation tasks and responsibilities are planned;
- "Airborne Spacing": overall responsibility for the separation remains at the controller, but pilots have new tasks for achieving and maintaining a given spacing with a designated aircraft;
- "Airborne Separation": overall responsibility for the separation remains at the controller, but pilots have limited delegated responsibility to ensure that the applicable airborne separation minima is met;
- "Airborne Self-Separation": full delegation of responsibility to the pilot, which separate their aircraft in accordance with the applicable airborne separation standards and rules of flight;

Based on these categories, controllers might delegate tasks like "merge behind", "remain behind" to the pilots, so that they become partially or fully responsible for reaching and maintaining a cleared distance from the surrounding aircraft. Due to this delegation of responsibilities, the controllers' workload is expected to be reduced, as less monitoring would be needed. In most of the concepts and projects addressing ASAS, this task is handled by using advanced aircraft automation and cockpit instruments, especially Cockpit Display of Traffic Information (CDTI) technology, flight-deck based trajectory tools and data links (see chapter 2.3.5. and chapter 4).

The major investigations focusing on ASAS include the (i) Full Aircraft Separation Transfer (FAST) [44] / the Free-Route Experimental Encounter Resolution (FREER) [50], (ii) the CoSpace [30, 51, 52], (iii) the DAG-TM [46, 47] (concept element 11), and the NASA Small Aircraft Transportation System Higher Volume Operations (SATS HVO) [53, 54, 55]. In these the ASAS application covers "autonomous aircraft" mode in the context of a free flight airspace (FAST/FREER), and airborne spacing in the terminal area, which is further discussed in the chapter 2.3.4. . Besides that in these concepts ASAS was found in general advantageous

in addressing local separation and in enabling efficient conflict resolution strategies, the EUROCONTROL [44] found the following experimental evidences:

- most of pilots reported that the system is valuable in low density areas, and 46% of them thought it could help them to assure the autonomous separation tasks even in high en-route regions;
- 80 % of the flight crews considered that autonomous operations are manageable without ATC intervention, however over 60 % would have preferred to have the ATC as a supervisor to handle abnormal cases;
- the additional pilot workload is found to be very low.

Apart of the constraints addressed by EUROCONTROL (e.g. acceptance of separation responsibility, new pilot task) [44] NASA [23] considers that ASAS in general is limited in addressing the global traffic flow strategy, and the predictability of the flight paths. Even so, ASAS might be advantageous with respect to EPATS, and especially if local traffic problems were to be solved, for example constrained points or airport surroundings. Therefore further analysis is suggested to address, whether EPATS is expected to be used in these regions.

To enhance the pilot situational awareness and avoid collisions, flight crew might also be provided with Airborne Collision Avoidance Systems (ACAS) [56]. Based on secondary surveillance radar (SSR) and mode S, ACAS operates independently of ground-based aids and Air Traffic Control to (i) monitor the surrounding traffic, (ii) assess the risk of collision and (iii) provide advice to the flight crew on potential conflicts. The drawback of the system, and especially in the context of EPATS, is that only those aircraft are detected, which are equipped with SSR transponders [57, 58] This once again makes it reasonable to analyze the EPATS flights in the European airspace, since if the extra EPATS traffic increases the traffic complexity, the project should consider the supplementary means of the Airborne Collision Avoidance Systems. Anyhow, the use of ACAS is regulated in Europe. First on the 1st of January 2000, all civil fixed-wing turbine-engine aircraft in the European Civil Aviation Conference (ECAC) area having a maximum takeoff weight above 15 000 kg or a maximum approved passenger seating configuration of more than 30 were obliged to be equipped with ACAS II. From the 1st of January 2005, this was modified to 5700 kg and 19 passengers [57]. Seeing this, one might even expect that the use of ACAS II will also be mandatory on all small aircraft by 2020.

The combined trajectory-orientation and airborne separation assurance concepts, these use trajectory-based operations to create trajectories that meet certain requirements of the airspace users, and supports situational awareness and airborne separation and spacing by using ASAS. The intended benefits over other methods are to [24]:

- reduce the conflict resolution caused by prediction uncertainty;
- decrease the deviations from the 4D contract;
- reduce the controller workload;
- minimize the impact on the pilot workload;
- and enhance the flight crew and controller situation awareness.

Major investigations using these concepts or similar ones are the Cooperative Air Traffic Management (C-ATM) [59], the Single European Sky ATM Research (SESAR) [13] and other relevant research done by the NASA [24]. The Cooperative Air Traffic Management (C-ATM)

is a European Commission Air Traffic Management research project, which is scoped around separation management by ASAS, 4D based cooperative flight management and collaborative traffic flow management [59]. In the concept the flight plan is represented by a coordinated 4D plan, and ASAS is used to support situation awareness, separation management and to ensure better adherence to ATC separation minima. Whilst the separation responsibility remains at the controller, it is envisioned that the 4D plans will define the segment of the flight in which ASAS might be applied and the pilot will overtake certain tasks related to spacing and sequencing. The concept might provide the benefits mentioned above however, in 2006 only high level descriptions are available and the concept has not yet been validated. Therefore this investigation rather focused on SESAR, which in any case is reasonable, since according to EUROCONTROL, this program will drive the modernization of the European ATM system [38]. SESAR represents trajectories as commonly agreed business intentions of the airspace users in the 4 dimension, which is elaborated by integrating the ATM and the airport capacities. The objective is to minimize the changes to trajectories, their environmental impact and to achieve the most reasonable outcome for all actors. As the aircraft is not just concerned with the management of its own trajectory but as well as those of the others, the concept also calls for a number of ASAS applications. In SESAR, the conflict management and the separation modes distinguish the managed and the unmanaged airspaces (see chapter 2.3.1.) [13]. While in the last the pilot is responsible for separation, in the managed airspace, the task remains in the hand of the air navigation service providers. However, in specific circumstances, self-separation and the limited delegation of certain responsibilities is envisioned under agreed criteria and within specified limits (e.g. time or distance). Seeing that controllers are staying in the loop, their workload – as one factor of the ATM capacity – is addressed in the followings [13]:

- automation of controllers' routine tasks;
- automation to support the traffic monitoring, conflict detection and resolution;
- reduction of the tactical intervention by distributing its tasks to the airspace users using airborne separation.

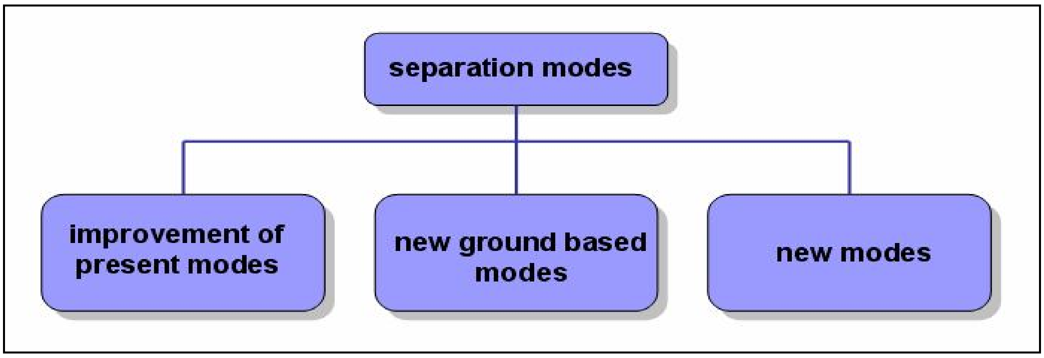

Figure 13. Separation modes envisioned by SESAR. (source: SESAR).

The proposed separation modes include the conventional, new ground based and new airborne separation methods [13] (see Figure 13.). The first covers the present modes with improved data and advanced tools to enhance the trajectory and the network efficiency. The new ground based method will include the Precision Trajectory Clearances, in which the airspace users will maintain their trajectory, since this – as expected – enables controllers to handle the increase in

traffic volume while keeping their workload at acceptable levels. To further reduce the ANSP tasks, a trajectory control mechanism is proposed, an automated system performing horizontal and vertical speed adjustments within a medium term time horizon to reduce the traffic complexity by de-conflicting the flights. Based on the clearances of the controller, the airspace users could proceed three types of trajectories. Depending on the performance required, these might be 2D routes (with lateral restrictions as in the current methods), 3 D routes (with lateral and vertical trajectory definition), or 4 D contracts (in which the flight course is defined in the time and the 3 dimensions). With respect to the new ground airborne separation modes, SESAR proposes to use ASAS [13] to perform cooperative or self-separation. While in the first the pilots are only temporarily responsible for the separation, in the last they are fully designated along a predefined segment of the flight. One intention of the program is also to allow a mixed operation, meaning that both self-separation and controller separated flights could operate in the same airspace. It is predicted that by 2020, self-separation will be available in the low density areas, but in the medium and high-density regions, and especially in the managed airspace, not all the modes will be available. This drives the potential opportunities for EPATS, since at this stage of the investigation, it is rather expected that small aircraft will fly to relatively short distances and therefore at low altitudes, which could reach the regions of the major European airports, and thus the high-density regions. Thus, once ASAS might not fully be available by 2020, the airborne separation might require to be combined with other concepts (e.g. airspace management). However, ASAS could solve the problem of conflicting aircraft; there remains a problem of what to do with multiple conflicts, meaning that the conflict resolution of two aircraft creates a conflict with other flight(s) (see Chapter 3.6.2.).

With respect to collision avoidance, SESAR envisioned that the Short Term Conflict Alert (STCA) and the above introduced Airborne Collision Avoidance Systems (ACAS) will continue to play a major role. The program aims to further develop these areas, so that the shared information could be used at both, at the pilot and at the controller side [38].

2.3.4. Airport and terminal area management

In SESAR [13] the airports are aimed to be fully integrated into the ATM network with particular focus on runway throughput and turnaround management. This is explained to be reasonable, since the capacity of airports with the terminal airspace around them is one of the limiting factors of the overall capacity, and thus should be addressed [13]. The view is that the aircraft should be managed by passing the turnaround process and the flight operations as a single continuous series of events, since this improves to meet the estimated times of the events such as take-offs. On the airport the separation between the aircraft and other objects is proposed to be guaranteed by visual means with support of automation. Controllers and pilots will be supported by enhanced ground surveillance information, runway incursion alerts, ground route planning, advanced automated systems (e.g. auto-brake) and CDTI technology to improve the situational awareness of controllers and other actors of ground movements. According to SESAR [13] this would improve the throughput in low visibility conditions, decrease the uncertainties, which enables capacity expansion. To further maximize the runway utilization and throughput, the program considers that the following major actions should be in place [13]:

- reduction of the dependency on wake vortex, by improved prediction/detection (e.g. by X-band Doppler radar [60]), and by the use of wider categories;
- group similar aircraft in categories; re-sequence the traffic flow;
- minimize the runway occupancy time and reduce departure spacing;

- enhance final approach using ASAS and time-based separation taking into account wake-vortex;
- enhance efficiency by redesigned and optimized runway configurations and by enabling more utilization in Low Visibility Conditions (LVC).

With respect to the terminal operations, and the low/mid density regions, multiple arrival routes with curved route segments are proposed in the objective to optimize the profiles for all trajectories [13]. In high-complexity terminal areas, an advanced airborne and ground system is suggested to be combined with efficient airspace organization. On the other hand, this is only achievable though the cost of limitations on individual intended trajectories. The airborne spacing capabilities are planned to be combined with Arrival and Departure Management (A/DMAN) tools to assist controllers and to optimize the spacing on the approach [13]. One relevant European investigation in this field is the Darts 4D [61] product, which is the word's first proven, arrival and departure manager. Its components are in operational use at several airports across Germany, and have evidences for delay and cost reductions, capacity improvements, enhanced organization of traffic, and environmental impact reduction. Beside A/DMAN, the arrival and departure routes in SESAR are suggested to be either defined by "cones" enabling to fly closer to the intended trajectory, or by "tubes" to maximize runway throughput once traffic density is highest (see Figure 14.). This approach could be promising if EPATS would fly in the vicinity/at the major European airports with high traffic complexity, since that enables small aircraft to be separated from the commercial flights flying in the "tubes".

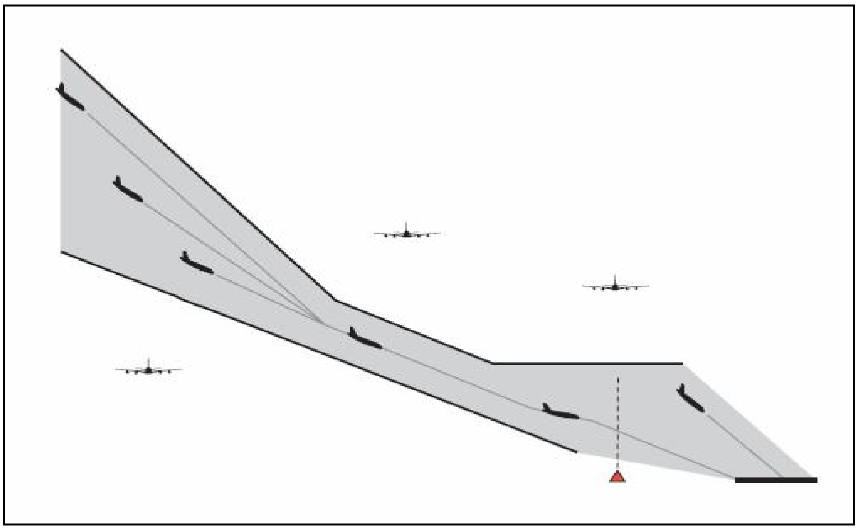
Figure 14. Departure and arrival route at high density terminal operations using "tubes" in the sky.

Consistent with SESAR, the CoSpace [30, 51, 52] addresses the final approach by ASAS. It improves the sequencing of arrival flows through the delegation of tasks like "remain behind", "merge behind" and "vector then merge". According to the experimental evidences, the concepts enables to [51, 52]:

- reduce the number of maneuver instructions by 67% for the speed and by 73% with respect to the heading;
- reduce the spacing deviation (+/- 5s) by 44% relative to the conventional condition;
- enhance flight efficiency with straighter aircraft trajectories and reduced time / distance flown per aircraft (by 10 and 5% respectively);

By using several entry point in the same time to sequence the arrival flows, CoSpace might even enable to handle EPATS and commercial flights in the same time, if the flight characteristics would be different (e.g. piston small aircraft vs. large jets).

On the other hand (in 2007), the only available investigation that focuses on small aircraft in relation to ATM is the NASA Small Aircraft Transportation System project with four enabling operating capabilities [53]. The Higher Volume Operation (HVO) [53, 54] in particular targets the simultaneous operations by multiple small aircraft at and around small non-towered airports in nearly all weather conditions. The concept is based on the self-controlled-area (SCA), where the air traffic management functions are distributed between the pilots and the ground system called the airport management module (AMM), located at or near the airport [53, 54]. When an aircraft approaches the SCA, the pilot must request entry from the AMM. Once the reply is received and an entry is guaranteed, the pilot should contact the ATC to get approval to depart from the controlled airspace. Within the SCA, pilots accept responsibility for maintaining self-separation and to fly according to the landing sequence information given by the AMM on a "first-come first-served" basis. In HVO, the approach path is based on a "GPS-T" [53, 54], consisting of two initial path that merge into a 90 degree turn to the final path leading to the runway (see Figure 15.). When several aircraft are involved in the approach, the pilot is responsible to stay within a safe distance from the others and remain on the path given by the AMM. In case of deviation from the desired course, autonomous conflict detection and alerting algorithms alert the pilots. These tasks are supported with various aircraft equipage; including GPS based navigation, cockpit display of traffic information (CDTI), Automatic Dependent Surveillance – Broadcast (ADS-B) and Traffic Information System – Broadcast (TIS-B).

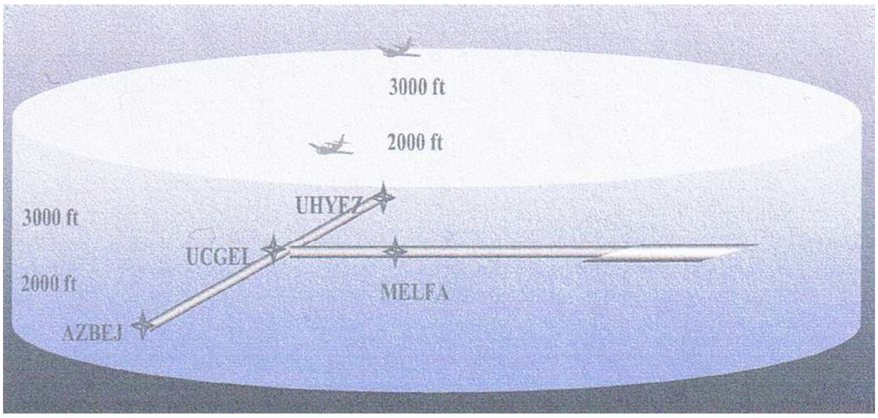

Figure 15. The self-controlled area and the approach geometry of the SATS HVO (source: NASA).

By 2005 the concept and its procedures have been validated through simulation and real flight experiments. Major results show that low experienced instrument rated pilots could fly the procedures safely and with acceptable situation awareness [55]. However, for its potential application for EPATS requires further investigations to evaluate whether the mixed traffic consisting of HVO and non-HVO equipped aircraft might be handled safely. If the mixed traffic is not manageable, than the major limitation of the concept is the equipage of small aircraft with the system requirements, for example ADS-B.

Communication, navigation, surveillance technologies

An initial view of the Communication, Navigation, Surveillance (CNS) technologies needed to support the ATM architecture for 2020 is given in SESAR [13].

In short, those communication technologies are envisioned that enable voice and data exchanges between all participants of the SWIM architecture. The suggested methods cover IP

based ground-ground communications, 8.33 kHz and SATCOM voice and new airport datalinks to support ground communications.

In general navigation is envisioned to be improved with the combination of global navigation satellite system (GNSS), self-contained navigation systems and navigation aids enabling enhanced positioning, guidance and 4D trajectory operations in all phases of flight. The aircraft positioning is advised to be satellite supported [62] with aircraft and satellite based augmentation systems (A/SBAS), such as the EGNOS in Europe or the WAAS in the USA, since these transmits corrected time and distance to enhance the GPS signal precision and reliability [63]. SBAS is particularly expected for the use of General Aviation (GA), since these in most of the cases fly to less equipped landing facilities (e.g. without ILS). On the other hand, the present terrestrial navigation aids for example the Distance Measuring Equipment (DME) or the Instrument Landing System (ILS) is proposed to remain a backup system, as most of the aircraft/airports are equipped with, crews are trained and the supporting infrastructure exists.

With respect to the surveillance technologies, the objective according to SESAR [13] is to enable precision monitoring of all traffic and to ensure safe and efficient operations. Both the cooperative and the independent non-cooperative surveillance systems are envisioned, in order to detect non-operating transponder or unidentified vehicles, the so-called non-cooperative flights. For this last, the primary surveillance and the surface movement radars are suggested. The choice of the cooperative surveillance technology remains flexible, seeing that the aircraft by 2020 are envisioned to have the necessarily Mode S and ADS-B equipage.

In 2007, the most relevant investigation dealing with CNS technologies in the context of small aircraft is the Lower Landing Minimums (LLM) [54] concept of the NASA SATS' four enabling operating capabilities. The LLM aims to provide precision approach and landing guidance to small airports in low visibility, through the use of multifunction displays with graphical flight-path guidance, artificial or enhanced synthetic vision, and also head up displays. A major progress was achieved with the Synthetic Vision Systems (SVS) that aims to enhance the pilots' situation awareness through a three dimensional perspective presentation of the outside world, regardless of any weather condition. The Figure 16 indicates the system [64], in which the artificial vision is generated by the combination of advanced on-board sensors, digital terrain databases, geo-positioning records (with GPS satellite signals), relevant traffic data from radars or ADS-B [65] and digital processing technologies.

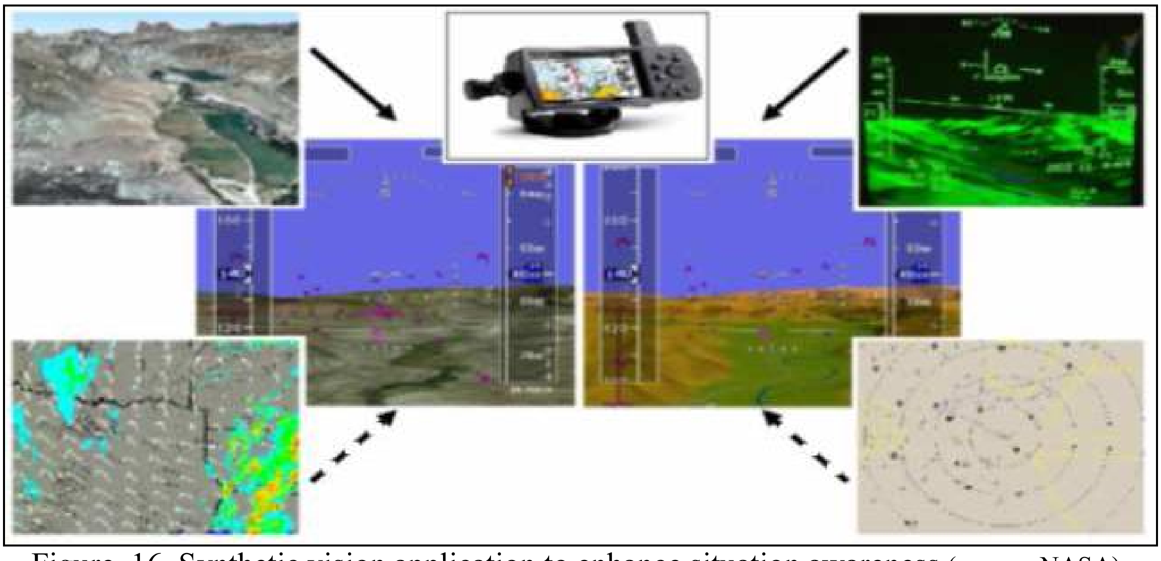

Figure. 16. Synthetic vision application to enhance situation awareness (source: NASA).

To reduce accidents where weather is a contributing factor, the SVS is also supported by real-time aviation weather information services. An example for such an instrument is the Aviation Weather Information System (AWIN) [66] that offers 3-D description of the weather patterns such as wind-shears, thunderbolts, or storm cells. In addition, SVS or other advanced cockpit displays also enable the artificial representation of the flight path by tunnel or pathway-in-the-sky representations [67, 68]. Numerous simulation tests and flight trials [69, 70, 71] demonstrated that by using these pilots gained increased situation awareness and reduced workloads. By combining the flight path representations and the advanced displays, the cockpit view of certain small aircraft, especially those produced in the recent years, provide a more familiar representation of the surroundings and the flight characteristics (see Figure 17). As demonstrated in 2003 [72], this leaded to the reduction of the greatest contributing factor to fatal worldwide airline and general aviation accidents [73], the Controlled Flight Into Terrain (CFIT). For that reason, the technologies introduced above are particularly envisioned for EPATS to handle complex traffic regions, even if the equipments and especially when TCAS (Traffic Collision Avoidance System) and ADS-B are applied might raise the purchase price of the aircraft [24].

Figure 17. The cockpit environment of the Columbia 400 (picture by author).

3. IMPACT OF EPATS FLIGHTS ON THE ATM PARAMETERS

3.1. Generally used approaches and metrics of evaluation

Chapter three aims to analyze the impact of EPATS flights on ATM parameters. Seeing that this should cover numerous ATM domains (see chapter 2), the initial task is the identification of the generally used approaches, since this would enable to explore how the ATM domains might be analyzed and influenced by EPATS. The investigation should cover the applied methodologies and the major ATM parameters.

In the literature, the characteristics of the ATM domains (e.g. ATFM, ATC, and ASM) are assumed to be driven by the outcomes of the ATM performance analysis. According to EUROCONTROL [1, 6, 21], the metrics of evaluation should cover at least the followings:

- safety: number of ATM incidents for example runway incursion or inadequate separation;
- flight efficiency: ranging from added flight time or fuel consumption due to maneuvers or route extension relative to great circle distance (see Figure 4.);
- cost: covering the delay cost and the capacity cost (or the cost of Air Traffic Services) as proposed by the EUROCONTROL Capacity Assessment and Planning Guidance [6]
- effective capacity: given as the traffic volume that the ATM system could handle with one minute per flight average en-route ATFM delay;
- delay: measured at the network level, given in average ATFM delay per flight (which expresses the ratio between the total ATFM delay and the number of flights in a defined area over a defined period of time).

To cover the domains introduced above, the literature generally considers the followings, or their combination [1, 13, 21, 74]:

- number of flights;
- distribution of flights (meaning for example a FL distribution, or the most constrained city pairs, airports and waypoints [1]);
- number of interactions (lateral, vertical, overtaking);
- number of separation looses;
- number of conflicts;
- sector capacity;
- controller, pilot workload (expressed generally in percentage of workload increase/decrease);
- flight time or fuel consumption (to estimate flight efficiency);

In addition, investigations [74] show that some of these ATM metrics are correlated, seeing that for example the controller workload is a factor of the traffic volume, the traffic complexity, the working methods or the applied technologies and tools (e.g. Short Term Conflict Alert, A/DMAN).

Besides, to capture the external factors that impact the controller workload and the level of difficulty attributed to their tasks, without considering internal factors (for example the Air Navigation Service Provider organization, controller tools), the EUROCONTROL [75]

proposed the traffic complexity indicator rather than the traffic density itself. The complexity indicators are based on the concept of interactions, which is a predefined cell including simultaneously two aircraft in the same time (see Figure 18).

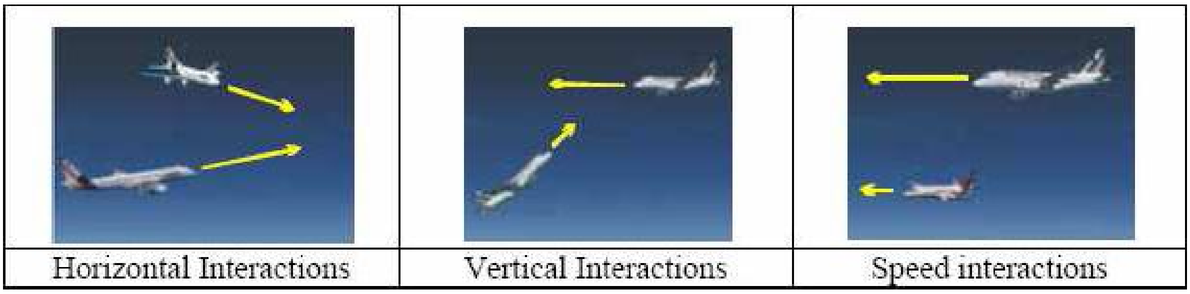

Figure 18. Structural complexity indicators (source: EUROCONTROL).

The traffic complexities are given for each European ANSP, calculated as the product of two major components: (i) the traffic density and (ii) the structural index. The density indicator is a measure of the potential number of interactions between aircraft, expressed in the total duration of all interactions (in hours) per flight-hour. On the other hand, the complexity indicator distinguishes the following three components [75] (all given in ratio of interactions relative to the total duration of all interactions):

- horizontal interaction: to capture the complexity of the flow structure based on the potential interactions between two aircraft on different headings;
- vertical interaction: to reflect the complexities arising from aircraft in vertical movements;
- speed interaction: to take into consideration the complexities due to dissimilar speeds. mixed traffic with different flight characteristics and more particularly the speeds.

Traffic complexity is advantageous in the context of EPATS, since besides the potential impact arising from the envisioned traffic volume, it enables to analyze whether the mixture of traffic with different flight characteristics results in interactions (e.g. piston vs. commercial jets at airport surroundings, or turboprops vs. jets at higher altitudes).

To perform analysis in the domains introduced above, numerous European airspace analyzing tools are available, ranging from the model based means (e.g. NEVAC, SAAM, COSAAC, TAAM, RAMS, DARTS) to real time simulators (e.g. EDEP, ELECTRA) [6]. NEVAC (Network Evaluation & Visualisation of ACC Capacity) [76] is a EUROCONTROL software application enabling to compute ACC capacity indicators, to detect bottleneck sectors and to evaluate the effect of new configurations or changes in sector capacities on an ACC. SAAM (System for traffic Assignment & Analysis at a Macroscopic level) [77] addressing the analysis and the visualization of the route network and airspace development, RAMS (Reorganised ATC Mathematical Simulator) [6] enables investigations for the en-route aspects, while TAAM (Total Airspace and Airport Modeller) [6] and DARTS (see chapter 2) are focusing on the airport movements. Developed through EUROCONTROL and DSNA cooperation, COSAAC (COmmon Simulator to assess ASM & ATFM Concepts) [78] is a pre-tactical ATFM simulator that uses CFMU records.

3.2. Limitations of the generally used approaches and tools

Seeing that the future ATM and traffic characteristics of both the traditional and the EPATS flights are the driving factors of the metrics to be analyzed, an extensive investigation would require numerous inputs, including for example the aircraft characteristics (e.g. size, flight attributes, propulsion technology), the operational features (e.g. flights in controlled or in uncontrolled airspace, professionally or personally operated aircraft, airport preference: small vs. regional), the expected traffic size (e.g. the number of flights, the distribution of flights, the most frequently used city pairs), and the envisioned ATM characteristics (e.g. airspace organization, controller workload, different ATM system capacities). With respect to the last, while SESAR already proposed the guidelines for the ATM in 2020, at this stage it is not fully clear how exactly the metrics of evaluation would be in the coming ATM architecture. This lack of data is a recurrent problem in similar investigations as well [74], and unfortunately limits the applicability of the above introduced ATM analyzing methods (see required input) and therefore the possibilities of this work. For example it might not be accurate to evaluate the impact on the sector capacities or on the controller workload, once the capacity and the layout of the airspace regions are uncertain. Same problem should be faced with respect to the assessment of the number of conflicts due to EPATS, for which – driven by the lack of data – only vague outcomes are feasible, such as naming the most concerned areas without expressing an exact rate of growth. In addition, the currently available EPATS prediction does not allow to perform a fast time or real time simulation, seeing that this would require numerous inputs (like the daily distribution of the envisioned traffic or a city pair list) that are unavailable. On the other hand, using the city pair list of the envisioned EPATS traffic and the EUROCONTROL records on the most congested airports and waypoints across Europe, it would be feasible to analyze whether EPATS is predicted to use the same region of airspace, and how it would interact with the traditional flights in these regions.

Moreover, while "general" predictions are given for the traditional flights (e.g. number of flights), the information on flight distances or the FL distribution is limited. As a result, this investigation takes the EUROCONTROL COSAAC tool, as this permit to clone the traffic for 2020, and to obtain the required inputs for this analysis. Furthermore, COSAAC enables to select the small aircraft flights from the CFMU database and therefore enables the analysis of the current state of the EPATS flights (e.g. number of flights, propulsion technology preference, served cities).

As a consequence of these uncertainties and limitations, the available records (aircraft characteristics and the predicted traffic size) would only enable to locate the domains and the areas that require further investigations to cope with EPATS. This could be carried out by covering for example a traffic density analysis to investigate the ratio of EPATS flights relative to the amount of total traffic, especially once this supports further traffic complexity estimations, seeing that the traditional flights might interact with the EPATS traffic at both low and high altitudes. At low levels vertically, due to descending or climbing traffic, and at high level horizontally, seeing that the aircraft performances (e.g. speed) are different. Naturally, in both cases this might increase the traffic complexity and therefore Air Traffic Controllers (ATCOs) workload, or the pilot's tasks. For the same reason, the most preferred Flight Levels (FLs) of the two class of traffic should be analyzed, and give the ration of flights that is envisioned to fly in the same altitude. FL distribution might also show whether EPATS flights would use low altitude regions and how they might interact with high aircraft density regions at lower FLs such as airport surroundings (in which traffic complexity and the controller/pilot workload is relatively high).

3.3. EPATS aircraft characteristics

The analysis of the impact of EPATS flights on the ATM parameters is **based on the outcomes of the WP1 and WP2**, providing respectively the classes of aircraft to consider (Institute of Aviation: "EPATS Aircraft Mission's Characteristics to be Used for Demand 2020 Calculation") and the predicted traffic size (M3 Systems: "Synthesis of the EPATS Estimation Method and Results").

The EPATS aircraft characteristics are grouped into the following four categories:

- single-engine piston-powered aircraft, as being the most popular personal aircraft due to its relatively low acquisition cost;
- multi-engine piston-powered aircraft;
- single or multi-engine turboprop aircraft, which being used for different purposes, covers in general a larger, faster and more expensive aircraft than the pistons;
- jet aircraft, to consider the greatest speeds and range capabilities between the small aircraft. EPATS further distinguishes Very Light Jets and Light Jets, to capture the differences in the cost and the operational characteristics.

According to the project, these aircraft categories might be used for different purposes, such as:

- Personal – aircraft used for personal intentions, which is piloted by the owner(s) and operated under FAR 91 (number of passenger seats include the pilot seats);
- Business – aircraft piloted by the owner (without a professional crew) for individual or group business transportation (number of passenger seats exclude the pilot seats). Such owners are assumed to share a hangar with other users and pay a business insurance rate. They are assumed to purchase the commercial weather report service since travel is important to the conduct of their business and, on average, they fly more frequently than personal users. Operating under FAR 91;
- Corporate – aircraft generally in company or fractional ownership. The owners of these aircraft are supposed to rent a private hangar, pay the corporate insurance rate, and hire a professional crew (pay and benefits). Operating under FAR 91;
- Air taxi – aircraft operated on-demand under FAR 135;
- Commuter – aircraft enabling scheduled passenger service that operates under FAR 135.

These different categories and operational characteristics, EPATS considers the following aircraft types:

- ACP-1– Single-engine piston – personal;
- ACP-2 – Twin-engine piston – business;
- ACT-1 – Single-engine turboprop – air-taxi;
- ACT-2 – Twin-engine turboprop – commuter;
- ACJ-1 – Twin-engine Very Light Jet (<5000 kg) – air-taxi;
- ACJ-2 – Twin-engine Light Jet (< 7000 kg) – corporate.

The main characteristics of these aircraft are given in the Figure 19.

On the other hand, the EPATS prediction model considers only three classes of aircraft: (i)

Class of aircraft	ACP-1	ACP-2	ACT-1	ACT-2	ACJ-1	ACJ-2
Crew	1	1	1	1	1	1
Pas. Seating (PS)	3	5	9	19	5	9
Max Payload [kg]	285	475	855	1805	475	855
Useful load [kg]	530	560	1850	2400	1100	2200
Takeoff weight [kg]	1300	2000	4500	7200	2700	6000
TO Field length [m]	600	600	1000	1200	800	1000
Initial gradient [m/m]	0,12	0,18	0,14	0,18	0,18	0,18
Cruise speed [km/h]	320	350	550	550	700	750
Climb speed/Cruise speed CC	0,5	0,5	0,55	0,55	0,6	0,6
Cruise altitude [FL]	100	250	250	250	350	350
Range [km]	1000	1000	1500	1500	2500	2500
ATM Capability: SESAR level	1	1	3	3	3	3
SFC [l/km]	0,1	0,2	0,3	0,55	0,3	0,55
Operational costs [Euros/h]	200	300	1000	1300	1300	2000
Estimated Price [1000 Euros]	200	400	2000	4000	1500	3500
Total fixed operations time (TFOT) [min]	33	49	47	63	52	56
Average Load Factor (LF)*	0,7	0,7	0,7	0,7	0,7	0,7
Hours flown by year*	300	400	500	1400	400	400
Life Cycle [years]	20	20	20	20	20	20
Average Great Circle Distance (GCD) [km]	400	400	700	700	1100	1200
Average throughout distance to GCD rate (R)	1	1	1,1	1,1	1,15	1,15
Airport access/egress time [min]	15	15	20	20	20	20

Figure 19. EPATS aircraft characteristics (source: EPATS).

ACP-2, (ii) ACT-2 and (iii) ACJ-2, seeing that these are proved to offer the highest potential transfer to small aircraft. Additionally, the estimations of the number of flights and the aircraft fleet have been derived from the projected number of passengers transferred to EPATS and from the category of aircraft that is considered on each connection.

Knowing that the analysis of the impact of EPATS on ATM parameters is based on the outcomes of the demand model, this investigation considered the same aircraft categories and their classification according to the trip distance.

3.4. EPATS flights in 2007

To analyze the current EPATS flights in Europe (as in 2007), the analyst selected the EUROCONTROL COSAAC Software [78], as this is compatible with the CFMU ATFM records, enables to select the most similar flights to EPATS and advantageous in graphical imaging. Using COSAAC and the aircraft characteristics given by the WP1, the analyst shorted the EPATS flights from the total traffic registered by the CFMU. The Figure 20. shows the screenshot of the simulation made for a busy day (22^{nd} of June 2007), in the objective to present the geographical distribution of the movements over one day, and therefore to locate the most congested areas.

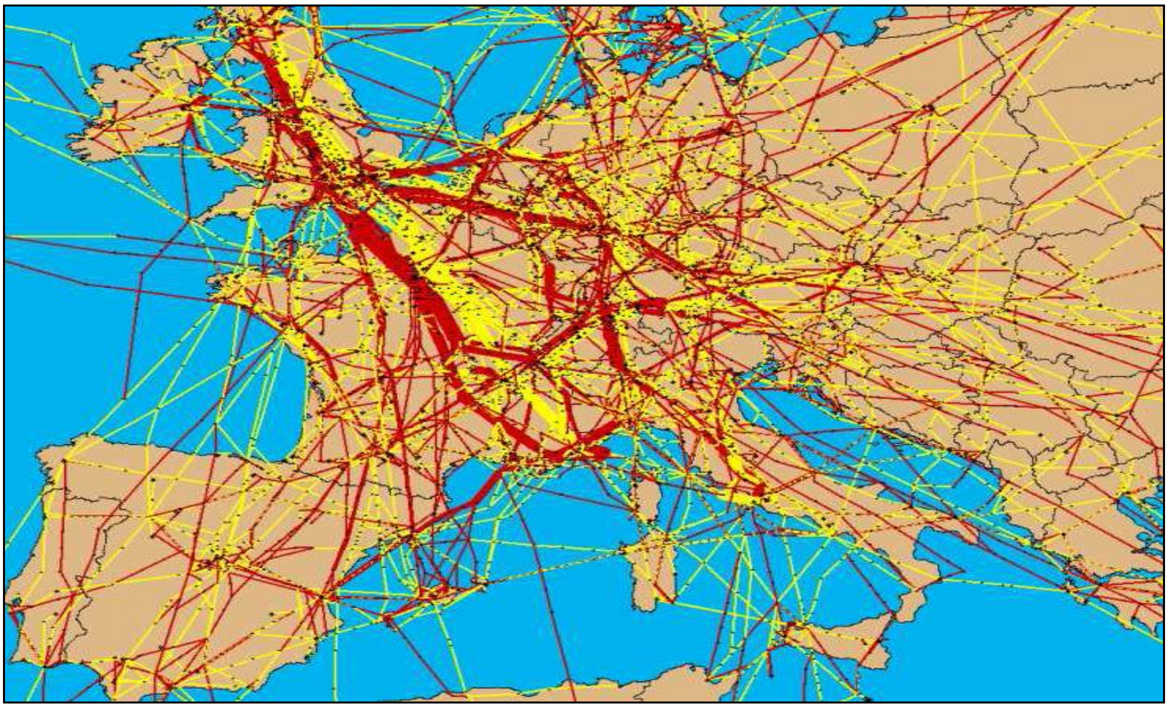
Figure 20. One typical day of EPATS flights in 2007.

Accordingly, small aircraft movements are non-homogenously distributed, and the most crowded regions are matching with those of the traditional traffic (see Figure 21.). In addition, the hourly distributions (see Figure 22.) of the two classes of movements show a similar shape, and peak at the same period of the day. Even so, the impact of EPATS on the rest of the airspace users is limited, seeing that small aircraft accounted for 2661 flights, or 8.1 % of the total of 32 594 movements at the analyzed day. Knowing the difference between the summer and winter periods [29], EPATS gives about 839 500 flights a year for 2007. This is exactly in line with the estimations of the European Commission [79], which projects small aircraft traffic to be less than 1 million. On the other hand, with the

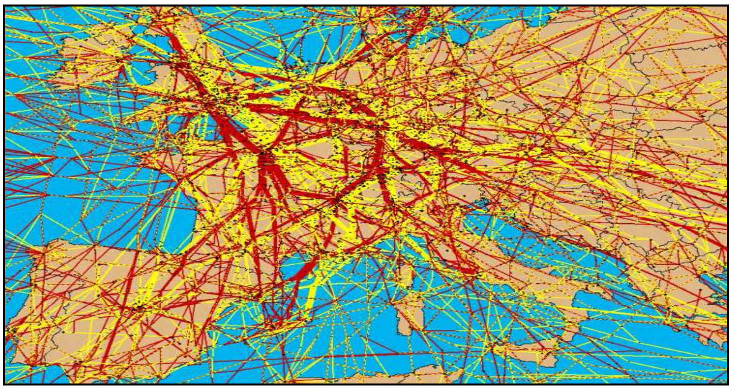
Figure 21. One typical day of the traditional flights in 2007.

envisioned EPATS growth, the impact of small aircraft is expected to change, and therefore there is a clear need to analyze ATM with respect to EPATS flights in 2020.

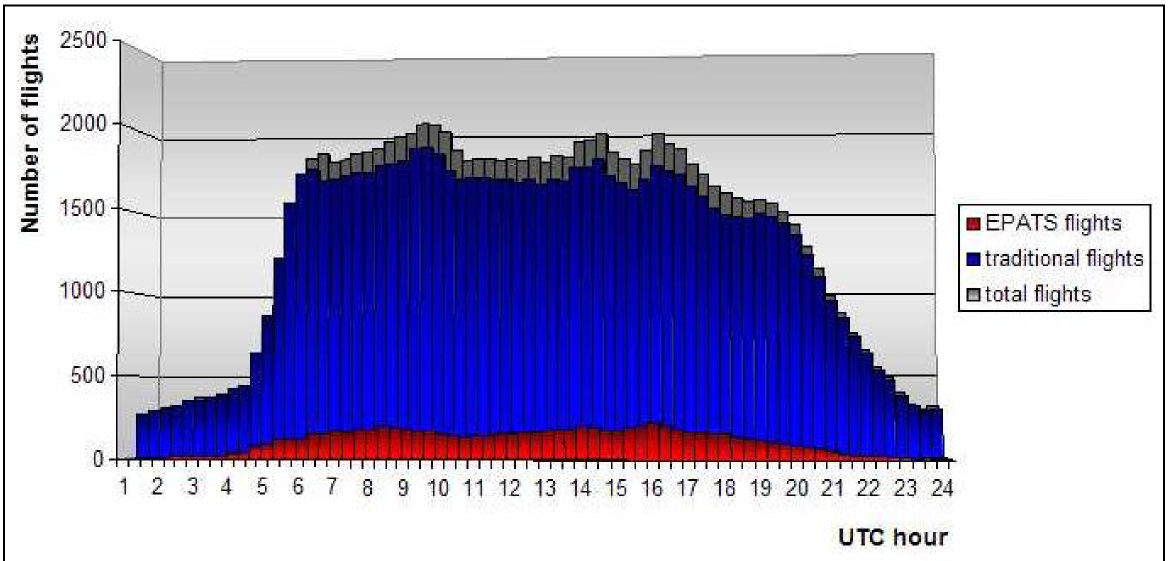

Figure 22. The hourly distribution of the EPATS (red), the traditional (blue) and the total flights (grey) in 2007.

- ***EPATS accounts in average for 2661 flights a day (or 839 500 movements a year) in 2007***
- ***EPATS represents 8.1% of the total traffic in 2007***
- ***Impact of EPATS on ATM is limited in 2007***

3.5. EPATS flights in 2020

The flight analysis for 2020 is **based on the EPATS prediction model provided by the WP2**. Accordingly, the projections are given in the context of ASSESS scenarios, which was developed in order to evaluate the effects of the White Paper measures. To consider the different degree of implementation of the White Paper, initially the following four scenarios were distinguished:

- N-scenario: Null scenario assumes that none of the measures of the White Paper is implemented, neither at the European level nor in the Member States;
- P-scenario: Partial implementation scenario that includes measures already implemented and the ones likely to be implemented before 2010;
- F-scenario: Full implementation scenario, which includes all 78 measures introduced in the White Paper and in the White Paper action program;
- E-scenario: Extended scenario that is a combination of the partial and the full implementation scenario.

On the other hand, the final version of the prediction model distinguishes only two cases (Case A and Case B) based on the different limits of application with respect to the jets. Seeing this, the predictions used the following rule:

- Pistons for trip distances up to 250 km (for both Cases);
- Turboprops for trip distance between 250 and 800 for the Case A, and 250-1000 with respect to the Case B predictions;
- Jets 800 and 1000 with respect to the Case A and Case B predictions respectively;

Unit of traffic	Original transport	Trip purpose	Case A	Case B
Millions of PKM	road	business	150 271	150 271
	air	typical business	1 734	2 961
Thousand of PAX	road	business	315 512	315 512
	air	typical business	3 599	4 995
Total number of flights			44 179 030	42 924 291

Figure 23. The estimated traffic and the EPATS fleet (source: EPATS).

By using the scenarios introduced above, the prediction results are summarized in the Figure 23. . Accordingly, by 2020 EPATS would range from 42 924 291 to 44 179 030 flights a year in Europe, and call from 89 000 to 99 000 personal aircraft respectively for the Case A and Case B estimations.

3.5.1. EPATS IFR flights in 2020

From the projected EPATS movements (as given in the Figure 23.), the ratio of flights based on the Instrumental Flight Rules (IFR) and the Visual Flight Rules (VFR) is unknown. On the

other hand, it is reasonable to distinguish IFR and VFR, since these have different characteristics, for example in the separation responsibility, the pilot ratings, the cockpit instrumentation, or the airspace to be used. As the vast majority of the commercial traffic and all scheduled air carriers operate under IFR, the most important is to analyze the impact of the EPATS IFR flights on the traditional (IFR) traffic.

Due to the limitations of the EPATS prediction model provided by the WP2, and the lack of other relevant European source, this investigation used the outcomes of the European Commission to estimate the ratio of the EPATS IFR flights from the total EPATS traffic. According to the above introduced document, titled "An Agenda for Sustainable Future in General and Business Aviation" [79], the followings were found:

"It is estimated that in 2005 approximately 15 million General and Business aviation flights took place in Europe. Less than 1 million of them were operated under the supervision of air traffic control"

Therefore, in 2005, a total of 15 million small aircraft flights took place, from which about 6.66 % or 1 million was IFR. From the total of 9.2 million IFR flights in Europe [21], EPATS IFR then represents 10.8 % in 2005.

	Thousands of IFR movements	Annual growth	Average annual growth 2020/2005	Traffic multiple 2020/2005
Scenario A	16 502	3.5%	3.7%	1.7
Scenario B	15 048	3.2%	3.3%	1.6
Scenario C	14 729	3.3%	3.2%	1.6
Scenario D	13 543	2.6%	2.7%	1.5

Figure 24. Long-term forecast of the European IFR movements (source: EUROCONTROL).

EUROCONTROL STATFOR [80] investigations include a long-term forecast of the European IFR movements (see Figure 24.), which projects from 13 543 000 to 16 502 000 flights for 2020. The provided predictions cover four different scenarios, being qualitatively and quantitatively quite different from each other, but not representing the most extreme futures in a particular direction. Using the high-growth scenario (Scenario A) and assuming (due to lack of data) that the above illustrated ratios (total IFR flights vs. EPATS IFR flights and EPATS IFR flights vs. total EPATS flights) hold for the timescale of this investigation, it becomes possible to assess the EPATS IFR movements for 2020. The key findings of this approach are summarized in the Figure 25. Accordingly, a total of 16 502 000 IFR and 26 733 240 EPATS flights would take place in 2020, from which EPATS IFR would call for 1 782 216 movements.

	Total IFR flights	EPATS IFR flights	Total EPATS flights
2005	9 200 000	993 600	14 904 000
2020	16 502 000	1 782 216	26 733 240

Figure 25. Long-term forecast of the European IFR movements based on the EURCONTROL and the EC records.

In contrast with the total EPATS flights estimation based on the EUROCONTROL STATFOR and the European Commission records that gave 26 733 240 movements for 2020 (see Figure 25.), the WP2 assessed this traffic to be 44 179 030 and 42 924 291 with respect to the Case A and Case B predictions (see Figure 23.). It is clear that there is a difference between the two predictions, reaching 17 445 790 and 16 191 051 EPATS flights, respectively for the Case A and Case B scenarios. Once the WP2 projections are correct, then STATFOR underestimated the small aircraft movements. Knowing that STATFOR records (as given in the Figure 24.) only accounts for IFR traffic, and that the EPATS IFR represents 6.66 % from the total EPATS flights, the underestimations are 1 161 889 EPATS IFR flights from the Case A, and 1 078 323 EPATS IFR movements from the Case B predictions. These should be adjusted to the STATFOR estimations presented in the Figure 24. . As a result, the total EPATS IFR flights to be considered in 2020 are 2 944 105 with respect to the Case A and 2 860 539 for the Case B scenario. On the other hand, the total IFR flights are found to be 17 663 889 and 17 580 324, respectively for the Case A and Case B projections, which relative to the original STATFOR findings indicate less than 10% of difference. As the results show, the EPATS IFR flights are finally represent from 16.6. to 16.2 % of the total IFR traffic.

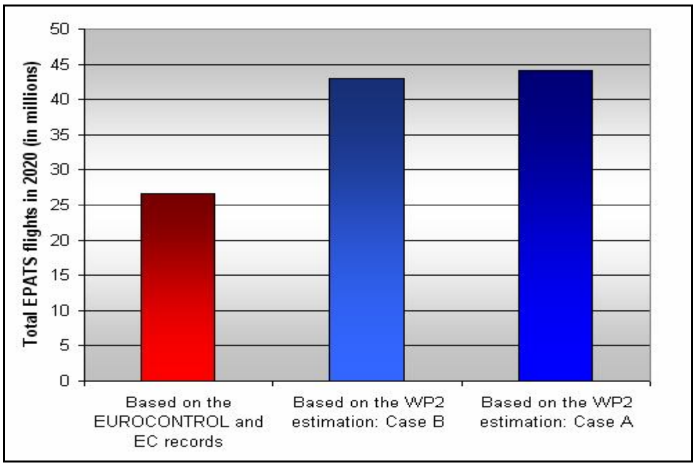

Figure 26. Summary of the total EPATS flights estimations for 2020.

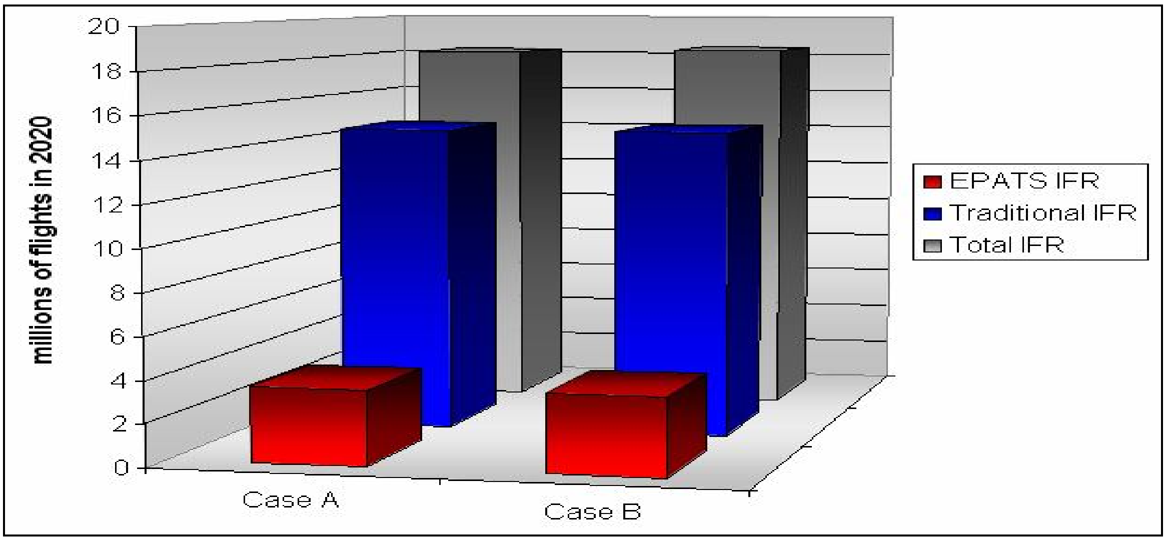

Figure 27. Summary of the total IFR and EPATS IFR predictions to be considered for 2020.

Total IFR flights to be considered in 2020:
- ***17 663 889 (Case A) or 17 580 324 (Case B)***

EPATS IFR flights to be considered in 2020:
- ***2 944 105 (Case A) or 2 860 539 (Case B)***

3.5.2. EPATS VFR flights in 2020

EPATS VFR movements are estimated from the total EPATS flights and the EPATS IFR traffic in 2020. Accordingly, relative to the small aircraft VFR baseline provided by the European Commission in 2005, this segment passed from 14 million flights a year to 41 234 924 or 40 063 751, respectively for the Case A and Case B scenarios. In average, this indicates a total growth of 232 % over the timescale of 2005-2020. Results also indicate that for both (Case A and Case B) predictions, EPATS VFR flights are in majority, giving respectively 91 and 92 percent of the total small aircraft movements (see Figure 28.).

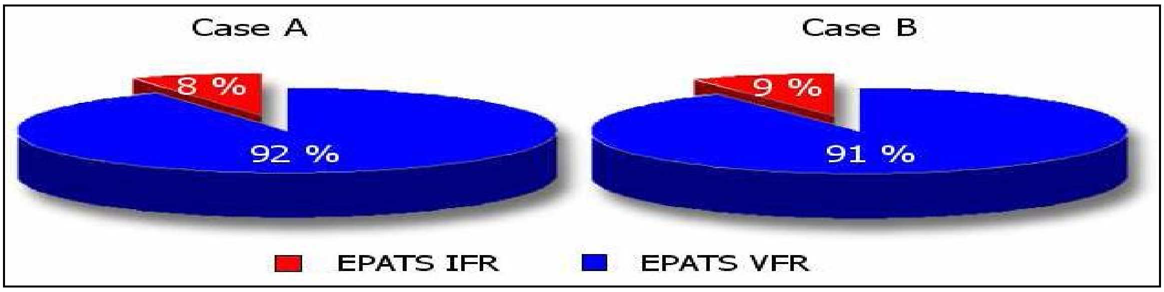

Figure 28. The contribution of the EPATS IFR and VFR flights to the total EPATS flights in 2020.

- ***EPATS VFR flights to be considered in 2020: 41 234 924 (Case A) or 40 063 751 (Case B)***
- ***EPATS VFR flights give about 91 % of the total EPATS flights***

3.5.3. Total EPATS flights in 2020 (IFR and VFR)

While the previous chapters distinguished the EPATS IFR and VFR flights, this section analysis the total (IFR and VFR) traffic in the aim of (i) placing small aircraft movements in the airspace, (ii) recognizing the most congested regions, waypoints, airports, flight levels (iii) and analyzing whether EPATS interacts with the traditional flights. To meet this objective, a detailed prediction model is required. Even so, the projections provided by the WP2, are only considering NUTS2 regions and not city pairs. While the Nomenclature of Territorial Units for Statistics (NUTS) reflect the demand in the regional statistical regions, a model on the city pair level would be more favorable to obtain the demand on exact arrival / departure locations and therefore to enable the investigations introduced above. As a consequence, the author distributed the projected demand provided by the WP2 between the airports in each NUTS2 region. For the distribution, numerous relevant airports from the EPATS airport database were considered (made by the WP1). Depending on the size of the region, this resulted from 1 to 7 airports in the NUTS2 areas and gave a total of more than 400 airports for the 28 countries considered by the WP2. The distribution was (due to lack of data) homogenous and performed in MATLAB. To visualize the EPATS flights on a European map, MATLAB used the GPS coordinates of the airports, as given by the WP1. Note that a Universal Mercator Projection was selected [81], since this results in a grid having equally spaced and straight meridians / parallels which therefore does not require converting the coordinates while plotting them in MATLAB. Nevertheless, the projection ends in limited shape distortions, or at least once compared with traditional maps using e.g. Orthographic Projections [81].

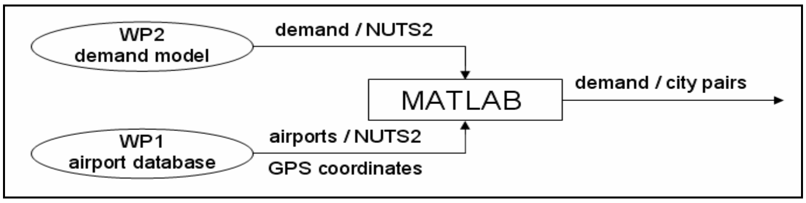

Figure 29. Distribution of flights between the airports of the NUTS regions.

The Figures 30, 31 show one typical day of EPATS flights for the Case A and the Case B scenarios respectively. As the Figures indicate, the difference between the scenarios is limited, since all shows that EPATS would cover the core area of Europe. To better visualize the flights and especially the most congested regions, Figures 32, 33 illustrate the traffic classified into four groups, covering from 5 to 20, 20-50, 50-100 and at least 100 movements a day.

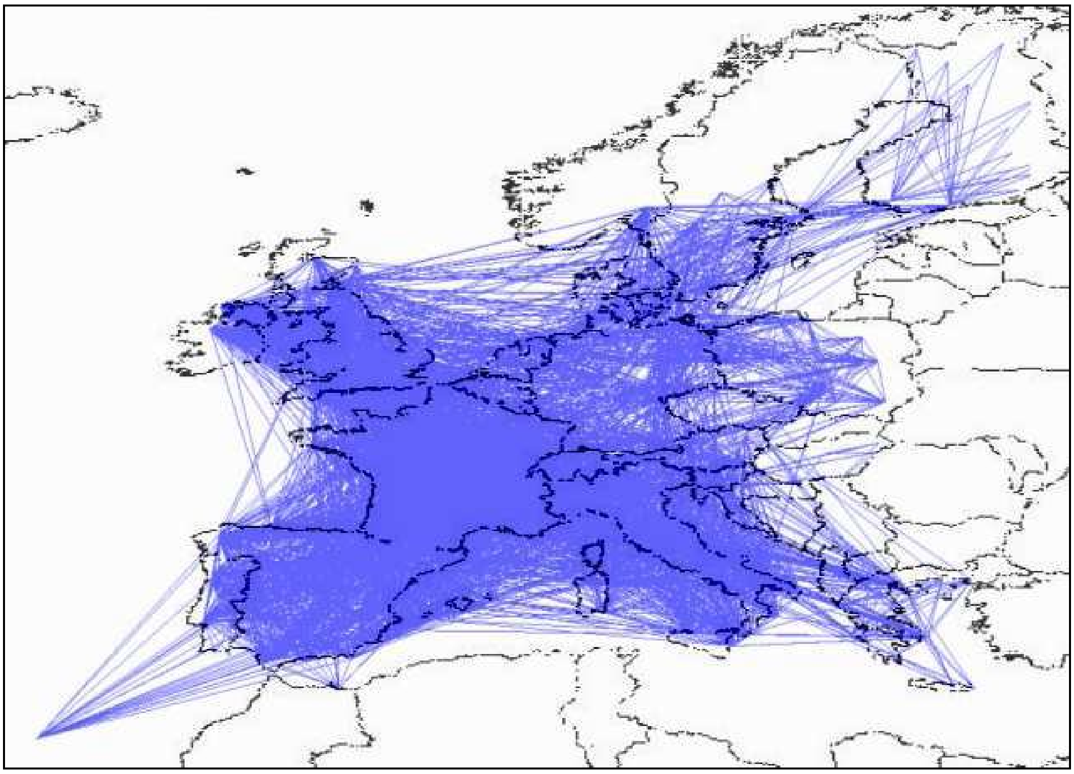

Figure 31. One typical day of EPATS flights: Case B

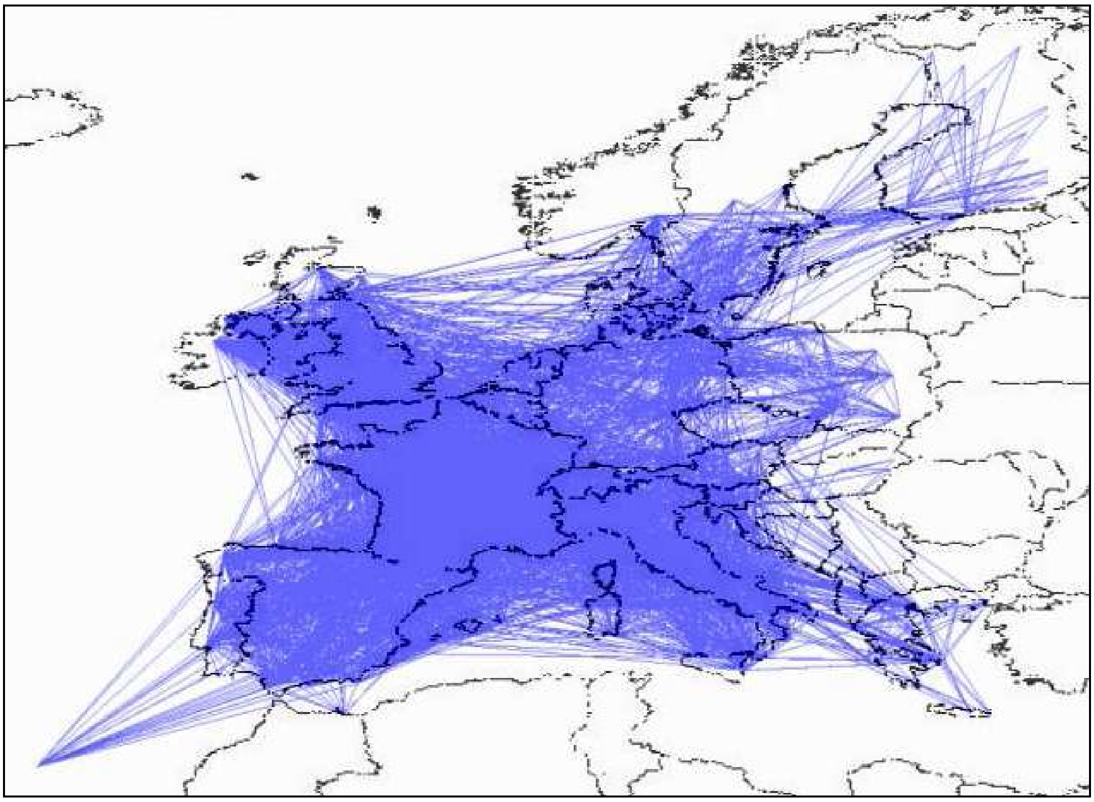

Figure 30. One typical day of EPATS flights: Case A

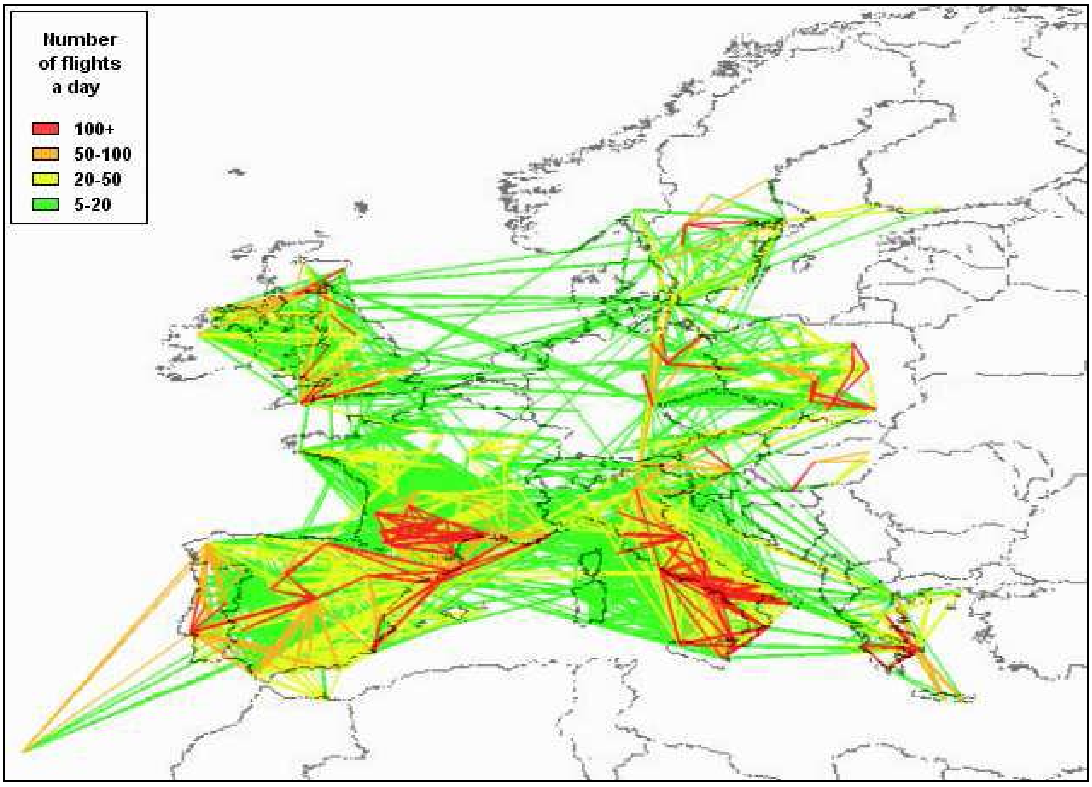

Figure 33. One typical day of EPATS flights: Case B

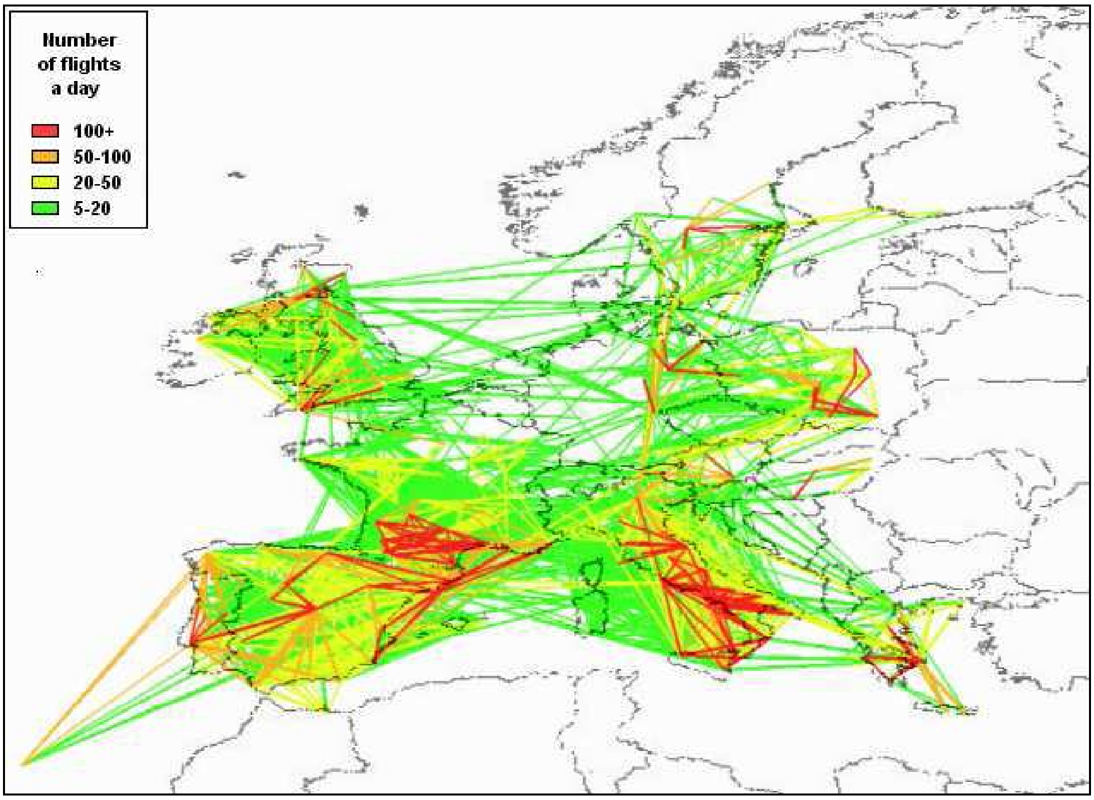

Figure 32. One typical day of EPATS flights: Case A

At this stage the question is whether the most preferred areas of EPATS are overlapping with those of the traditional flights. With respect to this last, EURCONTROL publishes the most congested airports and waypoints across Europe. While recent forecasts addressing rather 2025, it is assumed that the predictions hold for 2020. According to the available data, the most congested airports of the traditional flights are presented in the Figure 34 [80].

2005	2025							
Actual	Globalisation and rapid growth		Business as usual		Strong growth and regulation		Regionalisation	
PARIS CH DE GAUL	PARIS CH DE GAUL	0	FRANKFURT MAIN	1	FRANKFURT	1	FRANKFURT	1
FRANKFURT MAIN	FRANKFURT MAIN	0	PARIS CH DE GAUL	-1	PARIS CH DE GAUL	-1	MADRID BARAJAS	3
LONDON/HEATHROW	MADRID BARAJAS	2	MADRID BARAJAS	2	MADRID BARAJAS	2	PARIS CH DE GAUL	-2
SCHIPHOL AMSTERDAM	SCHIPHOL AMSTERDAM	0	SCHIPHOL AMSTERDAM	0	SCHIPHOL AMSTERDAM	0	SCHIPHOL AMSTERDAM	0
MADRID BARAJAS	LONDON/HEATHROW	-2	MUENCHEN 2	1	MUENCHEN 2	1	MUENCHEN 2	1
MUENCHEN 2	MUENCHEN 2	0	LONDON/HEATHROW	-3	LONDON/HEATHROW	-3	BARCELONA	1
BARCELONA	BARCELONA	0	BARCELONA	0	BARCELONA	0	LONDON/HEATHROW	-4
ROME FIUMICINO	ROME FIUMICINO	0	ROME FIUMICINO	0	ROME FIUMICINO	0	PRAHA RUZNYE	18
COPENHAGEN KASTR	COPENHAGEN KASTR	0	PRAHA RUZNYE	17	PRAHA RUZNYE	17	ROME FIUMICINO	-1
LONDON/GATWICK	PRAHA RUZNYE	16	WIEN SCHWECHAT	2	COPENHAGEN KASTR	-1	WIEN SCHWECHAT	2
ZURICH	WIEN SCHWECHAT	1	COPENHAGEN KASTR	-2	WIEN SCHWECHAT	1	COPENHAGEN KASTR	-2
WIEN SCHWECHAT	FERIHEGY-BUDAPEST	25	DUBLIN	12	STOCKHOLM-ARLAND	2	DUBLIN	12
BRUSSELS NATIONAL	MILANO MALPENSA	2	MANCHESTER	3	ZURICH	-2	WARSZAWA/OKECIE	19
STOCKHOLM-ARLAND	ZURICH	-3	WARSZAWA/OKECIE	18	WARSZAWA/OKECIE	18	FERIHEGY-BUDAPEST	23
MILANO MALPENSA	STOCKHOLM-ARLAND	-1	FERIHEGY-BUDAPEST	22	FERIHEGY-BUDAPEST	22	PALMA DE MALLORCA	8
MANCHESTER	DUBLIN	8	ZURICH	-5	DUBLIN	8	ZURICH	-5
PARIS ORLY	LONDON/STANSTED	4	STOCKHOLM-ARLAND	-3	MILANO MALPENSA	-2	STOCKHOLM-ARLAND	-3
ISTANBUL-ATATURK	BRUSSELS NATIONAL	-5	LONDON/STANSTED	3	BRUSSELS NATIONAL	-5	BRUSSELS NATIONAL	-5
OSLO/GARDERMOEN	MANCHESTER	-3	MILANO MALPENSA	-4	ATHINAI E. VENIZ	6	LONDON/STANSTED	2
DUESSELDORF	WARSZAWA/OKECIE	12	ATHINAI E. VENIZ	5	PALMA DE MALLORCA	3	MILANO MALPENSA	-5
LONDON/STANSTED	HELSINKI-VANTAA	1	BRUSSELS NATIONAL	-8	LONDON/STANSTED	0	ATHINAI E. VENIZ	4
HELSINKI-VANTAA	ATHINAI E. VENIZ	3	PALMA DE MALLORCA	1	MANCHESTER	-6	HELSINKI-VANTAA	0
PALMA DE MALLORCA	PALMA DE MALLORCA	0	HELSINKI-VANTAA	-1	ANTALYA	20	SCHOENEFELD-BERL	55
DUBLIN	OSLO/GARDERMOEN	-5	ANTALYA	19	OSLO/GARDERMOEN	-5	MANCHESTER	-8
ATHINAI E. VENIZ	PARIS ORLY	-8	OSLO/GARDERMOEN	-6	HELSINKI-VANTAA	-3	OSLO/GARDERMOEN	-6

Figure 34. The evolution of the top 25 airports in Europe between 2005 and 2025 (source: EUROCONTROL).

On the other hand, the most preferred city pairs and airports of the EPATS flights are given in the Figure 35 and 36 respectively. As one might observe, by the exception of two records (excluded in the EPATS prediction), all of the top 25 airports of the traditional flights are envisioned to be used by small aircraft. Their rank in the EPATS database is the following: Athinai E. Venizelos (2); Rome Fiumicio (4); Madrid Barajas (11); Barcelona (12); Warsaw Okecie (53); London Heathrow (83); Copenhagen Kastrup (86); Stockholm Arlanda (111); Budapest Ferihegy (135); Palma de Mallorca (164); Oslo Gardermoen (172); Milan Malpensa (191); Paris CDG (194); Helsinki Vantaa (200); Wien Schwechat (215); Muenchen 2 (230); Manchester (255); London Stansted (275); Brussels National (298); Praha Ruznye (300); Amsterdam Schiphol (309); Frankfurt Main (335). Accordingly, Athens, Rome, Madrid, Barcelona, Warsaw, London are the most influenced by EPATS, while the most congested locations of the traditional flights such as Frankfurt, Amsterdam or Paris are less concerned (see Figures 32, 33, 36).

A country	A name	B country	B name
Greece	ATHINAI E. VENIZELOS	Greece	MEGARA
Greece	ATHINAI/Athens	Greece	MEGARA
Greece	ATHINAI E. VENIZELOS	Greece	ARAXOS/PATROS
Greece	ATHINAI/Athens	Greece	ARAXOS/PATROS
Italy	PALERMO PUNTA RAISI	Italy	REGGIO CALABRIA
Italy	PALERMO PUNTA RAISI	Italy	CROTONE
Italy	CATANIA FONTANAROSSA	Italy	REGGIO CALABRIA
Italy	CATANIA FONTANAROSSA	Italy	CROTONE
Italy	PESCARA	Italy	ROME FIUMICINO
Italy	L'AQUILA-PRETURO	Italy	ROME FIUMICINO
Greece	ATHINAI E. VENIZELOS	Greece	SPARTI
Greece	ATHINAI/Athens	Greece	SPARTI
Spain	MURCIA SAN JAVIER	Spain	VALENCIA
Spain	MURCIA SAN JAVIER	Spain	ALICANTE
Spain	VALLADOLID	Spain	MADRID TORREJON
Spain	VALLADOLID	Spain	MADRID BARAJAS
Spain	SALAMANCA MATALAN	Spain	MADRID TORREJON
Spain	SALAMANCA MATALAN	Spain	MADRID BARAJAS
Portugal	LISBOA	Portugal	COVILHA
Portugal	LISBOA	Portugal	COIMBRA
Portugal	LISBOA	Portugal	AVEIRO
Spain	VALENCIA	Spain	GIRONA
Spain	VALENCIA	Spain	BARCELONA
Spain	ALICANTE	Spain	GIRONA
Spain	ALICANTE	Spain	BARCELONA

Figure 35. The most preferred city pairs of the EPATS flights.

Country	Airport
Greece	ATHINAI/Athens
Greece	ATHINAI E. VENIZELOS
Greece	MEGARA
Italy	ROME FIUMICINO
Italy	REGGIO CALABRIA
Italy	CATANIA FONTANAROSSA
Italy	PALERMO PUNTA RAISI
Italy	CROTONE
Greece	ARAXOS/PATROS
Portugal	LISBOA
Spain	GIRONA
Spain	BARCELONA
Italy	ANCONA FALCONARA
Greece	SPARTI
Spain	MADRID BARAJAS
Spain	MADRID TORREJON
Spain	ALICANTE
Spain	VALENCIA
Italy	PESCARA
Italy	L'AQUILA-PRETURO
Spain	SALAMANCA MATALAN
Spain	VALLADOLID
Spain	MURCIA SAN JAVIER
Italy	TRENTO MATTARELLO
Spain	BILBAO

Figure 36. The 25 most congested airports of the EPATS flights

Beside the airports, EUROCONTROL publishes the most congested waypoints. Seeing that these might be the bottlenecks with respect to EPATS flights, it is reasonable to take them into consideration in the context of this investigation.

			Extra miles					Extra miles	
Waypoint	State	Constrained flights	Total	Per flight	Waypoint	State	Constrained flights	Total	Per flight
RIDSU	Germany	33 245	1 520 321	46	NTS	France	21 173	474 430	22
MOU	France	55 315	1 275 312	23	MOLUS	Switzerland	20 322	466 403	23
RESMI	France	46 783	1 151 005	25	MASEK	Germany	14 939	452 442	30
MAKOL	Bulgaria/turkey	30 152	899 230	30	*BCN	Spain	29 549	450 660	15
KUDES	Switzerland	45 751	872 537	19	MAXIR	France	16 041	439 670	27
PAM	Netherlands	47 370	794 696	17	BZO	Italy	27 125	438 806	16
TRA	Switzerland	37 738	763 785	20	PIGOS	France	16 840	434 928	26
SPY	Netherlands	40 212	727 190	18	STG	Spain	23 123	431 257	19
SUMIR	Italy	24 078	697 056	29	DIDAM	Netherlands	26 918	424 705	16
LERGA	France	46 880	685 212	15	MHN	Spain	16 137	411 893	26
LOHRE	Germany	32 104	681 430	21	ALSUS	Cyprus	12 064	402 696	33
ARTAX	France	52 334	647 428	12	MJV	Spain	18 856	400 158	21
BOMBI	Germany	57 950	646 958	11	KEPER	France	15 430	393 907	26
GEN	Italy	42 302	635 538	15	OBLAD	France	12 210	391 450	32
VADOM	France	14 584	600 793	41	LAM	UK	21 652	387 338	18
BRD	Italy	17 400	582 304	33	PIXIS	France	22 289	383 949	17
MUT	Turkey	17 148	574 492	34	RODOL	UK	35 159	382 126	11
GOW	UK	20 858	531 360	25	RDS	Greece	21 398	379 305	18
ALG	Italy	22 871	524 076	23	LGL	France	24 197	372 123	15
CPT	UK	37 425	517 882	14	VIBAS	Spain	22 323	362 538	16
MILPA	France	28 380	502 753	18	POL	UK	34 958	361 890	10
OLBEN	Switzerland	22 460	492 251	22	ROMIR	Germany	11 764	358 243	30
WAL	UK	69 458	490 167	7	ELB	Italy	38 025	356 394	9
BAG	Turkey	29 508	489 851	17	RKN	Netherlands	20 210	351 552	17
DJL	France	33 055	477 157	14	RLP	France	24 091	346 018	14

Figure 37. The most congested waypoints of the traditional flights (source: EUROCONTROL).

The Figure 37 shows the 2006 records, since predictions on the most used waypoints for 2020 are limited. Accordingly, more than 80 % is situated in Western-Europe, and more particularly in France, Germany, England and the Netherlands. In view of the Figures 38, 39, these locations are fully covered by the EPATS flights over a typical day. Seeing that for small aircraft the great circle routes were considered, its most congested points are located at the itineraries of the top city pairs. Considering the envisioned small aircraft traffic, these directions and the top 25 congested waypoints of the traditional flights are illustrated in the Figures 40, 41. These show the evidences for the fact that generally, EPATS keeps off the most crowded regions of the traditional flights (e.g. RIDSU). However, with further traffic increase of this last, small aircraft influences the rest of the airspace users in Italy, Greece, Portugal, Spain, the Southern regions of France, England, the South-Eastern areas of Poland and the North-Western locations of Germany.

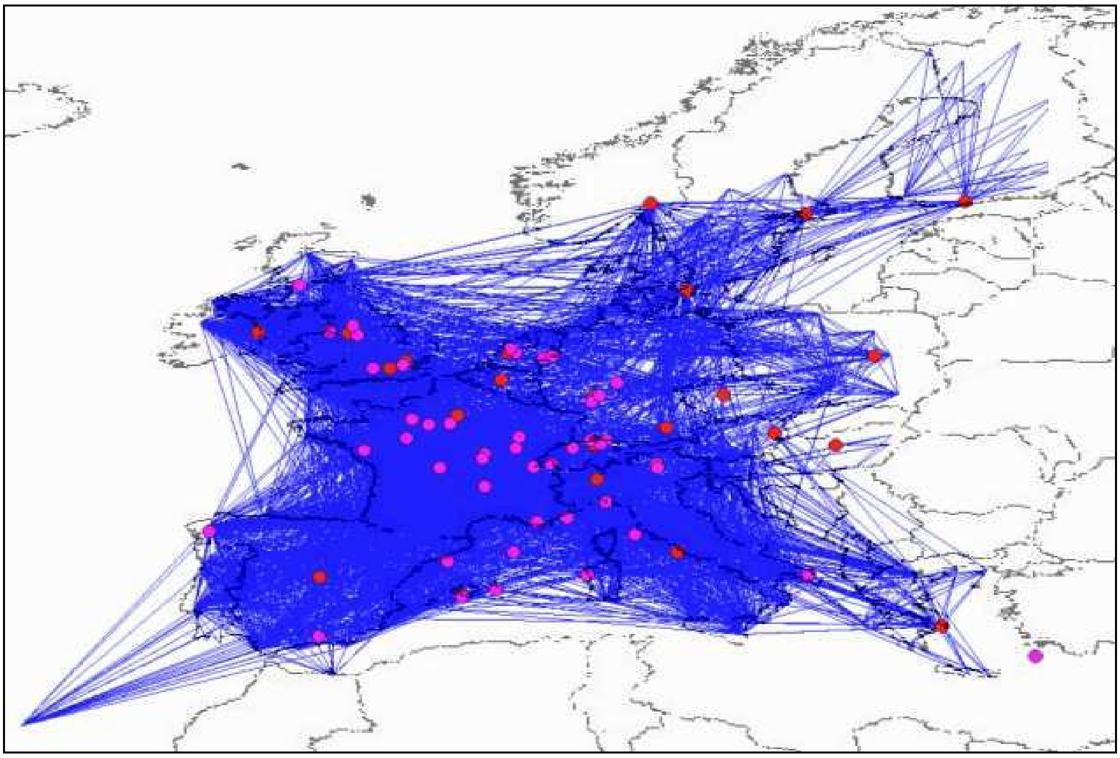

Figure 39. The most congested waypoints (magenta) and airports (red) of the traditional traffic versus the airspace covered by one typical day of EPATS flights in 2020 (Case B).

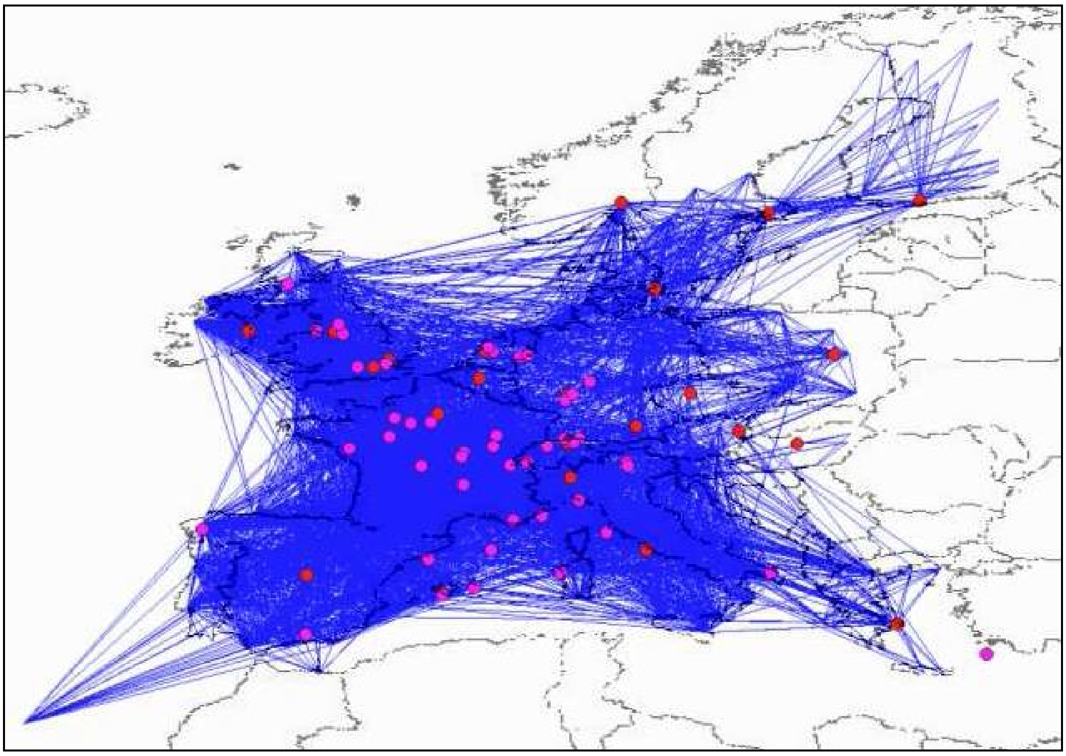

Figure 38. The most congested waypoints (magenta) and airports (red) of the traditional traffic versus the airspace covered by one typical day of EPATS flights in 2020 (Case A).

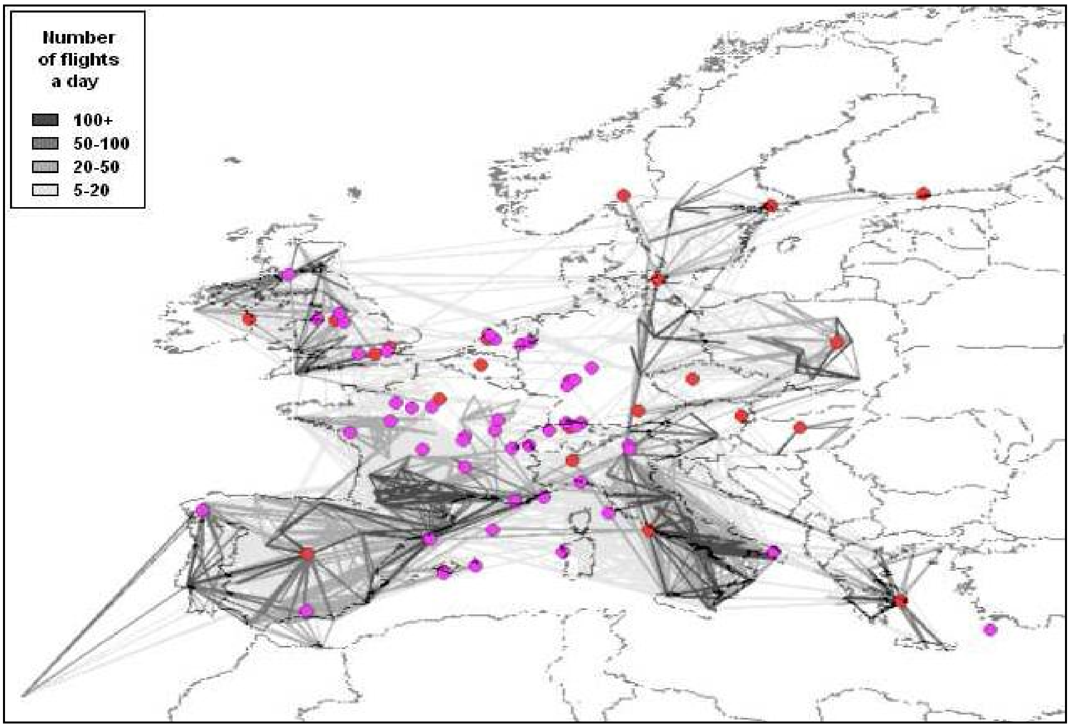

Figure 41. The most employed routes of EPATS (Case B) versus the most congested waypoints (magenta) and airports (red) of the traditional traffic in 2020.

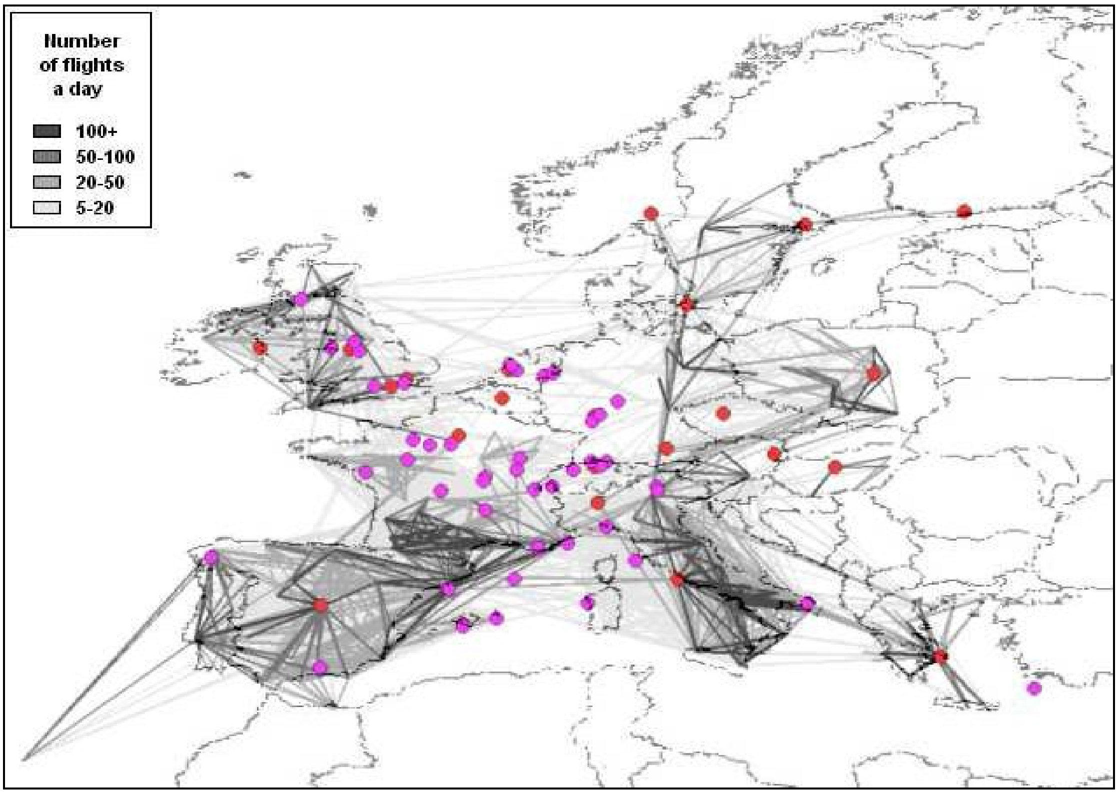

Figure 40. The most employed routes of EPATS (Case A) versus the most congested waypoints (magenta) and airports (red) of the traditional traffic in 2020.

Seeing that the figures above gave the evidences for the fact the EPATS might interact with the traditional flights at numerous regions across Europe, it is essential to analyze, which altitude is envisioned to be used by small aircraft. More particularly, this investigation focused on the cruising altitudes, since according to the Flight Safety Foundation [82] this level represents the longest flight phase. In view of this, the author assessed the FL distribution of EPATS by using (i) the trip distance between the airports (from the great circle distance and the "R" ratio of the EPATS aircraft specification given by the WP1: see Figure 19), (ii) the small aircraft flights characteristics (WP1) and (iii) the distribution of the flight phases (e.g. climb, cruise, descend) over the total block time. For this last, the analyst adapted the results of the Flight Safety Foundation [82], since it provides the requested data for flights having similar block distances with those of this investigation. As for the aircraft characteristics, the EUROCONTROL BADA [83] records were selected, since it is a so-called total energy model that provides a widely used database for numerous altitudes, and even covers several relevant small aircraft (including pistons, turboprops and jets).

According to the WP1 findings, the maximum altitudes that are associated to the different classes of aircraft are the FL 250 for the ACP-2/ACT-2 and FL 350 with respect to the jets (see Figure 19). Presenting the FL distribution of the small aircraft flights in 2020, these upper boundaries of the pistons turboprops and jets result in the lack of traffic between 25 000 and 35 000 feet (see Figure 42).

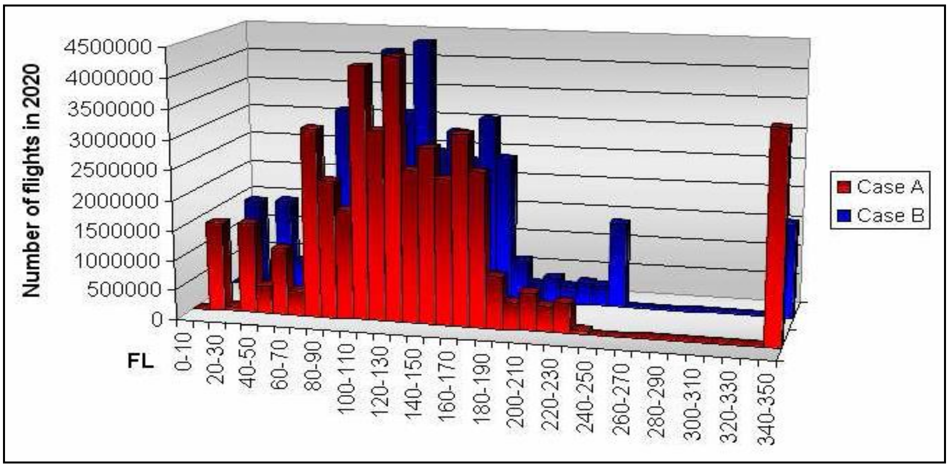

Figure 42. The distribution of the cruising altitudes of the EPATS flights in 2020 (using the maximum FLs of the EPATS aircraft database).

Otherwise, pistons and turboprops are estimated to take the lower regions of airspace, between FL 20 and 250. Knowing that jets are envisioned to be used for trip distances above 800 or 1000 km (with respect to the Case A and Case B predictions), all of these aircraft are assessed to use the FL 350. As a result of the aircraft characteristics and the cruising altitude that is given by the WP1, the most preferred cruising region is the FL 110, which – in average – presents 9,66 % of the total traffic.

Seeing the relatively high proportion of flights at the FL 250 and 350 (as compared to lower altitudes for example FL 220 and FL 340 respectively) it might be reasonable to permit EPATS aircraft to fly at higher altitudes than the above given flight levels (if aircraft characteristics would enable). Considering this issue, the cruising altitude of the predicted small aircraft flights (for 2020) is given in the Figure 43. Relative to the previous estimation, this shows

numerous flights between FL 250 and 350, which more exactly decreases gradually to zero at FL 300. Seeing the given aircraft characteristics and the fact that generally airliners prefer to employ higher levels of airspaces, the distribution of the cruising altitudes of the Figure 43. is more reasonable than the one given in the Figure 42. . This distribution shows that the impact of the EPATS flights on the cruising altitude of the traditional traffic is most concerned between the FL 100 and FL 190. Above FL 190 the interaction decrease to zero, expect the vicinity of the FL 400, in which about the same amount of traffic is envisioned than below FL100.

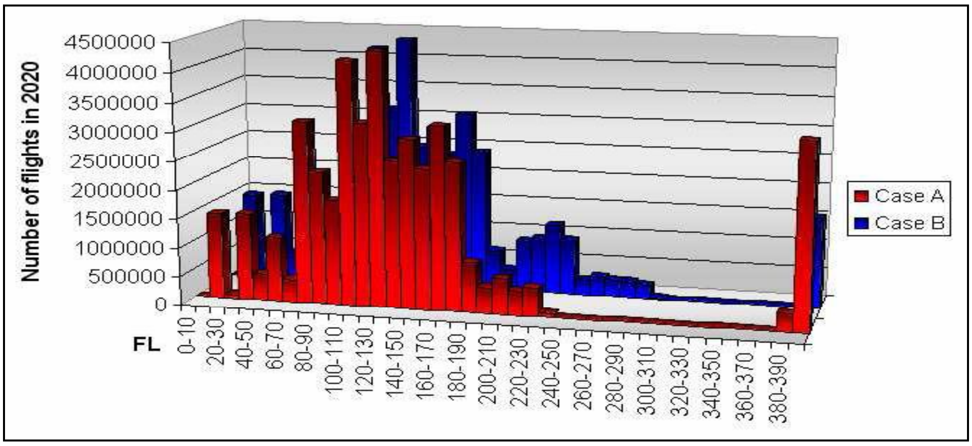

Figure 43. The distribution of the cruising altitudes of the EPATS flights in 2020 (without considering the maximum FLs for the turboprops and the jets from the EPATS aircraft database).

However, the EUROCONTROL CFMU records show the evidence for the fact that the nominal cruising altitudes (that might be reached using the nominal flight characteristics of the aircraft) are usually not reached. The major reason for this might be the constraints of the ATM system, such as deviations due to air traffic control, or the presence of STARs (Standard Terminal Arrival Routes) and SIDs (Standard Instrument Departure). Using a European PhD focusing on small aircraft and its complex CFMU database [29], real flight data became available, which enabled to assess a function between the trip distance and the cruising altitude for more than 50 000 small aircraft flights in the past. While the applied database was made in 2005, due to the lack of other records, the obtained result was assumed to be relevant for the timescale of this analysis. By using the method defined above, the outcome of the FL distribution for the projected EPATS traffic is given in the Figure 44.

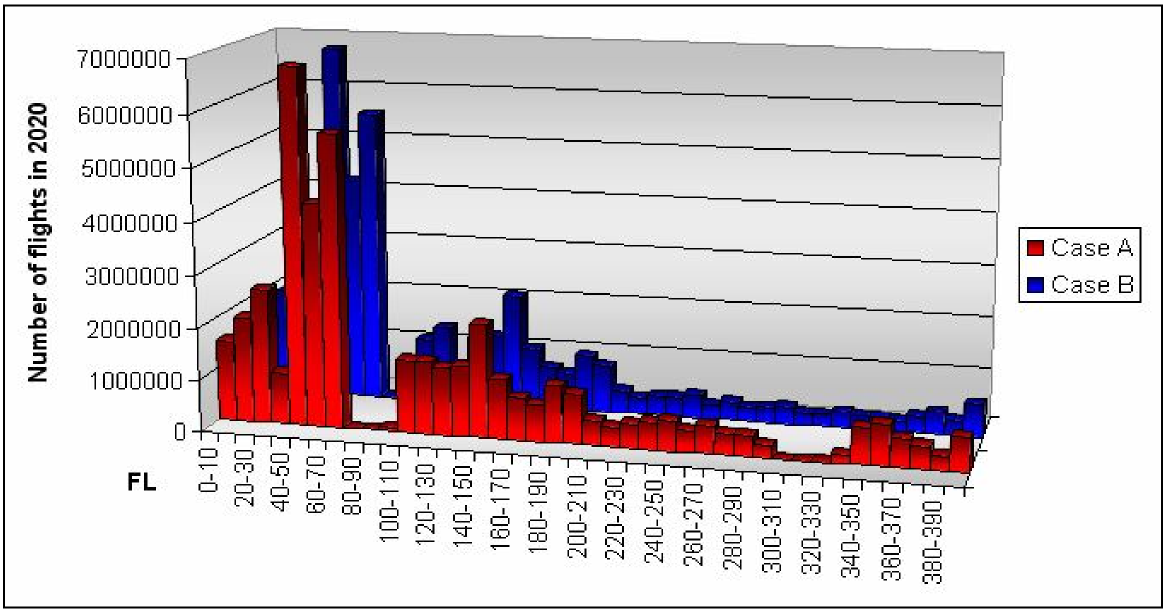

Figure 44. The distribution of the cruising altitudes of the EPATS flights in 2020 (by considering the FLs attributed in the past CFMU records).

In the face of the previous figures, this distribution clearly distinguishes three groups of altitudes: the (i) FL 40-80, the (ii) FL 110-200 and the (iii) FL 320-400. Considering the envisioned flights in 2020, the ratio of these from the total EPATS traffic is respectively 53.9 %, 28.2 %, 7.9 % for the Case A and 55.5 %, 28.8 %, 6.2 % with respect to the Case B. In fact, as that the propulsion technology preference of the EPATS aircraft (see Figure 45) gives almost the same distribution, the three groups of FLs (presented in the Figure 44) is supposed to be respectively the most reasonable altitudes for the pistons, turboprops and the jets. This assumption is also in line with the flight distance evaluation, which is given in the Figure 46. Accordingly, the most preferred flight distance of the EPATS traffic is in the range of 200 and 300 km. beside, 88.7 % of the flights are shorter than 700 km, and 5.4 % flies further than 1000 km.

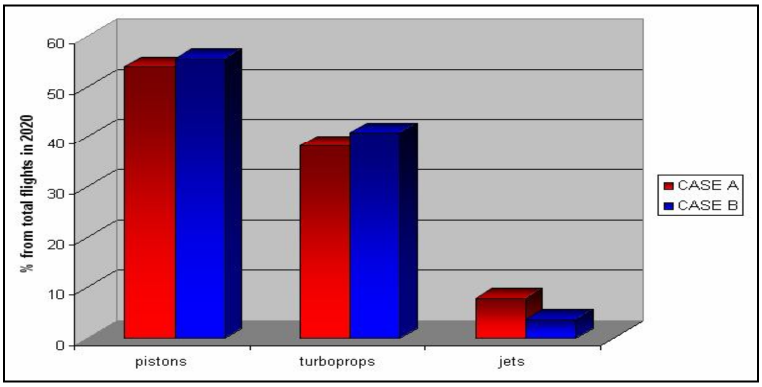

Figure 45. The propulsion technology distribution of the EPATS flights in 2020, extended scenario (blue: pistons, red: turboprops, grey: jets).

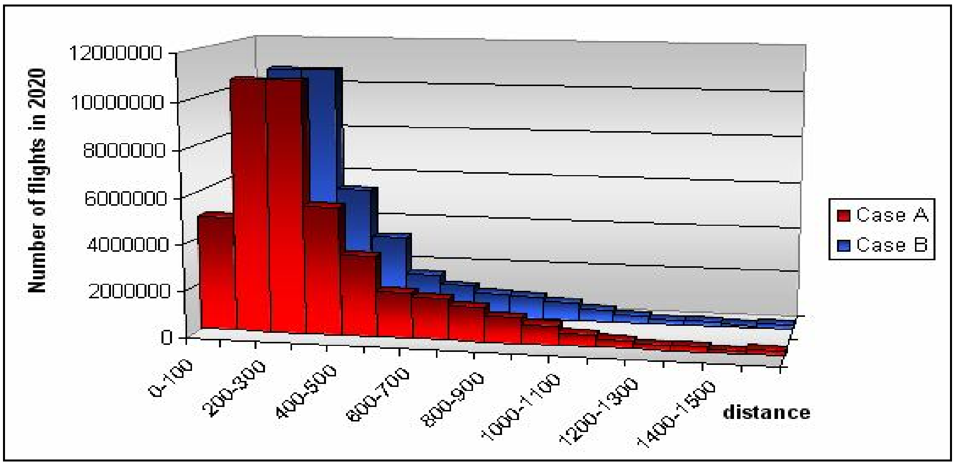

Figure 46. The flight distance distribution of the EPATS flights in 2020.

To compare the cruising altitude allocation of the EPATS flights with respect to the rest of the airspace users, the analyst assessed the FL distribution of the traditional flights. To do so, the COSAAC tool was applied, since this enables to clone the traditional traffic from the real CFMU records in 2007, to the envisioned number of flights (for 2020) given by the EUROCONTROL STATFOR documents.

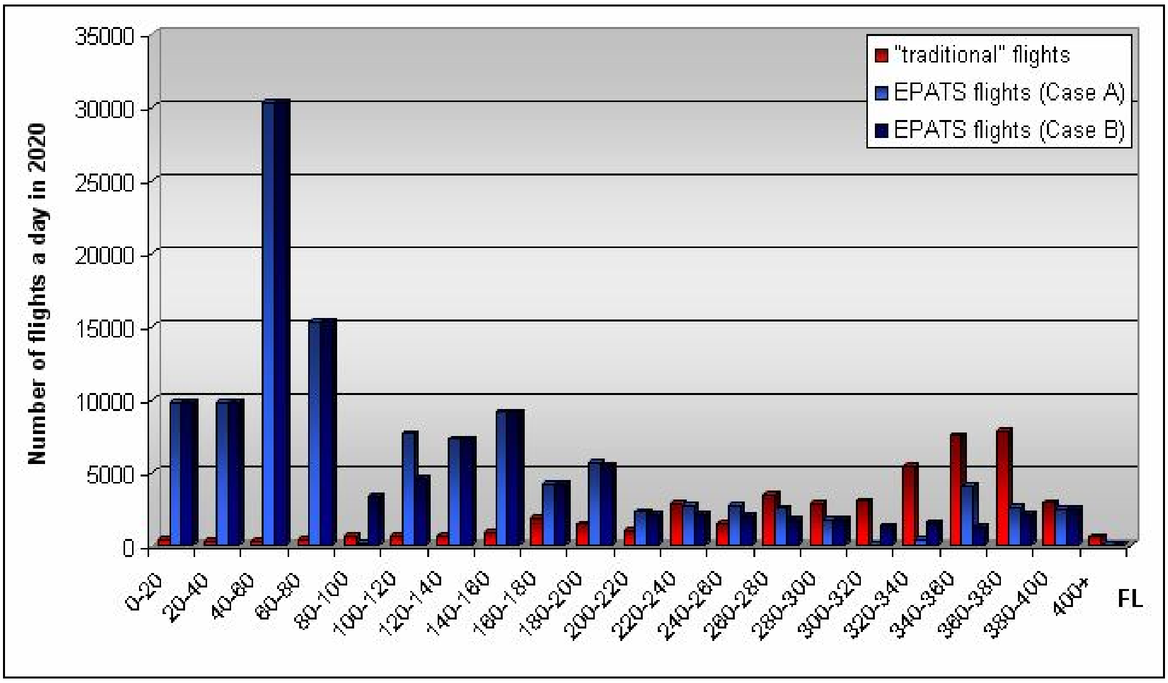

Figure 47. The cruising altitude distribution of EPATS and the traditional flights in 2020.

The Figure 47 represents the result of the two cruising altitude distributions. Accordingly, between FL 300 and 400 the impact of EPATS Case B prediction on the traditional flights is limited, especially in the most preferred regions of this last (FL 320-380), in which small aircraft represents barely 18,8 % of the total traffic. On the other hand, the Case A EPATS prediction (that considers jets to be used from 800km) results in more flights between the FL 320-380 and represents 19,9 % of the total movements. Even so, these altitudes are envisioned

to be used by jets small aircraft, which by having similar flight characteristics with the rest of the airspace users, limits the complexity to manage the traffic (e.g. due to speed interactions). Seeing the objectives of SESAR, ATM in 2020 should be able to cope with this added traffic at higher altitudes. Conversely, in the range of FL 120 and 200, EPATS would be in majority for both, the Case A and Case B predictions. While this region is less preferred by the traditional flights (15.3 % of traffic relative to those at FL 340-380), the impact of EPATS is relatively high. Finally, the highest ratio of EPATS flights takes place in the region below FL 100, which accounts for 59.1 and 60 % of the total envisioned small aircraft traffic in 2020, respectively for the Case A and Case B predictions.

Total EPATS flights in 2020:

- ***Daily traffic covers the core area of Europe;***
- ***Flights are highly distributed;***
- ***The most congested regions of EPATS are different from those of the traditional flights;***
- ***The most influenced regions / airports cover:***
    - ***Italy, Greece, Portugal, Spain, the Southern regions of France, England, the South-Eastern areas of Poland and the North-Western locations of Germany;***
    - ***Athens, Rome, Madrid, Barcelona, Warsaw, London, Copenhagen, Stockholm.***
- ***The cruising altitude distribution of EPATS and the traditional flights is different:***
    - ***4 % of EPATS take place at the most preferred FLs of the traditional flights;***
    - ***1,7 % of the traditional flights use the most crowded FLs of EPATS movements.***
- ***60 % of EPATS take place below FL100.***

3.6. Potential constraints due to EPATS IFR

As estimated above, the total IFR flights to be considered in 2020 are 17 663 889 and 17 580 324, from which EPATS IFR represents 2 944 105 and 2 860 539 movements, respectively for the Case A and Case B projections. In other words, EPATS IFR is responsible for about 16 % of the total IFR traffic in 2020. To assess the impact of these flights on the ATM, the analyst used the capacity targets defined by SESAR, since according to EUROCONTROL, this program "will lead the way for the modernization of the Air Traffic Management system in Europe" [38]. As defined by SESAR [40], the ATM target concept should enable a three-fold capacity gain by 2020 (from the baseline of 2005). Therefore, the question remains whether / how EPATS IFR will fit in the capacity gap envisioned by SESAR. In the literature, there are numerous definitions of capacity. The EUROCONTROL PRC [21] defines "effective capacity" as:

"The traffic volume which the ATM system can handle with a given level of en-route ATFM delay".

Based on this approach and the effective capacity values published by EUROCONTROL [1], the Figure 48 shows the total IFR, traditional IFR and the EPATS IFR traffic size over the timescale of 2007-2020. While the personal IFR flights cause from 14 to 14.5 % of total traffic growth relative to the 2007 total IFR baseline, it is clear that in 2020 **the predicted EPATS IFR flights fit in the capacity targets defined by SESAR**. Although this traffic is closing the capacity gap, the impact of the EPATS IFR flights on the ATM remains limited by 2020.

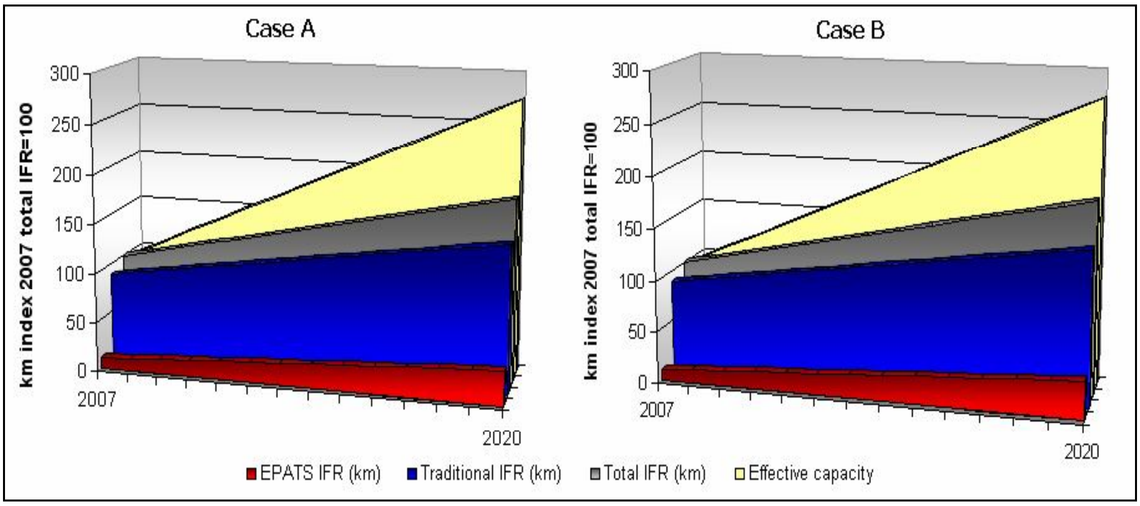

Figure 48. Envisioned traffic size and the effective capacity in 2020.

According to the envisioned capacity (three-fold increase relative to the 2005 baseline) and the predicted number of flights for 2020, there will be a capacity gap (see Figure 48.). If this margin if fully dedicated to the EPATS IFR movements, then the maximum volume of EPATS IFR traffic that could be handled by SESAR in 2020 is 12.59 and 12.56 million flights respectively for the Case A and Case B estimations. This is about 3.5 times more than the envisioned EPATS IFR traffic.

Nevertheless, the predicted EPATS IFR flights were also analyzed with COSAAC, in order to assess the daily distributions, and therefore to evaluate whether personal IFR flights has an impact on the traditional movements at certain waypoints or airports. To meet this objective,

the analyst cloned the EPATS IFR traffic size obtained for 2007 (see Chapter 3.4.) to the personal IFR size assessed in the Chapter 3.5.1. . Note that an average value was considered for the Case A and Case B estimations, since the difference between these two is barely 3 %. With respect to the traditional IFR flights for 2020, the EUROCONTROL STATFOR [80] estimations were used.

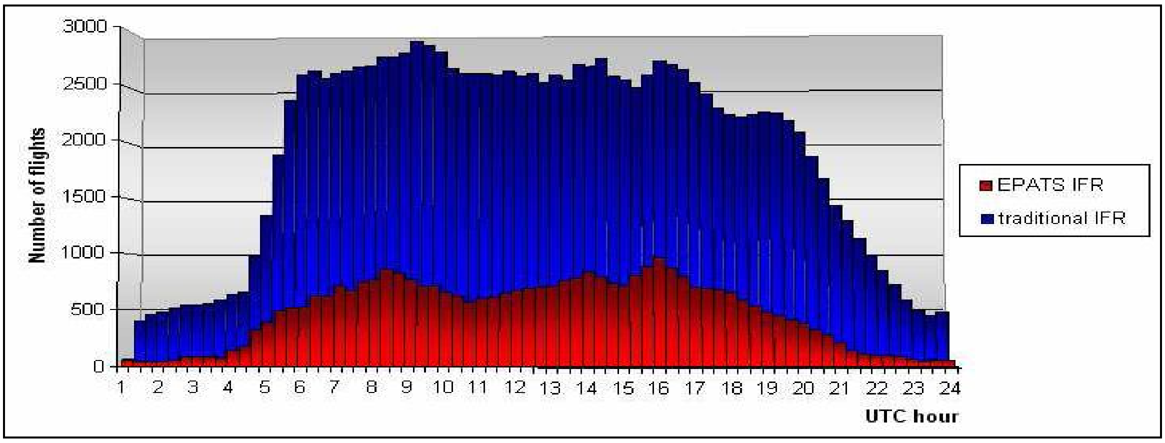

Figure 49. The hourly distribution of the EPATS and the traditional flights in 2020.

The Figure 49 shows the hourly distribution of the EPATS IFR and the traditional IFR flights over one day in 2020. As one might observe, the two distributions follow a similar shape and peaks at about the same times. While the most important interactions are expected to happen at 8 A.M and 4 P.M., even at these timeframes EPATS IFR "only" represents 29 % of the traditional movements. Knowing the capacity targets defined by SESAR and the capacity gap estimated in the previous chapter, it is not expected that EPATS IFR would lead to congestions. However, personal IFR movements were further analyzed against a limited number of airports and waypoints, in order to assess whether these are affected by EPATS IFR. In this document, Paris airport and MOU waypoint are discussed, as according to EUROCONTROL [80], these expected to be in the top most congested locations.

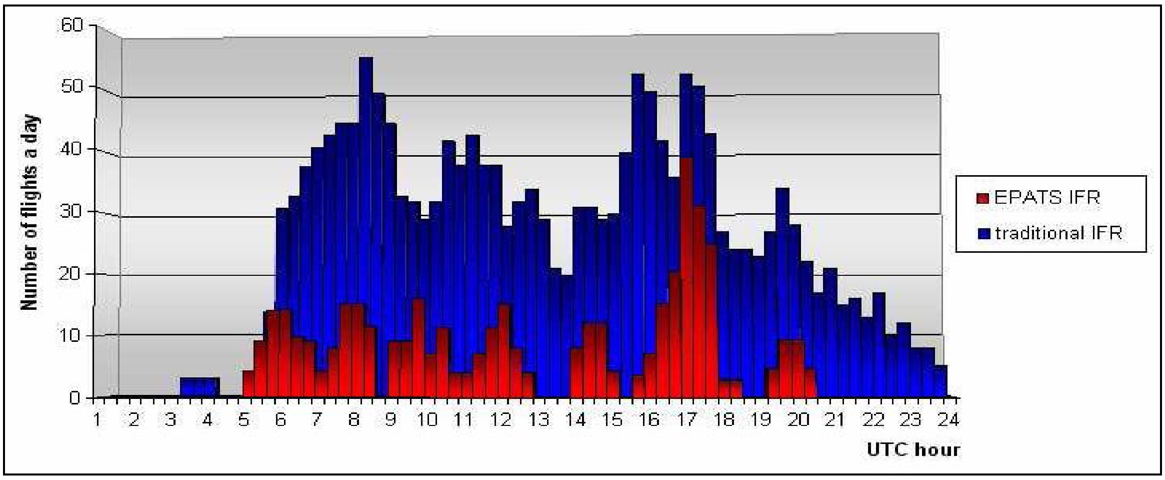

Figure 50. The hourly distribution of EPATS and the traditional flights at the waypoint MOU (in 2020).

With respect to the waypoint MOU, its traffic distribution is given in the Figure 50. . Generally, the impact of EPATS IFR at the selected waypoint is acceptable, and meeting the capacity targets given by SESAR. On the other hand, the figure also shows that the peak of the EPATS IFR (at 5 P.M.) is already reaching the limit, but still fits in the capacity gap. As this peak takes place at the same timeframe that the one of the traditional IFR movements, the influence of the personal IFR flights might be further reduced once the traffic is better distributed. For example a homogenous distribution between 4 P.M. and 7 P.M. would end in about 16 EPATS IFR flights an hour that is clearly more manageable.

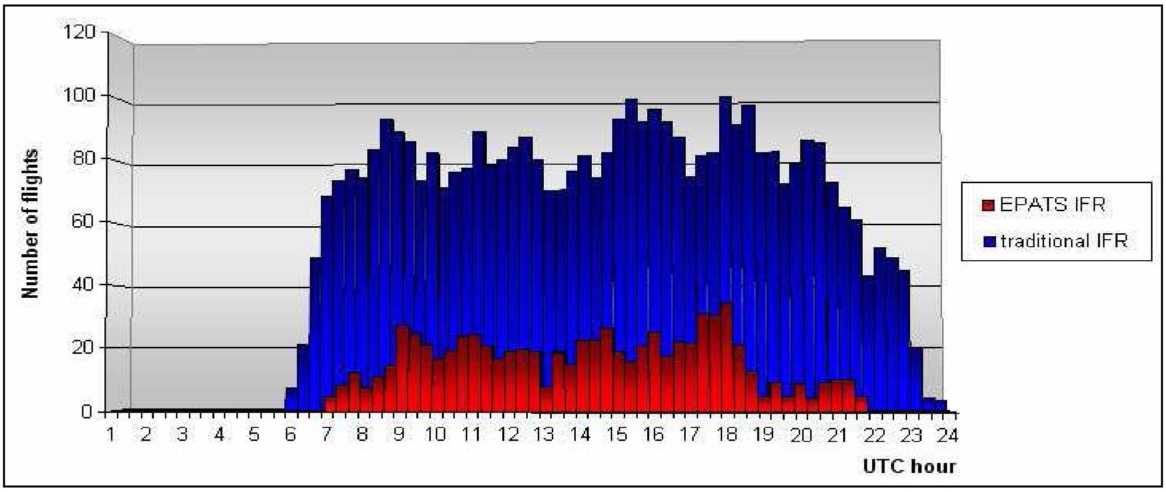

Figure 51. the hourly distribution of the EPATS and the traditional flights at the airports of Paris.

The Figure 51 indicates the impact of the EPATS IFR flights on the traditional IFR movements at the airports of Pairs. No generic targets are defined in SESAR for complex airports. On the other hand, the fact that EPATS IFR gives at maximum 33 % of the traditional IFR flights suggests that the impact of the personal IFR flights remains limited. On the other hand, one might also consider that COSAAC cloned the flights without distributing them between the available airports. This fact is also in line with the findings of the total EPATS flight analysis (see Chapter 3.5.3.), indicating that personal flights are generally keep of the most congested regions of the traditional flights. Therefore, it is expected that EPATS IFR would be less present at the major airfields.

Seeing the number of envisioned flights and all the findings of this chapter, it is clear that in 2020 EPATS IFR flights fit in the capacity targets defined by SESAR. While the impact on the capacity is limited and therefore there is no need to analyze each ATM domain, personal IFR movements could influence the traffic complexity and the safety of air navigation. With respect to the traffic complexity, the root cause is that personal IFR flights might have different aircraft characteristics than the rest of the airspace users, which in general employs jets. Relative to these traditional flights, it would be reasonable to compare the propulsion technology distribution of the EPATS IFR movements and further analyze the problem. On the other hand, the envisioned propulsion systems for the personal IFR flights are unknown in the current state of the project, and therefore further investigations in this field could only be based on assumptions. Once jets would be in majority for the EPATS IFR traffic, then the influence is

limited, since these aircraft offer similar performances (e.g rate of climb, cruising altitude and cruising speeds) relative to the traditional movements. On the other hand, by assuming that the large majority of the EPATS IFR traffic would employ piston small aircraft, the impact on the traffic complexity is more important, seeing that the performance difference between the EPATS and the traditional aircraft might lead to horizontal and vertical interactions. Besides the complexity coming from the aircraft performance, the effect of turbulence is another issue that influences the traffic complexity at the terminal areas (if EPATS IFR and the traditional flights were to share the same airport). This problem occurs, as EPATS (with any propulsion system) is generally lighter than the rest of the airspace users, and therefore more sensitive to the wake vortex generated by larger aircraft.

With respect to the safety of air navigation, further investigations are needed, since the envisioned EPATS IFR operations – especially the single-pilot operation and the concepts leading to ASAS or the transfer of certain procedures / responsibilities to on-board – is expected to influence the pilot roles. In the face of this fact, statistical records show that the primary case for the hull-loss accidents is attributed to the flight crews (see Chapter 4.2.). In addition, investigations prove that the cockpit equipments aiming to enhance the pilot's situational awareness (e.g. TCAS) still require a clear understanding of when/how to apply it. Otherwise, misunderstandings might lead to collisions, especially in the hand of low skilled EPATS pilot.

Potential constraints due to EPATS IFR:

- ***The impact of EPATS IFR on ATM is limited in 2020;***
- ***The predicted EPATS IFR fits in the capacity targets defined by SESAR;***
- ***Maximum EPATS IFR that could be handled by SESAR in 2020 is 12.5 million movements / year;***
- ***EPATS IFR is not leading to congestions at the airports and waypoints in 2020;***
- ***Influence on traffic complexity and safety are relevant issues for further investigations with respect to EPATS IFR.***

3.7. Potential constraints due to EPATS VFR

While the EPATS IFR traffic represents approximately 3 million movements in 2020, the EPATS VFR segment is expected to grow from 14 million flights a year (as in 2005) to 41.2 or 40 million, respectively for the Case A and Case B predictions. As mentioned above, these indicate a total growth of about 232 % over the timescale of 200-2020.

The impact of the EPATS VFR flights on the ATM is an unknown problem, since the VFR movements are not clearly addressed in the current state of SESAR. For example, it is questionable whether this traffic should fly in the unmanaged regions, and if so, at which FL the boundary of the managed and unmanaged airspace would be (see Figure 8.). On the other hand, seeing the cruising altitude distribution of the personal flights, and especially the fact that the majority of the movements take place below a certain altitude, the exact information on the managed and unmanaged airspaces would be favorable to be available. These limitations did not permit to exactly address the impact of EPATS VFR on the ATM. On the other hand, without showing the evidences for the hypothesis below (due to lack of data), the following thought were drawn.

3.7.1. Airspace management

The relatively high number of EPATS VFR flights and the cruising altitude distribution suggests that Airspace Management will have a role to cope with the added personal VFR traffic. ASM will call for flexible and dynamic use of the airspace capabilities over specific regions across Europe. More particularly these cover the airport surroundings, in which EPATS VFR flying at relatively low altitudes (see Figure 47.) are projected to meet the arrival / departure flows of the traditional flights. Two different approaches could manage the problem. In the first, the flexible and dynamic use of the airspace capabilities will be needed to cope with EPATS VFR and the rest of the airspace users, seeing that at the lower altitudes piston personal flights are predicted, which – by having different flight characteristics than the rest of the airspace users – might lead to e.g. speed interactions or wake vortex problems. In addition, personal flights might also call to be fully separated from the traditional flights, if controller / pilot roles and responsibilities are different. The second approach is to oblige personal VFR flights to make a deviation at the "crowded" regions and leave the airspace for the rest of the traffic. Even so, it is questionable how these deviations influence the flight efficiency (in terms of route extensions), and whether these are feasible on a European scale. This last is particularly questionable, seeing the closeness of the major European airports' TMAs (see Figure 52.).

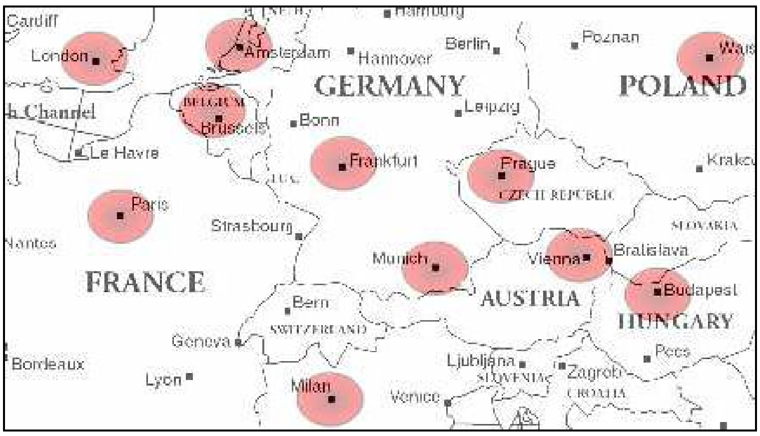

Figure 52. Silhouettes of the TMAs related to the most congested European airports in 2020 (silhouettes are based on the average TMA size as shown on Jeppesen charts).

3.7.2. Air Traffic Control

After the term VFR, separation between the EPATS VFR flights should be based on the see-and-avoid concept. In the face of this, the projected 40.6 / 39.2 million personal VFR movements translate to relatively high daily traffic size, about 100 000 flights a day. Therefore ATC requires further investigations, e.g. to address airborne separation assurance approaches. As in 2007, it is unknown, whether self-separation would be capable to handle the envisioned number of flights.

Further investigations should also consider the airspace dimension (to be used by EPATS VFR) and therefore the traffic density, since by 2020, SESAR [13] envisions that self-separation will only be available at low density regions. At any case, if conflicts needed to be solved between two aircraft, the deviations from the original flight path might lead to conflict(s) with other flight(s). Knowing the relatively high number of projected movements, this problem of multiple conflicts (see Figure 53.) might further increase the complexity to manage the flights.

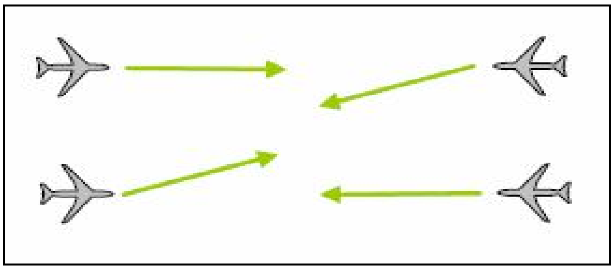

Figure 53. Multiple conflicts (source: EUROCONTROL).

3.7.3. Collaborative planning and decision making

Seeing the cruising altitude distribution of the projected EPATS flights, future traffic has to be collaboratively planned and demand might require to be balanced versus capacity, especially by distributing the flights more homogenously to avoid e.g. congestions at FL 40-60 (see Figure 47.). Even so, the impact of EPATS VFR on the ATM is limited, since SESAR [13] already foresees a Network Management Function to make this achievable. This links the partners in a transparent and a collaborative manner and therefore ensures that the network has an achievable operational performance. The result of such planning is foreseen to be reflected in a continuously updated Network Operations Plan (NOP) that enables collaborative demand and capacity balancing through an integrated airspace / airport organization and management in accordance with the traffic complexity that should be managed (see Chapter 2.3.2.).

In the current stage of the project, the business model – and more particularly the fact whether the flights will take place by request or by scheduling – is not fully clear. However, flying on request might be contradictory with the targeted process of the SESAR business trajectory, since it is unknown (i) how these movements will fit in the iterative process of the Shared Business Trajectories (optimizing the overall network performance), and (ii) how EPATS will influence the Reference Business Trajectories. Therefore, further investigations should address the business model of EPATS in order to clarify whether/how the envisioned number of small aircraft flights might influence the SESAR business trajectory process.

3.7.4. Communication, navigation and surveillance

The level of CNS tools might be driven by the characteristics of other ATM domains (e.g. separation responsibility, pilot roles). For example, if ASAS is envisioned to manage EPATS VFR, then more advanced cockpit instruments will be needed to ensure the pilots' situation awareness. Anyhow, the impact of EPATS VFR on CNS technologies is relatively low, since

SESAR [13] already identified an extensive list of the potential solutions to overcome the future limitations. In short, for the communication numerous voice and data exchange methods are given for the participants of the SWIM architecture. The navigation is envisioned to be improved by the combination of global navigation satellite system (GNSS), self-contained navigation systems and navigation aids. With respect to the surveillance, numerous precision monitoring technologies are named to ensure the safe and efficient operations.

In addition, this domain is also addressed by one of the most relevant investigations, the NASA Small Aircraft Transportation System's Lower Landing Minimums (LLM). As mentioned in the Chapter 2.3.5., the objective of the LLM is to provide precision approach and landing guidance for small aircraft, through the use of multifunction displays with graphical flight-path guidance, artificial or enhanced synthetic vision, and head up displays. Synthetic vision systems and advanced cockpit instruments also enable the artificial representation of the aircraft surroundings including tunnel or pathway-in-the-sky representations. If needed, the available technologies permit EPATS pilots to cope with the flexible and dynamic use of the airspace capabilities, for example as introduced in the Chapter 4.2.

3.7.5. Airport and terminal area management

The airports are not projected to become the bottlenecks with respect to the EPATS VFR traffic. This is particularly reasonable, once the personal movements are distributed between all of the available airports. The EPATS airport database of the WP1 located 2567 sites across Europe, covering major hubs, regional, small and all other landing facilities (see Figure 54.). If no other locations are taken into consideration, the EPATS VFR traffic translates to the average of 42.7 movements a day at each landing facility. Seeing even the 750 flights/day capacity constraint of a single runway layout (as defined by SESAR [40]), the envisioned VFR movements are manageable, especially if further airport developments are planned.

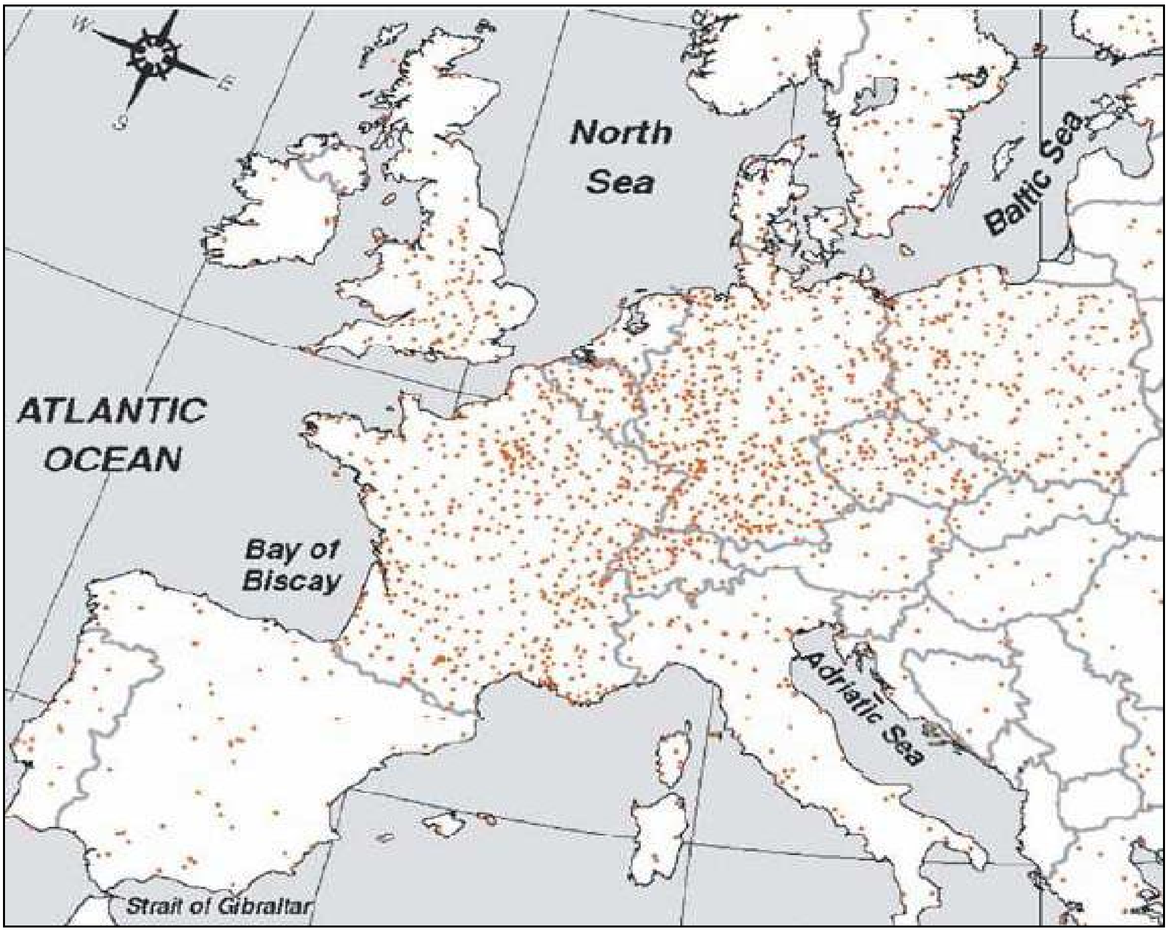

Figure 54. The European airports and landing facilities (source: EPATS).

As mentioned above, the terminal area requires further analysis, as personal VFR traffic flying at low altitudes meets the arrival and departure flows of the traditional traffic at the airports vicinities. If the same airport handles both EPATS and traditional flights, then the problem requires advanced methods to handle the mixed flow. One solution includes the use of e.g. Arrival and Departure Managers, for example the one of Darts (see Chapter 2.3.4.). On the other hand, if the airport serves only the traditional movements, then EPATS might be obliged to make a deviation at the airport vicinity to leave the airspace for the rest of the traffic. If this is not feasible, then EPATS VFR should be separated in order to avoid e.g. wake vortex or speed interaction problems.

Potential constraints due to EPATS VFR:

- ***EPATS VFR expected to growth from 14 million flights a year (as in 2005) to 41.2 (Case A) or 40 million (Case B);***
- ***The impact of EPATS VFR on the ATM is an unknown problem, as the VFR movements are presently not clearly addressed in the coming ATM;***
- ***ASM needs to be flexible and dynamic to cope with the EPATS movements at the airport surroundings;***
- ***ATC should analyze ASAS and other means of self-separation;***
- ***CNS: advanced cockpit instruments are needed, but these already foreseen by SESAR and other small aircraft concepts (NASA SATS LLM);***
- ***Airport and terminal area management:***
  - ***airport capacities envisioned by SESAR meet the predicted number of flights;***
  - ***terminal area: personal VFR movements flying at low altitude meet the arrival / departure flows of the traditional traffic. Advanced methods are needed to cope with the two segments together or separate them from each other.***

3.8. Further influences of EPATS

3.8.1. *Efficiency*

EUROCONTROL [1] published that in 2006, 67 % of the city pairs in Europe had a route extension below 5 %, 27.5 % between 5 % - 12 % and 5.5% above 12 %. From a flight efficiency point of view, the analysis of the EPATS and the traditional traffic indicated that generally small aircraft keeps off the most congested airports and waypoints of the rest of the airspace users. Additionally, as the cruising altitude distribution of the two classes of traffic peaks at different Flight Levels, it is expected that the impact of EPATS on the flight inefficiency – as expressed above in route extensions – is limited. On the other hand, the piston small aircraft flying in the vicinity of the major airports might cause a route extension, once the personal flights are obliged to deviate the vicinities of the major airports.

Efficiency in terms of delay is a crucial data to analyse for numerous actors in air transportation (e.g. airliners, airport operators). However, its assessment could not be carried out in the context of this preliminary investigation due to lack of data, and therefore further analysis are required in this field.

3.8.2. *Costs*

According to SESAR [13], the operational costs of an aircraft depend as well on the airborne and ground costs. While the first covers the applied communication (e.g. satellite-based, ADS-B, access to SWIM), navigation (e.g. 4D trajectory-based) and surveillance capabilities (e.g. ASAS, TCAS), the second includes the business trajectory-, schedule management and the SWIM. As the airborne costs varies the most with respect to EPATS, only these are further analyzed. In SESAR [13], the different levels of application of the airborne instruments are covered by three classes of operations: (i) the business, (ii) the GA IFR and (iii) the GA VFR. The business comprises the most advanced tools (advanced communication, navigation and surveillance capabilities), while GA and especially the GA VFR is far less equipped. According to the results, the unit cost per aircraft for the GA IFR with respect to the business aircraft is barely 1.5 %, due to less on-board instruments. By considering these estimations, it is concluded that EPATS operational aspects (e.g. IFR or VFR) have a direct and relatively high influence on the operating costs.

4. ATM PERSPECTIVES, VISIONS AND PROPOSALS TO SUPPORT EPATS

4.1. EPATS characteristics to be considered

This section aims to provide the ATM perspectives, visions and proposals to support the EPATS traffic. The investigation first identifies a limited number of special small aircraft characteristics, in order to highline the specific features that the coming ATM should consider with respect to the personal flights. These are the followings:

- aircraft performance: the majority of the EPATS traffic is performed by pistons small aircraft. Relative to the traditional flights, which employ jets for most the cases, this distribution of the propulsion systems leads to different aircraft performances. In specific circumstances this leads to speed interactions with the rest of the airspace users. On the other hand, piston propulsion systems and the relatively low cruising speeds also enable actors to have more time to manage the air traffic flow and to perform tasks such as conflict detection / resolution, especially if the conflicting aircraft are pistons.
- the effect of turbulence: the most frequently used altitude of EPATS comprises the region in which the metrological activities are relatively frequent, and the airspace is more turbulent. Seeing this, the small aircraft operations are envisioned to be more dependent on the meteorological conditions, and more particularly on the turbulence. Additionally, EPATS – being lighter than generally the rest of the airspace users – is also more affected by the effects of wake turbulence. This should be considered at low altitude airspaces within both classes of flights meet with the highest probability, for example due to dealing with arrival / departure flows composed from both traffic, or due to managing EPATS to fly in the vicinity of the most congested airports of the traditional flights.
- cost of the solutions: while safety is the highest priority in defining the targets of the European ATM, cost plays a major role, especially in the context of EPATS. Mostly this is due to the fact that EPATS is predicted to be more sensitive to cost since generally the purchase prices of these small aircraft are inferior than those of the traditional, and therefore e.g. the on-board equipments (such as ADS-B, TCAS) are relatively more expensive. Seeing this cost sensitivity, further investigations are suggested to keep a balance between the ATM related proposals and the primary costs of the solutions.

4.2. Most important future perspectives, visions and proposals

This section introduces the future perspectives, visions and proposals to cope with the predicted number of EPATS flights in 2020. The elaborated proposals are based on the key findings of this preliminary investigation.

Chapter 3 indicated that the envisioned airspace organization and management might be flexible and dynamic, in order to overcome the possible interactions and more particularly to cope with the airport vicinities, in which piston personal flights meet the arrival / departure traditional traffic. Due to the difference in the aircraft performance and the envisioned pilot roles and responsibilities, it is suggested that further investigations analyze whether the two classes of aircraft (EPATS and traditional) might be handled together, or whether any of them requires to be separated from the other. In case of this last, the proposed solution to be analyzed covers the application of specific corridors or tubes, leading EPATS (or the traditional aircraft) through the most congested regions to decrease the traffic complexity for the rest of the airspace users. On the other hand, this approach is only reasonable, once the evidence was found to the fact that other solutions are irrelevant with respect to EPATS. According to the findings of the Chapter 3, this means the deviation of the personal flights at the airport vicinities. Therefore, further investigations should also demonstrate how the deviations from the original flight path influence the flight efficiency (in terms of route extension), and whether these cause congested regions between the airports (see Figure 55.).

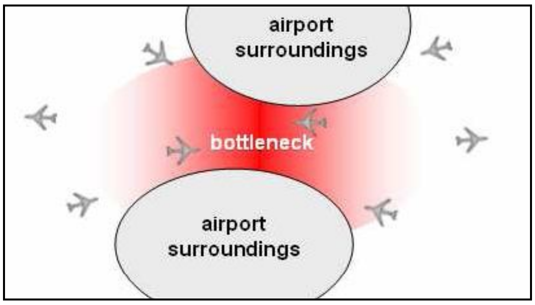

Figure 55. Deviations at the airport surroundings might lead to further traffic complexities.

Beside the analysis of the proposed solutions, it is suggested that future decisions concerning the airspace organization would take into consideration that about 40 million personal flights would rely on the see-and-avoid concept and a significant percentage of the EPATS traffic would take place below FL 100. More particularly, these issues are proposed to be considered by SESAR, once defining the FL of the boundary between the managed and unmanaged airspace.

With respect to ATC, a general recommendation is to carry out a fast or real time simulation with the envisioned movements. While this would require detailed traffic records (currently unavailable), the advantage is that it provides the influence of EPATS on the generally used metrics of evaluation (e.g. the number of interactions, separation looses, conflicts, the controller / pilot workload), and therefore enables to analyze the probability of further problems such as the multiple conflicts. In addition, to capture the external factors that influence the controller workload and the level of difficulty attributed to their tasks, the author suggests the use of the traffic complexity indicators, as proposed by EUROCONTROL [75]. This is particularly advantageous with respect to EPATS, since beside the potential impact arising from the envisioned traffic size, traffic complexity indicators enable to reflect whether the mixture of the small aircraft and the traditional flights with different flight characteristics leads to interactions (e.g. between small pistons and large commercial jets meeting at low altitudes around the airport vicinities). The outcomes of the investigations above would be particularly valuable to show the most appropriate method to cope with EPATS.

To support the personal VFR flights, it is suggested to further analyze ASAS, or other means of self-separation. A vision covers the use of extended priority rules, based on for example those developed in the FAST/FREER and ATLAS projects [44, 50, 84], including (i) the Altitude for Direction-of-Flights, (ii) the Extended VFR Overtaking Rules and (iii) the Extended Flight Rules for the phase-of-fight priority. As these assign different rules or priorities (see Figure 56.) in the objective to handle ambiguous air-ground relationships and to define how the airspace users should behave, it is reasonable to be investigated with respect to the envisioned amount of personal VFR movements.

Conflict situation	Description	Priority
Both in level *		The closest to the point of loss of separation
Both climbing*		The closest to the point of loss of separation
Both descending*		The closest to the point of loss of separation
A in level, B climbing		A has the right of way
A in level, B descending		B has the right of way
A climbing, B descending		B has the right of way

Figure 56. Extended Flight Rules summary (source: EUROCONTROL).

At the terminal area management, it is proposed to deal with different sequencing and separation methods, since a relatively high number of personal flights meet the arrival / departure flows of the traditional traffic at the airport vicinities. As mentioned above, a proposed solution covers the use of specific corridors or tubes. Consistent with SESAR, tubes are promising, as they enable to fly through the vicinity of the most congested airports associated to the traditional flights. On the other hand, it is still questionable, whether EPATS or the traditional flights should make use of the tubes (see Figure 57.). At any case, the navigation within the tube requires further investigations to assess whether these regions might be handled through the delegation of tasks like remain behind, merge behind, vector then merge (as in the CoSpace project [30]) or they would rather require to be fully managed by ATCOs. In addition, tubes might also cause conflicts at the entry / exit points, once the rest of the airspace has different capacity. Therefore, a particular attention is suggested for the further investigations addressing the terminal area management.

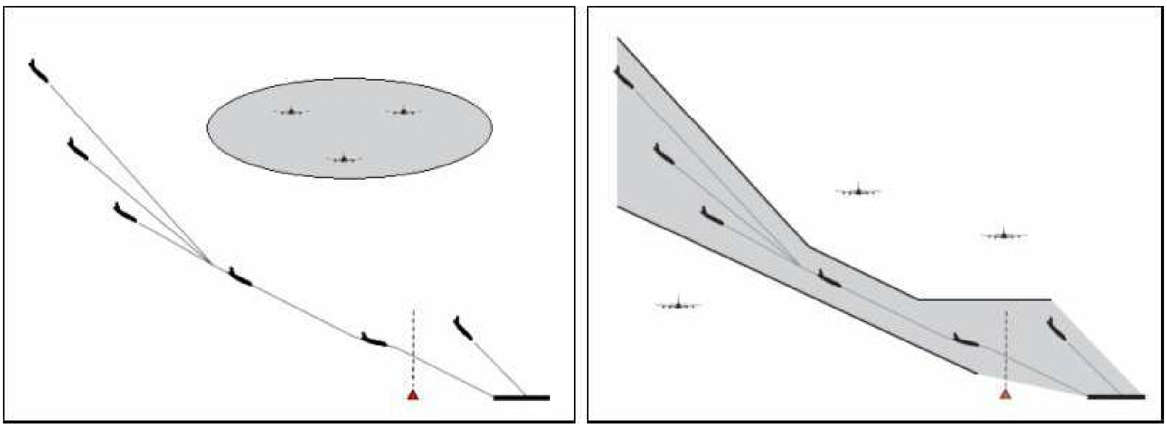

Figure 57. Two different approaches to use tubes at the terminal area: on the left for EPATS and on the right for the traditional flights (source: SESAR, modified by author).

The high number of the personal VFR flights will call for a relatively high level of advanced airborne system applications to enhance the communication, navigation and surveillance techniques. The cockpit instruments will be based on the combination of numerous on-board equipments (e.g. sensors, digital terrain databases), satellite-based techniques (e.g. geo-positioning records using GPS satellite signals) and other supporting services (e.g. traffic data from radars or ADS-B, digital data processing, aviation weather information) to support artificial / synthetic vision systems. Artificial / synthetic vision technologies are particularly suggested for EPATS, as relevant investigations in 2003 [72] demonstrated that these lead to enhanced situation awareness (through a three dimensional perspective presentation of the outside world), and therefore to the reduction of the greatest contributing factor to fatal worldwide airline and general aviation accidents [73], the Controlled Flight Into Terrain (CFIT). In addition, at high density regions and at complex traffic circumstances, such as the terminal area management, these will permit the flight path by tunnel or pathway-in-the-sky representations. On the other hand, as EPATS is sensitive to the cost of the proposed solutions, numerous technologies might not be affordable. TCAS II is one example, which according to a research viewpoint of ONERA [24] is not an appropriate solution to be proposed for light aircraft. If acquisition cost of TCAS II remains about the same level as in 2007, then its less expensive variant is suggested, the TCAS I. While this excludes the Resolution Advisory (RA) feature, the equipment is still advantageous in monitoring the traffic situation around the aircraft and generates collision warnings.

On the other hand, the whole concept should be analyzed from a flight safety point of view. This in any case is reasonable, since the envisioned EPATS operations – especially the single-pilot operation and the concepts leading to ASAS or the transfer of certain procedures / responsibilities to on-board – will influence the pilot roles, while according to numerous investigations [85] the primary cause for the hull-loss accidents is attributed to the flights crew (see Figure 58.).

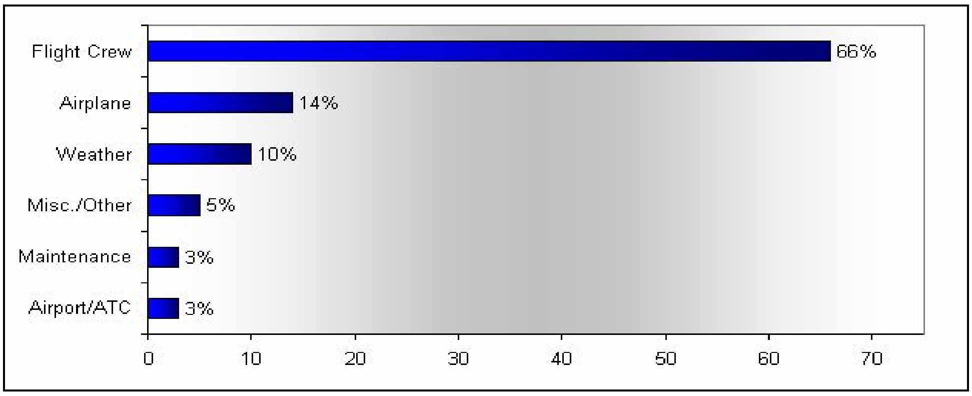

Figure 58. Hull-loss accidents per primary cause for the worldwide commercial jet fleet (source: BOEING).

The pilot involvement in the accidents also appears in the analysis of the cause of fatalities, indicating that the controlled flight into terrain and the loss of control in flight are the major accident causes. In addition, recent events show (e.g. Uberlingen on July 2002) that the on-board equipments (such as TCAS) aiming to enhance the pilot's situational awareness still

requires a clear understanding of when/how to apply it, otherwise misunderstandings might lead to collisions. Therefore, safety related problems are suggested to be kept in mind, especially, knowing that the most frequently used airspace of EPATS overlaps with the arrival and departure flows of the traditional traffic, while according to the statistical records these phases of flights account for the majority of the fatalities and accidents [86].

Perspectives, visions and proposals to support EPATS:

- ***Consider special small aircraft characteristics: aircraft performance, effect of turbulence/wake vortex, cost of solutions;***
- ***Consider that 40 million personal flights will rely on the see-and-avoid concept, from which a significant percentage (60%) will take place below FL 100 (might be an input for the airspace organization);***
- ***Clarify the upper boundary of the unmanaged region in SESAR;***
- ***Provide detailed traffic records to support real or fast time simulations;***
- ***Perform a fast or real time simulation to obtain the generally used metrics of evaluation;***
- ***Analyze whether ASAS is capable to handle EPATS VFR;***
- ***Analyze the probability of multiple conflicts and its impact on the traffic complexity;***
- ***Evaluate the impact of EPATS VFR on the traffic complexity indicators (e.g. number of speed interactions due to EPATS VFR);***
- ***Investigate whether / how EPATS and the traditional flights might be handled at the airport surroundings:***
    - ***Analyze whether A/DMAN is capable to handle EPATS and the traditional flights at the airports used by both traffic;***
    - ***Analyze whether corridors or tubes in the sky are reasonable to be applied at the terminal areas;***
    - ***Investigate whether the deviation of the terminal areas cause congestions in the airspace between the airports (provide a list of the terminal areas required to be deviated);***
    - ***Investigate how the deviation of the terminal areas influence the EPATS flight efficiency in terms or route extension.***

5. CONCLUSIONS

According to the WP2, EPATS would represent from 42 924 291 to 44 179 030 movements a year by 2020, and call for 99 000 and 89 000 aircraft, respectively for the Case A and Case B estimations. Using the EUROCONTROL and the European Commission findings, this investigation distinguished EPATS IFR and EPATS VFR flights.

The EPATS IFR flights are found to grow from less than 1 million (as in 2007) to 2 944 105 or 2 860 539, respectively for the Case A and Case B projections. Knowing the targets of SESAR, it is clear that these personal IFR flights fit in the envisioned ATM capacity. Results also indicate that the maximum EPATS IFR traffic that could be handled by SESAR in 2020 is 12.59 and 12.56 million flights respectively for the Case A and Case B estimations. This is about 3.5 more than the predicted personal IFR traffic. The found capacity gap appeared in the results of the COSAAC simulation, which showed that the impact of the EPATS IFR flights on the traditional movements is limited, and therefore the personal IFR movements are not leading to congestions at the airports or waypoints. On the other hand, EPATS IFR might generate further traffic complexities, if the aircraft performances/characteristics are different from the traditional flights, and therefore horizontal/veridical interactions or even wake vortex problems are faced.

On the other hand, the EPATS VFR segment is expected to grow from about 15 million flights a year (as in 2007) to 41.2 million for the Case A and 40 million with respect to the B prediction. The impact of the personal VFR flights on the ATM is an unknown problem, since these movements are not clearly addressed in the targets of the coming ATM. Nevertheless, this investigation showed that personal VFR movements flying at low altitude will meet the arrival / departure flows of the traditional traffic at the airport vicinities. Therefore, EPATS VFR will affect these regions, and call for advanced methods to cope with the two classes of traffic together (EPATS and traditional). If not feasible, the deviation or the separation of the flights will be needed.

With respect to the total EPATS traffic, this investigation showed the evidence for the fact that the geographical distribution of the envisioned EPATS flights is different from those of the rest of the airspace users. More particularly, the results indicate that generally personal movements keep off the most crowded regions of the traditional flights. However, EPATS will influence the rest of the airspace users in Italy; Greece; Portugal; Spain; the Southern regions of France, England; the South-Eastern areas of Poland and the North-Western locations of Germany. With respect to the impact of EPATS on the most preferred airports of the traditional flights, Athens, Rome, Madrid Barcelona, Warsaw and London are found to be the most influenced, while the most congested locations such as Frankfurt, Amsterdam or Paris are indicated to be less concerned. The cruising altitude distribution showed that 60 % of the personal movements take place in the airspace below FL 100, in which only 2 % of the traditional flights are present.

Major findings of the analysis suggested that future decisions concerning the airspace organization should take into consideration that (in 2020) about 40 million personal flights would rely on the see-and-avoid concept, from which a significant percentage would take place below FL 100. Beside, a particular focus on the terminal area management is also proposed to cope with the EPATS and the traditional flights at the airport vicinities. Finally, it is also suggested to address the business model of EPATS in order to clarify whether the flights will take place scheduled or on request, and how these will fit in the SESAR business trajectory process.

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