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iFly

Safety, Complexity and Responsibility based design and
validation of highly automated Air Traffic Management

Specific Targeted Research Projects (STREP)

Thematic Priority 1.3.1.4.g Aeronautics and Space

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Abstract

This report is the first deliverable of iFly project Work Package 1. The report is a high level approach to the A^3 concept of operations to be developed for a potential shift into autonomous en-route operations in busy airspace according to current standards.

Taking advantage of a large review of the state-of-the-art research results obtained in previous aeronautics research projects the High Level ConOps outlines the available options towards autonomous en-route aircraft advanced operations. In addition it leans significantly on the airborne human responsibilities and cognition analysis performed within Work Package 2.

A key objective on the iFly project is to assess for airborne self separation up to which traffic levels it can safely accommodate within Self Separation Airspace (SSAS). ASAS operations in the SESAR and NextGen concepts of operations are assumed to occur in low to medium traffic density, but not during high density airspace operations. It is our objective to evaluate the highest traffic density in which the autonomous aircraft can safely fly without ATCo support on the ground.

In this A^3 concept of operations we have specified key aspects of autonomous aircraft operations within SSAS. We have defined the operational environment of en-route autonomous aircraft operations, and stated our assumptions about future separation minima and the location and interface between Managed Airspace (MAS) and SSAS.

We have described the high level operational procedures for en-route autonomous aircraft operations and defined the airborne trajectory and separation management responsibilities and tasks within the SSAS. The airborne requirements for autonomous and safe flight operations in SSAS have been well documented in this A^3 ConOps.

The various aspects of distributed airborne decision making during tactical and strategic management of the flight have been depicted, as well as the required data exchange between airborne systems which is needed to create a high level of situation awareness for the pilot in this autonomous aircraft environment. Additional aspects that impact the

pilot's situation awareness were also discussed in detail. We introduced the types of hazards that must be addressed within A^3 ConOps to ensure that autonomous aircraft operations in medium to high density airspace can be realized at safety levels that are equal, or superior, to the safety levels of the existing ATM environment.

Although we have not answered all possible questions regarding ASAS operations in SSAS, we have built and selected the most promising and ambitious solutions upon the lessons learned and results gathered from ASAS programs that came before us (e.g. MFF, HYBRIDGE). Going forward, this document will be used by the remaining work packages on the iFly project as they analyze the safety and high level design requirements for this A3 concept of operations.

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1 Introduction

1.1 iFly project

The iFly project definition comes as a response to the European Commission 6th Framework Programme call for Innovative ATM Research in the area of 'Aeronautics and Space'. The program is expected to develop novel concepts and technologies with a fresh perspective into a new air traffic management paradigm for all types of aircraft in support of a more efficient air transport system. It is aimed at supporting the integration of collaborative decision-making in a co-operative air and ground based ATM end to end concept, validating a complete ATM and Airport environment, while taking into account the challenging objectives of Single European Sky and EUROCONTROL's ATM2000+ strategy (iFly Project Annex 1, 2007, p. 5).

Air transport throughout the world, and particularly in Europe, is characterized by major capacity, efficiency and environmental challenges. With the predicted growth in air traffic, these challenges must be overcome to improve the performance of the Air Traffic Management (ATM) system. The iFly project addresses these critical issues by developing a paradigm step change in advanced ATM concept development through a systematic exploitation of state-of-the-art mathematical techniques including stochastic modelling, analysis, optimisation and Monte Carlo simulation.

The iFly project will develop and analyze a highly automated ATM concept for en-route traffic, which takes advantage of autonomous aircraft operation capabilities and which is aimed to manage a three to six times increase in current en-route traffic levels.

Self-optimization way of flying might provide a more efficient, while still safe, traffic pattern with respect of fuel and time. The concept of Free Flight has been developed extensively since 1995, when Radio Technical Commission for Aeronautics (RTCA) defined it as "…a safe and efficient flight operating capability under instrument flight rules in which the operators have the freedom to select their path and speed in real time …" (RTCA, 1995).

Free Flight could also provide more efficient airspace usage for instance over the ocean or areas without radar coverage and maybe even in radar controlled areas. The reason for this is that in general (except the terminal area around airports) the human-centred separation assurance method, and not the airspace volume itself, is the most limiting factor on capacity. In Free Flight, the separation task is moved from the ground-based ATC to the cockpit. By using a system that broadcasts or transmits not only identification and altitude but also the position, velocity and some intent information about part of the intended route, every equipped aircraft could use this to ensure separation and exploit a more efficient airspace.

It has also been argued that Free Flight removes the main present bottleneck in increasing airspace capacity – the excessive workload of ATC personnel in very busy traffic sectors. This change in ATM workload is achieved by distributing ATM responsibilities mainly to the airborne systems through a highly automated, safe, ATM design for en-route traffic, which is the final aim of the iFly project.

The iFly project will perform two operational concept design cycles and an assessment cycle comprising human factors, safety, efficiency, capacity and economic analyses. During the first design cycle, state-of-the-art aeronautics Research, Technology and Development results will be used to define a “baseline” operational concept. For the assessment cycle and second design cycle, innovative methods for the design of safety critical systems will be used to develop an operational concept capable of managing a three to six times increase in current air traffic levels.

iFly will explore the airborne self separation alternative as a potential solution for high traffic demand airspace, and this is one of the most relevant points of the study due to the fact that during recent years ATM community research trend in Europe has been to direct airborne self separation research to situations of less demanding airspace.

The iFly key research questions arising from the overall analysis are the following:

a) Up to which en route traffic demands is airborne self separation sufficiently safe?
b) Which complementary support services from ground ATM are needed in order to accommodate higher traffic demands?

Regarding the aligning process to SESAR (and more precisely to the SESAR D3 Target Concept), the iFly project supports SESAR ATM Capability 3 ConOps by assessing the airborne self separation outside the busy en-route areas. Requirements for the supporting system Architecture and CNS technology will be included as well in the iFly project results.

The most important actions within the iFly project supporting SESAR D3 results are:

- ✓ Production of two advanced design references:
  a. Self Separation with maximal capacity accommodated; this relates to the autonomous aircraft advanced concept (A^3)
  b. A vision how A^3 equipped aircraft can be integrated with the SESAR ATM ConOps.
- ✓ Safety/capacity, human factors and cost-benefit assessment of the self separation concept
- ✓ Innovative features: predict traffic complexity, multi-agent situational awareness, guaranteed conflict resolution
- ✓ Development and validation in line with E-OCVM

iFly project brings together a powerful team from European ATM research and industry that initially came together in the successfully completed EC-INFSO project HYBRIDGE. The consortium is strengthened by additional key partners including a human factors specialist, a large Air Navigation Service Provider, an aviation psychology university specialist, an ATM cost-benefit specialist institute and a large system engineering consultant with wide experience in advanced ATM design.

1.2 iFly WP1

Work Package 1 will develop an autonomous aircraft advanced concept (A^3) including an airline strategy concept for autonomous aircraft operations, using state-of-the-art aeronautics research and technology results. The A^3 concept focuses on the en-route phase of flight, for a potential shift into autonomous en-route operations in busy airspace according to current standards.

The purpose of this work package is to develop an overall A^3 concept of operations able to safely accommodate in the en-route phase of flight as much traffic demand as is feasible. Work Package 1 also describes an airline strategy concept for the A^3 environment, optimizing the airlines performance with autonomous aircraft and improving customer services by making effective use of that autonomy.

Work Package 1 takes advantage of state-of-the-art research results obtained in previous aeronautics research projects and it also leans significantly on the pilot responsibility and cognition analysis performed within Work Package 2.

The tasks performed in this WP will be consolidated around an A^3 concept that is targeted to:

- Optimize the performance of airlines with autonomous aircraft.
- Safely accommodate as much en-route traffic demand as is feasible.
- Ensure the interoperability of the various A^3 services.
- Improve on customer services by making effective use of the autonomous navigation capabilities.

The Work Package 1 is organized in three sub-WPs. WP1.1 called “High level ConOps” describes the research efforts and available options gathered towards autonomous en-route aircraft advanced operations. WP1.2 called “Airline Strategy Concept” will describe the strategy concept for airline operations in an autonomous aircraft environment. WP1.3 called “ConOps” will describe the overall concept of operations within the autonomous en-route ATM environment.

1.3 Scope of the High Level A^3 ConOps development

During recent years the ATM community research trend is to direct large airborne self separation research projects to situations of less dense airspace. The iFly project aims to develop a step change in this trend, through a systematic exploitation and further development of the advanced mathematical techniques that have emerged within the HYBRIDGE project of EC’s 5th Framework Programme. This is remarkable because on iFly, airborne self separation has been proposed as a potential solution for high density airspace.

This report tries to offer some of the potential solutions towards a shift to en-route autonomous aircraft operations, which could lead to the required capacity breakthrough.

The objective of this report is to describe the first one of the two operational concept design cycles performed by the iFly project, which comprises the following activities:

- Assessment and definition of a common basis, e.g.: terminology and functionalities.
- Identification of candidate concepts or concept elements from previous state-of-the-art aeronautics Research & Technology projects.
- Operational environment description of autonomous aircraft operations en-route.

The A^3 ConOps will address an airspace concept where the airspace user is responsible for self-separation, assuming that AOCs and Ground based Traffic Flow Management (like CFMU) are working well. This airspace concept falls under what SESAR defines, in its service-oriented approach to airspace classification, as Unmanaged Airspace. However, since it is possible to consider greatly differing modes of operation under the Unmanaged Airspace definition, the term “Self Separation Airspace” (SSAS) has been coined to address specifically the airspace concept proposed by iFly.

A follow-up of the iFly project is to assess up to which traffic demand can safely be accommodated by the A^3 ConOps. When SESAR and NEXT-GEN propose to apply self separation at higher flight levels, this still is within managed airspace. Hence this means that there will be an ATCo monitoring. Because the impact of such a monitoring ATCo is very difficult to define in an exact way a lot of vagueness and uncertainties may arise when studying the safety assurance tasks performance in this situation. In order to avoid such vagueness, straight away from the definition of the iFly proposal there was absolutely none ATCo at all participating in the A^3 concept development within the iFly WP1 description. In line with the above, in the iFly technical annex it is explicitly stated as one of the key objectives of the iFly project to find out through research up to which traffic demand airborne self separation can be handled safely, i.e. without any ATCo support on the ground. The A^3 design should aim for an operation in unmanaged airspace where the concept can safely accommodate as high traffic demand as good and optimistic designers believe is possible.

If iFly is able to show that A^3 ConOps can safely be applied for high traffic demand, then this means for SESAR and NEXTGEN that they can take advantage of this directly within the unmanaged airspace. And if SESAR or NEXTGEN would like to add an ATCo on the ground then it can be implicitly assumed that at least the same capacity can safely be realized. Moreover, through the iFly refinement of the A^3 concept, which will be built up within the WP8 later on, iFly project will also contribute significantly to develop the managed airspace as it is described in SESAR and NEXTGEN.

1.4 Organization of this report

The remainder of this A^3 High Level ConOps report is organised as follows:

Section two presents the relation to previous research, identifying the problems that the iFly A^3 ConOps has to address and the research central line, including the decision criteria used in selecting the main candidate elements.

Section three describes and explains the “en-route” phase of flight within the context of iFly WP1.

Section four offers a detailed definition of the Self Separation Airspace within the global airspace concept in order to understand the mutual compatibility, describing the transition zones and the SSAS internal organization. The Separation Minima issue is tackled here from a different point of view, since in Self Separation Airspace more flexible and effective vertical profiles than in the current en-route ATM may impose new requirements on the separation standards definition.

In section five, the ATM in the SSAS is presented and the scope of “autonomous flight” within the iFly project is discussed. SSAS Trajectory Management and ASAS Separation Management are the two major layers of airborne ATM identified within the proposed structure. In addition there is ACAS, or an improved version of ACAS, as a safety net. A preliminary estimate of the airborne equipment requirements for the SSAS is also offered in this section.

Section six addresses the question how distributed trajectory management will be performed, taking into account that the function of Trajectory Management requires good medium to long term situation awareness. The process of optimizing the user preferred trajectory is also presented together with the different approaches to communicate the trajectory information to System Wide Information Management (SWIM).

Subsequently, in section seven, the Separation Management issues are introduced and Conflict Detection approaches presented. Conflict Resolution algorithms for ASAS/Free Flight operations are discussed afterwards and the Conflict Resolution process is described, taking into account the collaborative approach to decision making.

Section eight deals with a major topic within the Free Flight concept: Situation Awareness. Due to the fact that it is hard to achieve total SA, it is important to identify key elements that are related to pilots monitoring activity during en-route flight. Human Machine Interface (HMI) is also introduced as a necessary system to provide the aircrew with sufficient information at the right time. Information required to enable a high level of SA in iFly is presented together with other non-traffic SA issues. Finally, at the end of this section, flight rules and responsibility distribution are pointed out.

Section nine discusses the definition of air traffic complexity prediction and the applications of the complexity notion within the proposed ATM scheme.

Section ten presents a list of operational hazards compiled from iFly related projects and deduced by brainstorming activity in qualitative terms only, covering various hazard categories.

Finally, section eleven discusses the involved technology needed by the iFly A^3 ConOps presented in this document at its high level. Existing and new required equipment are described together with the SWIM.

In the appendices section, a high level review of SESAR and NextGen regarding airborne self separation is developed, and the input previous R&T projects working repository is shown in a summarized table format. At the end of the document, appendix D presents the iFly WP1 relation to other iFly work packages.

2 Relation to previous research

In order to identify the main candidate elements for the Autonomous Aircraft Advanced concept being developed by the iFly project, an intensive overview of the previous state-of-the-art aeronautics research and technology projects have been undertaken by the WP1 team.

iFly can be considered a follow-on to the Hybridge project, where an autonomous aircraft concept (the Autonomous Mediterranean Free Flight (AMFF)) was assessed. This concept was proposed by the Mediterranean Free Flight (MFF) Programme as one promising solution to the increasing air traffic demands. The iFly employs the ideas developed in Hybridge and MFF as well as other concept elements taken from previous research projects as a starting point and creates a new concept of autonomous operation capable of achieving higher levels of safety than the preceding ones. (see Figure 1)

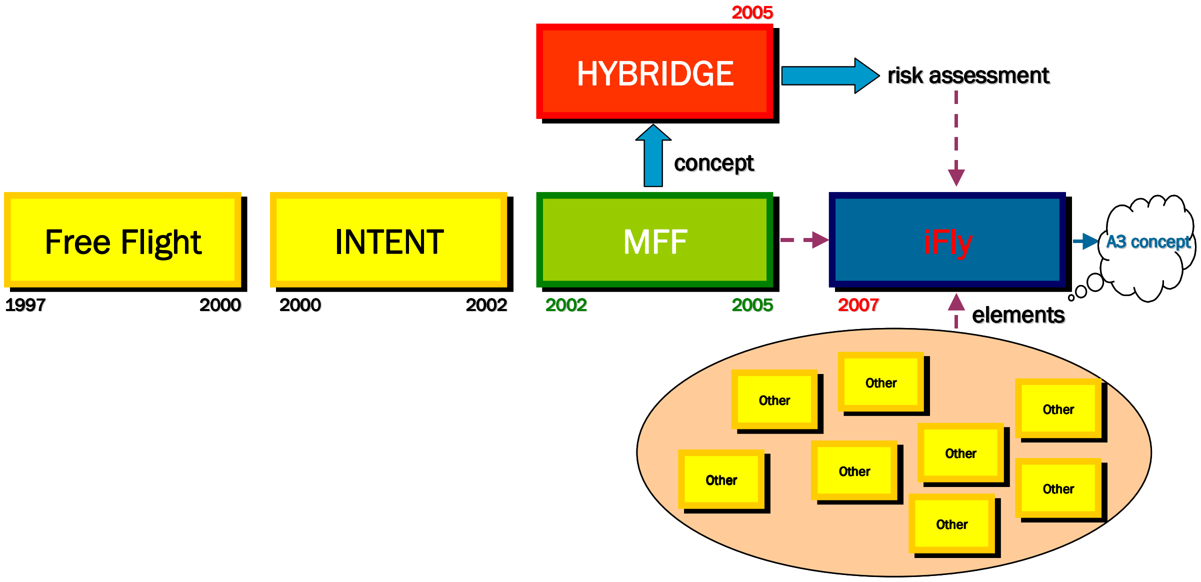

Figure 1: iFly Research Central Line

Thus, the WP1 team should be well familiarized with the AMFF concept and the assessment performed in order to identify various alternatives in which the concept can be strengthened in order to achieve even higher levels of safety.

The Autonomous Mediterranean Free Flight concept defines five applications or elements: (i) Free Routing, (ii) Air Traffic Situation Awareness (ATSAW), (iii) ASAS Spacing, (iv) ASAS

Separation, and (v) Airborne Self Separation. Within the iFly project, where Self Separation is the objective of the research, ATSAW is an enabler for Self Separation and Free Routing is considered implicitly.

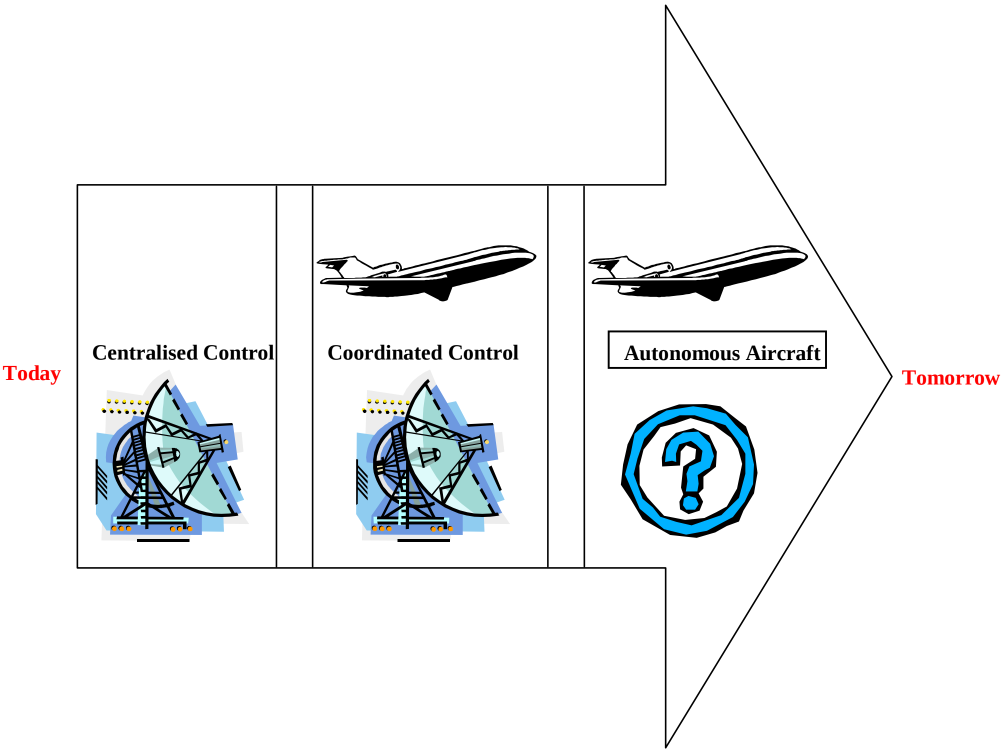

Figure 2: Degree of delegation and airspace autonomy evolution

Due to the fact that the review of the related projects to select the most interesting inputs and identify key concept elements is a complex task, common criteria to determine the most useful projects have been developed. Then, some core questions arise when looking for the areas of interest to define the new iFly concept:

What list of decision criteria will be used in selecting the main candidate elements?

- Does it address the major issues identified in Hybridge and other related projects?
- Is the element offering a major contribution to solving the issues identified in Hybridge and other related projects?
- Does the element keep the pilot in the loop?
- Is the element conflicting with other elements or does it introduce other major issues that may confuse the objectives proposed? All the alternatives available at the High

Level must be described but keeping the concept as simple as possible to avoid other potential problems in other areas of research.

What are the problems that the iFly A^3 ConOps has to address?

(i) It must be able to maximize the safety level in the en-route phase of flight while increasing three to six times current en-route traffic levels.

(ii) Aircraft flying are autonomous and have no support from centralised ATC.

(iii) The flight crew has to be able to handle responsibilities for autonomous operations and has to achieve an adequate situational awareness.

(iv) Complexity and uncertainties of air traffic have to be handled together.

(v) Innovative methods to model and predict complexity of air traffic must be developed as well as conflict resolution algorithms for which it is formally possible to guarantee their performance.

(vi) Complementary objectives of the various involved actors have to be integrated.

(vii) The en-route traffic shall also avoid no-go areas adequately.

(viii) Some questions still remain unclear at this stage of research, such as if the A^3 ConOps may include (at the High Level) other obstacles in the trajectory resolution apart from air traffic such as weather and terrain hazards, restricted airspace, wake vortex encounters, etc. Or may these other issues be tackled in the safety risk assessment and focus the ConOps description just on the air traffic obstacles?

(ix) What information must be broadcasted by the system to the other aircraft in order to maintain safety level and security issues, i.e. system(s) failures, terrorism acts, etc.

(x) The concept design shall include two different data: planned and real trajectories.

(xi) It must explore how flow management issues may be solved in the future.

(xii) Contingency situations and systems failures, recovery services and operation, redundancy, phraseology, etc. are other issues that must be addressed by the iFly A^3 ConOps.

What are the causes of the problems previously identified?

- In order to implement the iFly new concept elements (new systems, functionalities, human responsibilities, etc.) the present gap between the current technological situation and the required level to realize the future ConOps proposed must be overcome.

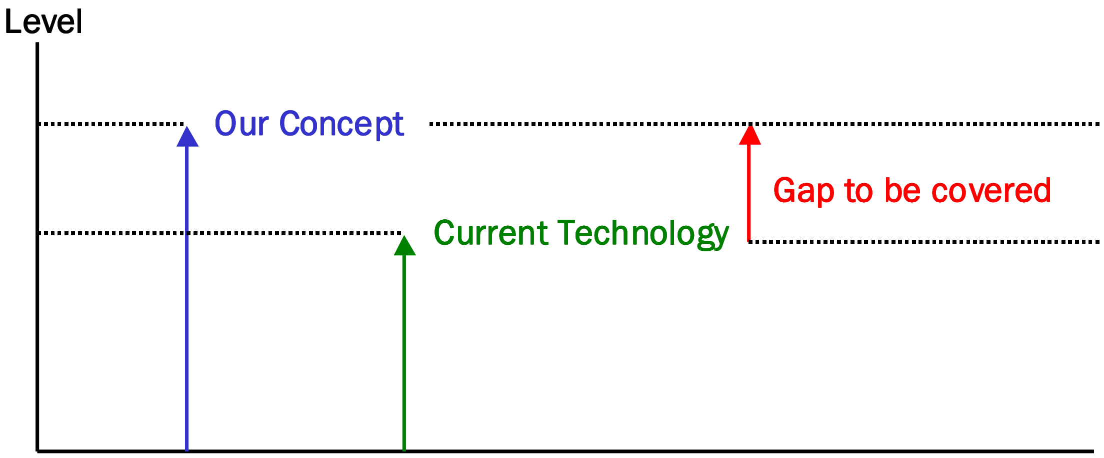

Figure 3: iFly technology gap

- The Hybridge analysis showed that in the two head-on aircraft scenario a major cause for collision risk lies in the reliability of GNSS, ADS-B and ASAS systems. For a multiple conflicts scenario the reliability of these systems is not a major cause.
  iFly project will investigate a better use of the power of co-operative algorithms in resolving multiple conflicts. Because of HMI reasons, for AMFF it was decided not to do so. Moreover, within AMFF a two-stage strategy was adopted. During the first phase of potential two-aircraft conflict resolution there will be an aircraft that solves the problem first. As kind of backup during the second phase of two aircraft conflict resolution there will be a cooperative approach.
- A significant modification of the sequence of work can be proposed: first, to start cooperatively (typically in horizontal direction), and then as backup to solve any remaining problem (typically in vertical direction). However, this approach involves two kinds of issues to be addressed:
  a) How to avoid that an aircraft is "playing chicken" (in game theory Game of Chicken is an influential model of conflict for two aircraft, both headed for a single trajectory from opposite directions) and how this relates with the type of resolution manoeuvres (this is part of the human factors research, including pilot-in-the-loop simulations).

   b) The second phase of ASAS should remain separated in time from the TCAS time frame. A key issue is at which level both systems keep on working redundantly. For the latter there may be several ways to investigate, covering technical systems (e.g. the same or different transceivers), but also HMI (e.g. same or different CDTIs, roles of crew members, etc.).

- The Hybridge conclusions showed that the sequential resolution of multiple conflicts is slow when resolving multiple conflicts. It can result in clusters of conflicts growing faster in size than the conflict resolution system can properly handle.
- The ACAS effects have not been taken into account in the Hybridge analysis. Accoriding to ICAO, the ACAS safety net contribution to safety should not be taken into account to assess against ICAO's TLS. However, it should ve verified that the novel airborne self separation concept is not working against the safety net role of ACAS.

Summarizing accordingly to the SESAR WP3.1 DLT annexes, the principal operational concept elements addressed by the iFly project are the following:

- ☐ New Separation modes
- ☐ Maximised Utilisation of Capacity
- ☐ Collaborative Decision Making (CDM)
- ☐ Trajectory Management
- ☐ Improved Situational Awareness
- ☐ Information Management

3 The “en-route” phase of flight

The “en-route” phase of flight is defined by the ICAO Common Taxonomy Team as:

“Under Instrument Flight Rules (IFR) “en-route” phase includes from completion of Initial Climb through cruise altitude and completion of controlled descent to the Initial Approach Fix (IAF)”.

This phase of flight includes the following sub-phases:

- Climb to Cruise: Under IFR, from completion of Initial Climb to arrival at initial assigned cruise altitude. Under Visual Flight Rules (VFR), from completion of Initial Climb to initial cruise altitude.
- Cruise: Any level flight segment after arrival at initial cruise altitude until the start of descent to the destination.
- Change of Cruise Level: Any climb or descent during cruise after the initial climb to cruise, but before descent to the destination.
- Descent: Under IFR, descent from cruise to either IAF or VFR pattern entry. Under VFR, descent from cruise to the VFR pattern entry or 1000 feet above the runway elevation, whichever comes first.
- Holding: Execution of a predetermined manoeuvre (usually an oval race track pattern), which keeps the aircraft within a specified airspace while awaiting further clearance. Descent during holding is also covered in this sub-phase.

A different way of defining “en-route” is to look at the objectives within the ATM system. The goal of air traffic management is to ensure the safe, orderly, expeditious flow of traffic. Safety is maintained by ensuring that aircraft are separated. Two fundamentally different tasks can be distinguished and these tasks are often linked to the phase of flight. One task is to ensure separation between flights whose trajectories cross. This task is usually associated with the en-route phase of flight. The other major task is to build arrival sequences for aircraft, which will land on the same runway or at the same airport. This task is usually associated with the arrival phase.

In moving towards autonomous aircraft operations a straightforward initial approach is to associate the crossing trajectories problem with Self Separation Airspace (SSAS) and to associate the arrival sequencing problem with managed airspace. With such a division the crossing problem must be solved by the autonomous aircraft. The arrival sequencing problem is essentially one of organizing efficient use of a serially reusable resource (a runway) and this problem lends itself naturally to a centralized approach.

Within the context of iFly WP1, rather than trying to define precisely what is meant by "en-route" and then trying to design an autonomous aircraft scheme which is sufficient for the en-route phase of flight, it seems more straightforward to distinguish between Self Separation and Managed Airspace, and to limit the autonomous aircraft problem (initially at least) to that of ensuring separation within the Self Separation Airspace without tackling the additional requirement of establishing arrival sequences. In other words, to limit the scope of the problem to be addressed in WP1, we should assume that Self Separation Airspace is at sufficient distance from areas where arrival sequencing will start to be performed.

4 Self Separation Airspace (SSAS)

As it is assumed that typically only a part of the flight is performed through SSAS, definition of this area inevitably requires a good understanding of the global airspace concept within which it should fit to ensure the mutual compatibility.

4.1 Location and Interface of SSAS

Within the SESAR airspace structure, SSAS should be a separate part of the Unmanaged Airspace where only properly equipped (self-separation capable) aircraft are hypothetically assumed to fly. In other words, we do not consider general unmanaged airspace where the self-separation aircraft are mixed with non-equipped ones.

There is a general agreement that for entering and exiting the SSAS the **transition zones** must be defined allowing a smooth and safe transition of the responsibility between ATC and flight crew. For example, within NextGen it is formulated as follows:

"*Transition airspace around self-separation airspace exists to allow for the safe transfer of separation responsibility between the aircraft and the Air Navigation Service Provider (ANSP). For aircraft entering self-separation airspace, separation responsibility is transferred so that the aircraft is safely able to assume it, implying that there are no very near-term conflicts with other aircraft or hazards. For aircraft exiting self-separation operations, the transition may include waypoints with Controlled Time of Arrival (CTA) to enable sequencing and scheduling by the ANSP. In this transition zone, the ANSP provides CTAs and possibly Trajectory Management (TM) to maintain safe separation between the aircraft exiting the airspace. As with delegated separation, the ANSP and aircraft automation track the transfer of separation responsibility and communicate it to those affected.*"

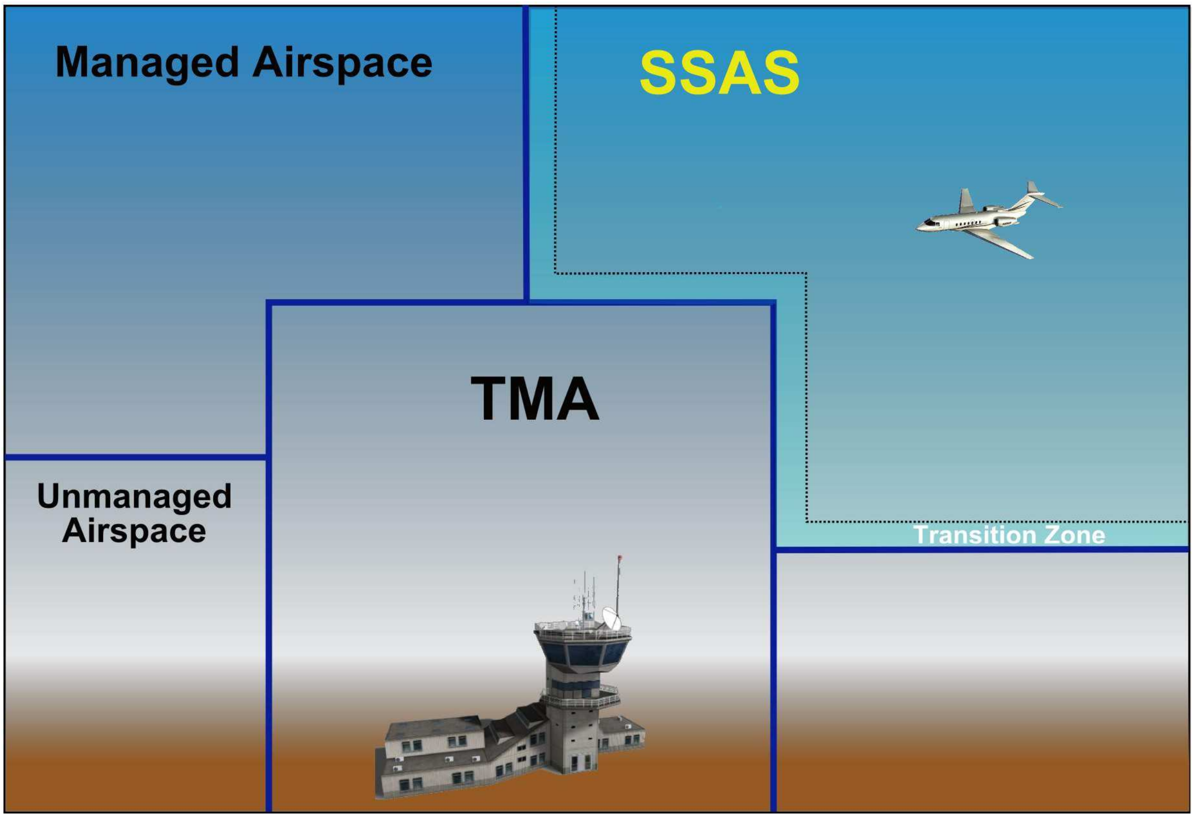

Figure 4: Self Separation Airspace (SSAS).

Most of the proposed transition solutions are inspired by transfer procedures between sectors in the current ground-based ATM. However, the fact that SSAS could be surrounded by the Trajectory-Managed airspace can considerably simplify the problem. In fact, if there is some kind of 3D+ trajectory contract (i.e., a 3D trajectory contract with time constraint(s) in some specific point(s) or a full 4D trajectory contract) immediately from/to the exit/entry point, the self-separation responsibility could be naturally transferred from/to the responsibility to fulfil this contract. A transition zone, e.g., for the exit point could thus be defined just as the zone inside SSAS where it is not already allowed to negotiate the part of the 4D trajectory directly attached to the exit point.

The main ambiguities concerning the transition zones definition are probably the following:

Will the transition layer be part of the SSAS (i.e., responsibility on the airborne side) or a part of the managed airspace (ATC managed)?

The Mediterranean Free Flight (MFF) project considered the transition layer to be part of SSAS. Note that there is no clear statement about this question neither in the SESAR, nor in the NextGen Concept of Operation documents.

Will the transitions be restricted to some limited number of points or possible through whole (or nearly whole) SSAS boundary?

The ATC route structured airspace without Trajectory Based Operations (TBO) would require a limited number of exit/entry points. However, there is a considerable drawback represented by the need of sequencing and merging of SSAS traffic through the exit points. This can result in capacity problems partially reducing the benefits of the SSAS concept. On the other hand, if the neighbouring parts of the airspace use TBO it should not be a problem for ATC to manage trajectories with arbitrary exit/entry points assuming that the corresponding trajectory contract exists. As mentioned above, the transition zones then could be defined as the zones where the transition trajectory contract must be frozen (not open to negotiation).

4.1.1 Assumptions

Based on the context discussion presented above and in 14.1 the following conceptual assumptions for the SSAS definition could be proposed:

- It is hypothetically assumed that all aircraft are ASAS Self Separation capable, i.e. there are no non-equipped aircraft in SSAS, part of Unmanaged Airspace.
- It is assumed that the intended trajectories (Reference Business Trajectory or RBT) for all aircraft entering the SSAS are known and stored in the SWIM. In this context it is possible to receive the trajectory intent[1] information for the other aircraft from the SWIM system, not just via direct air-to-air datalink communication.
- An aircraft is allowed to modify the part of its RBT that resides inside the SSAS without negotiation with the ground but it must provide the updated information to SWIM (via datalink). Changes in the trajectory that affect the

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[1] As there is not a common agreement about meaning of the term “intent” across the ATM community, a general definition is adopted for the purposes of this document. In this context we define the following terminology:

- **State information** covers only the information about the actual state of the aircraft. Note that we do not consider information about the setting of the guidance system (e.g., flight mode) to be included here as it already describes a segment of the flight, not just a local point.
- **Intent information** covers any additional information about succeeding parts of the flight beyond the state information. In particular, we do not restrict this term on the limited set of information defined, e.g., in new versions of ARINC 702a.

part of flight outside SSAS must still be negotiated with the ground. Each trajectory may be surrounded by an envelope for tactical maneuvering.

- When entering SSAS, aircraft already know their contracted exit conditions. Typically they will be specified in the form of an exit point with a time constraint (Controlled Time of Arrival (CTA)[2] or time interval).

4.2 SSAS Internal Organization

4.2.1 Route Structure

The original structure of the ATC airways was invented for two purposes:

- To facilitate navigation, as the airways are defined between two navigation aids.
- To facilitate ground based ATM.

With the advances of airborne navigation capabilities, like Global Navigation Satellite Systems (GNSS), an aircraft is able to accurately navigate independently of the airways structure. In fact, all modern aircraft are currently certified for Required Navigation Performance for Area Navigation (RNAV/RNP) capabilities and thus the route network is not necessary to maintain navigation performance, though there may be other reasons which implicitly define some network structure (for example points to enter or to exit SSAS).

Within the SSAS, separation management is performed by airborne systems. Thus there is not a priori reason to consider the ATC-defined airways for flight planning and execution. Users thus plan their SSAS routes between an entry point and exit point without reference to an ATC route network (MFF). Note however, that with the introduction of TBO this approach is considered to fall within ATC managed airspace. In fact, both SESAR and NextGen suppose that the route structure will be applied only when required by the capacity needs, typically just within the Terminal Area (TMA).

4.2.2 Altitude Structure

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[2] CTA is a term used in SESAR for a general trajectory time constraint. It can have a more general meaning than Required Time of Arrival (RTA) functionality actually implemented in all modern FMSs.

Should the flight level structure be preserved in the SSAS?

It is well known that the most effective (from the performance point of view) en-route flight is a climbing cruise. Evidently there is not an apparent reason why the flight level structure (also introduced as the support for the ground ATC) should be preserved for autonomous flight. However, after a detailed analysis some arguments appear:

- Safety – currently the even and odd flight levels are used for the traffic with the (predominantly) opposite directions,
- Trajectory description – as stated above, the intended trajectory must be provided to SWIM. Obviously a description of the trajectory with performance-dependent varying rate-of-climb is more complicated than the trajectory with step climbs.
- Flight procedures – it can be easier to use the same flight control procedures (guidance modes) as in ATC managed airspace.

4.2.3 Separation Minima (SM)

For the Free Flight concept, two zones were defined in order to maintain required separation among aircraft: **Protected Airspace Zone** (PAZ), and **Alert Zone** (AZ) (see Figure 5). While PAZ represents legal separation requirements and should not be penetrated in order to ensure safety, penetrating into AZ is a standard usage of AZ that issues alert about approaching conflict. More information about AZ can be found in Section 7.2. In literature (e.g., RTCA DO 263) there is also another, much smaller safety zone defined as Collision Avoidance Zone (CAZ). It represents the airspace around aircraft, which, if avoided, still ensures no collision. Nevertheless, this concept of operation is not based on usage of this term.

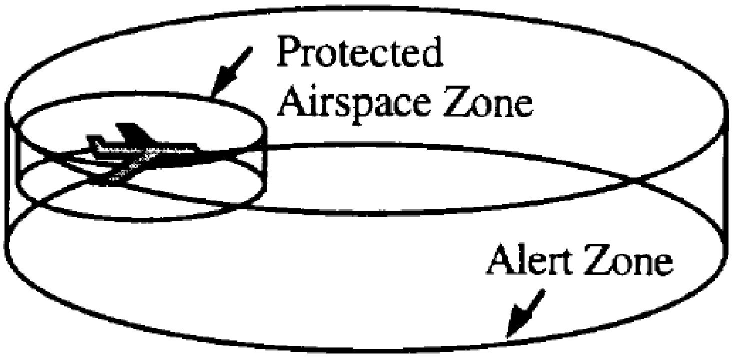

Figure 5: Protected Airspace Zone and Alert Zone according to Free Flight

Protected Airspace Zone (PAZ)

The separation standards used in current research to define the PAZ are based on today’s radar environment standards of 5 nautical mile (NM) horizontally and 1000 feet (ft) (or even 2000 ft) vertically. However, these separation standards were designed for controlled airspace, and are considered conservative today. Hence, the separation minima suitable for Free Flight are still to be determined.

How should PAZ for airborne self separation be defined?

There are several initiatives aimed at revising the existing separation standards (e.g., in project RESET, reduction of en-route horizontal separation from 5 NM to 3 NM is proposed for further investigation) or even developing general models for establishing new separations. Some ideas that should be considered in this process are presented in the next paragraphs.

Alert Zone (AZ)

The purpose of the AZ is related to the implementation of the conflict detection and resolution method. In some designs it is considered to be the intervention zone, i.e. a zone that, when penetrated, triggers an intervention by ATC. In other designs this may represent the resolution zone for conflict resolution.

The zone cannot be designed without first describing its use (i.e., what kind of conflict detection and how it will be performed). It should be a geometrically simple convex shape definable using only few vortices (edges, surfaces) so that the automatic conflict detection and resolution methods can be performed efficiently.

The shape could also reflect the properties of the aircraft, i.e. its type, current speed, navigation and surveillance capabilities. It should be emphasized that the AZ of different aircraft do not have to be the same, mainly when considering non-cooperative conflict resolution. Finally, the AZ should be designed such that the required level of safety will be kept.

Towards new separation minima

The current en-route ATM flight procedures typically force aircraft to fly on designated flight levels just with occasional climbs or descents. In such environment it is natural to define the separation minima separately for the vertical and horizontal case. To the contrary, in Self Separation Airspace more flexible and effective vertical profiles (such as continuous climb) may impose new requirements on the separation standards definition.

Should the current decomposition of separation into horizontal and vertical separation minima be maintained?

Although many separation standards used in research were defined using the rule of thumb, and there are not well documented foundations of many of them, several factors influencing the resulting separation under given circumstances can be identified. The ones possibly applicable for Self Separation Airspace could be:

- Complexity of the airspace
- Communication capability
- Surveillance capability
- Aircraft navigation performance
- Aircraft manoeuvrability
- Human performance
- Environment

The shape of the PAZ should reflect the above mentioned factors, and should maintain or exceed the required level of safety, have a shape simple enough to allow for easy computations, but sophisticated enough in order not to waste airspace and decrease capacity. An interesting solution is proposed in [Menon et al. 1999] where the authors suggest ellipsoidal shape (see Figure 6) with two semi-axes in vertical directions being 5 NM., and one semi-axe in vertical direction being 2000 feet. Ellipsoid has some desirable properties due to its smooth shape and absence of corners that appear in a cylinder. It is not supposed that computing with this shape would be problematic for ASAS automated tools, however, suitability of using ellipsoid should certainly be validated by human factors experts.

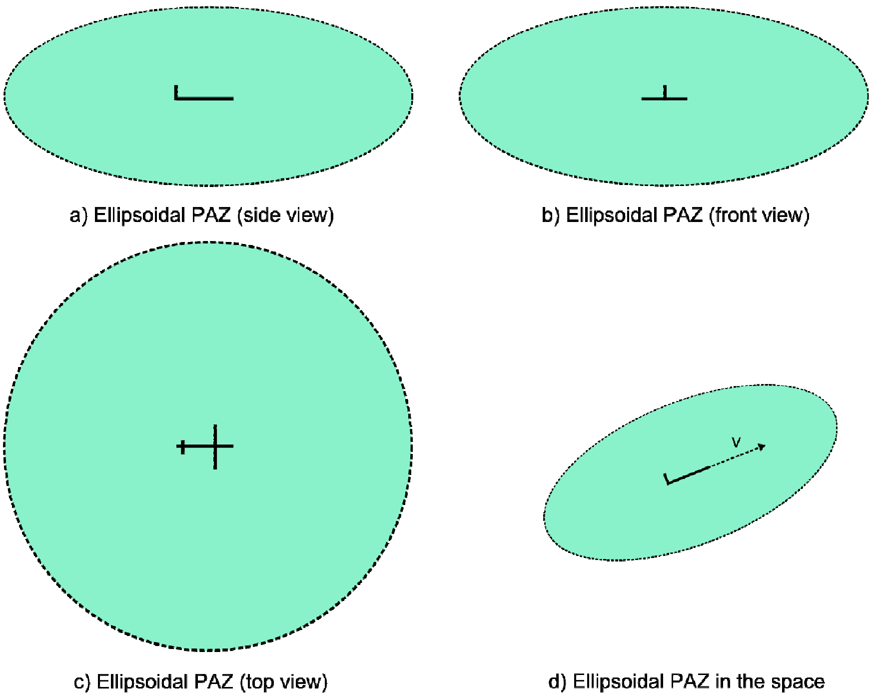

Figure 6: Ellipsoidal PAZ and its positioning in space according to the speed vector.

The potential use of the airborne Required Navigation Performance (RNP) capabilities with respect to the communicated trajectory also introduces new possibilities how to reduce separation minima. For example, considering the RNP-1 environment, the horizontal separation standard could be reduced at least to 3 NM with vertical separation being maximally 1000 ft. as is today in Reduced Vertical Separation Minima (RVSM). The work [Warren 1997] suggests even 2 NM for so-called Mature Free Flight.

The future limiting factors are expected to be wake turbulence and flight technical errors, more than surveillance position uncertainties.

What benefits would reduced separation standards bring?

If we use the current separation standards, we can easily compare the new concept of operation to the one currently in practice in terms of capacity, rate of conflicts, etc. However, more capacity could be gained if the separation standards were tailored to Free Flight's needs.

The final iFly approach to the PAZ and the related separation minima should be formulated on the basis of a detailed analysis of responses to the previous three questions.

5 ATM in SSAS

To discuss the ATM in the SSAS it is helpful to consider the overall structure of the ATM functions within the standard managed airspace. Figure 7 shows this structure for NextGen, while the SESAR's concept of the business (user-preferred) trajectory is shown in Figure 8. Both approaches are very similar and can (up to some details) be mapped to each other.

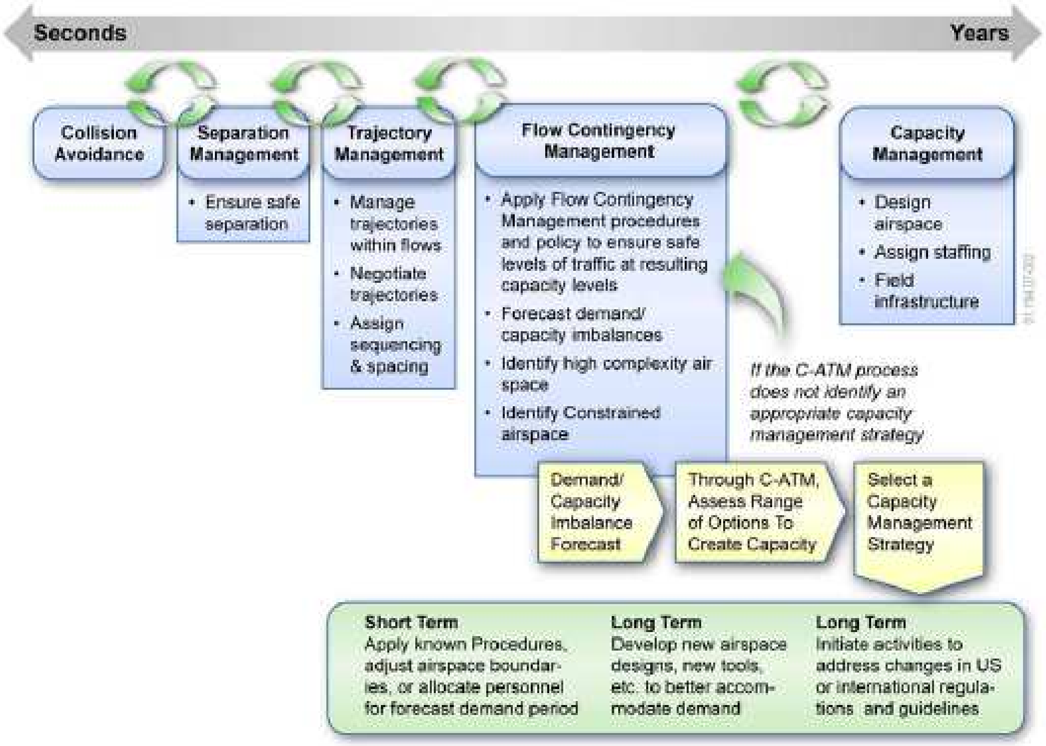

Figure 7: NextGen trajectory-based ATM.

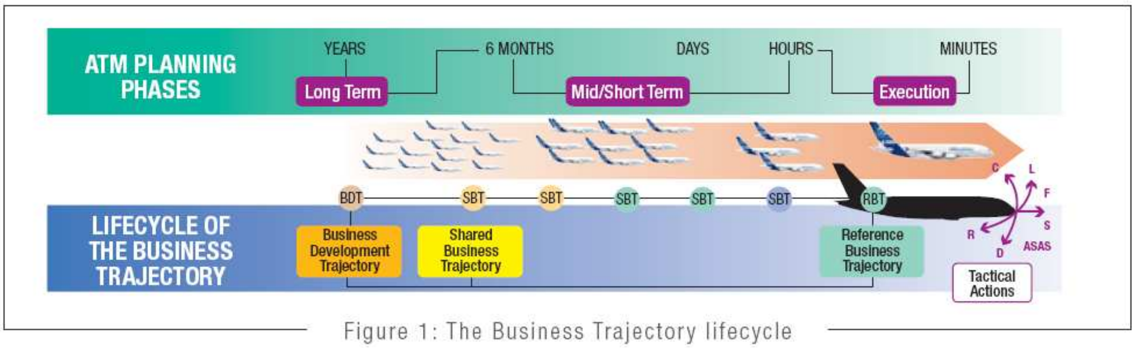

Figure 8: SESAR trajectory-based ATM.

The typical time scales, e.g., for NextGen tasks are:

- less than 1 minute for Collision Avoidance,

- up to about 20 minutes for Separation Management,
- up to 1 hour for Trajectory Management, and
- the whole flight for Flow Management.

Considering safety responsibilities in standard managed airspace within both SESAR and NextGen, Separation Management is performed by ATC, Trajectory Management is represented mainly by negotiation between ATC and airborne crew/systems, while Flow Management typically involves AOC on the user's side. The role of Trajectory Management is to provide strategic deconfliction while Flow Management ensures that complexity and density of the traffic does not exceed safety and capacity limits.

Within the TBO concept, the users' preferences are already considered through the initial process of the trajectory negotiation (the users are in this context represented by airborne crew and/or AOC) before the aircraft enters the SSAS, the updates of the trajectories should essentially be just a dynamic reaction on the time evolution of the situation (weather, traffic congestions, etc.). In this context, we consider that for SSAS purposes, the trajectory and limited flow management (while within SSAS) tasks could be joined into one application. Consequently, through this document the terms flow and trajectory management could be used interchangeably, however, "trajectory management" will be preferred.

There is little or no discussion in the argument that the Separation Management function can be transferred to the airborne ASAS system. However, there can be a controversy when we start to discuss the autonomy of "autonomous aircraft" or the 'freedom' in the "Free Flight" concept, as it is necessary to specify if, where, and how the other ATM tasks, namely Trajectory Management and Flow Management are performed for the operations within SSAS. In other words, the question is what the acceptable level of the ground support is in order to consider the flight to be still "autonomous".

What is the scope of "autonomous flight" within the iFly project?

The interpretation assumed for the A3 ConOps is that during an "autonomous flight" there is no active support from the ground ATC to aid in the ATM tasks. However, it is imaginable that Flow Management can also be performed by the AOC that uses ground datalinks to receive the necessary information from SWIM and communicates the trajectory to the aircraft.

5.1 Proposed SSAS ATM Structure

Based on the discussion presented above, a possible structure of ATM within SSAS is proposed (Figure 9).

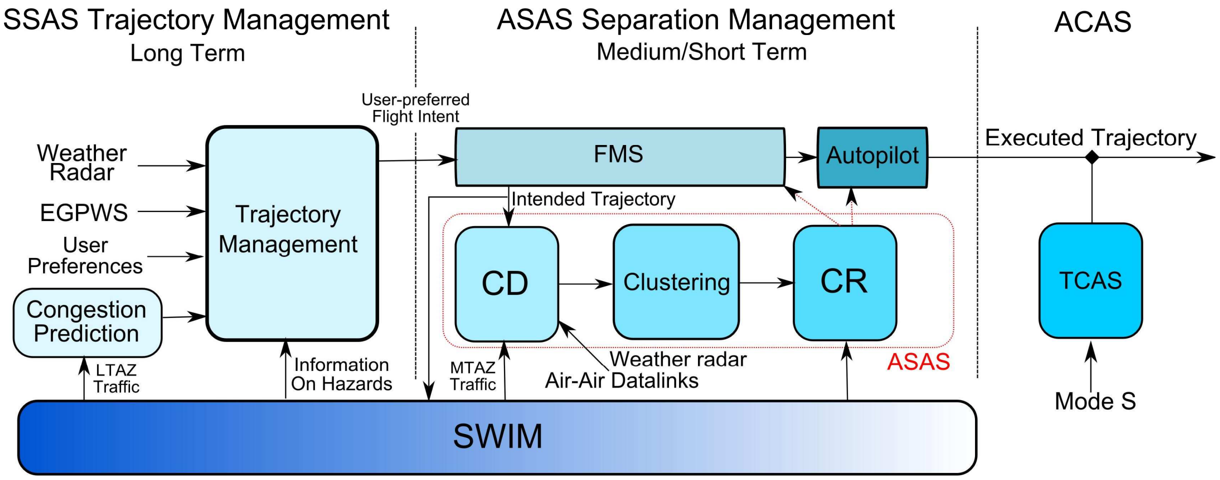

Figure 9: Proposed ATM Structure for SSAS.[3]

The individual components of this system are discussed in detail in the following parts of this document. From the conceptual point of view, there are three major layers of airborne ATM within the proposed structure:

- **SSAS Trajectory Management** – the goal of this subsystem is to generate the optimal path across the SSAS, satisfying the safety and boundary (SSAS/MAS transition) constraints. The key input to this process is the trajectory (for the whole flight) previously negotiated during the standard flow and trajectory management process before the aircraft enters the SSAS. Using updated information about the weather (from SWIM and weather radar) and the hazards in general, the SSAS part of this trajectory could be modified by the user without renegotiation. This task can also cover a prediction of the congested areas based on the known trajectories of all relevant flights (obtained from onboard systems or SWIM). The output of this process can be in the form of an updated flight plan with additional constraints, e.g., the Required Time of Arrival (RTA) at the SSAS exit point. Based on this optimized flight plan the

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[3] The information relevant to Long Term Awareness Zone (LTAZ) and Medium Term Awareness Zone (MTAZ) are provided in the Trajectory Management and Separation Management phases of the ATM process, respectively.

reference trajectory for the guidance system is generated (and also provided to SWIM) by the Flight Management System (FMS). This process is discussed more in detail in Chapter 6.

- **ASAS Separation Management**– this is the process performed by the ASAS self-separation application that considers the actual state and intent information of the own aircraft and the state and intent information of the other aircraft for Conflict Prevention, Detection and Resolution (CPD&R). Depending on the availability of intent information the CD module works in the State–State mode (ASAS S-S), State–Intent (ASAS S-I) mode, Intent–State mode (ASAS I-S) or the Intent-Intent (ASAS I-I) mode. For safety reasons, state only information may be used during the ASAS detection of threats with the time-to-conflict shorter than a threshold (NASA uses 3 minutes for this purpose, so-called “blunder” mode)[4]. Subsequently, the clustering module provides the cluster of aircraft involved in the conflict to the Conflict Resolution (CR) module. Based on this information the optimal CR manoeuvres are generated and executed via FMS or by pilot/autopilot.
- **Airborne Collision Avoidance System (ACAS)** – as the safety backup is based on an independent source of information (Mode S), ACAS will provide CR advisory in the case of failure of the ASAS separation management function.

The first estimation of the relevant timescales is shown in Figure 10. The final values of the time parameters are expected to be determined by the validation process.

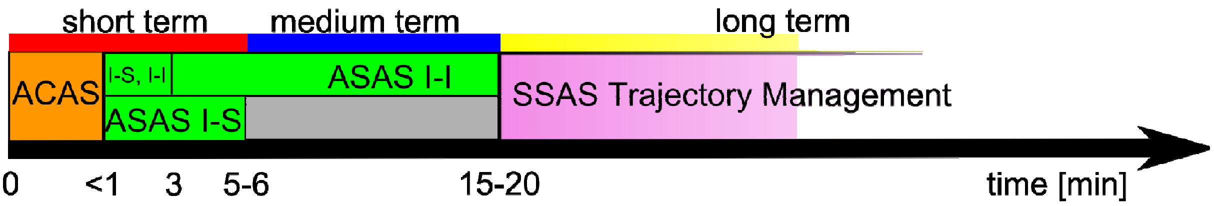

Figure 10: Proposed SSAS Time scales.

5.2 Equipment Requirement

The airborne equipment requirements for the SSAS are tightly connected to the final version of this Concept of Operation. In this context, this section represents just a preliminary estimate. In addition to the details discussed below, the minimum equipment for all tasks should be: FMS, ASAS, ACAS, Cockpit Display of Traffic Information (CDTI), and a Communications Management Unit (CMU) able to communicate with SWIM and other aircraft via datalink (at least ADS-B In/Out). Considering the three layers of the ATM process, the following systems should form the core equipment:

- **Trajectory Management –**current airborne systems are not able to generate the optimal lateral trajectory with respect to different hazard areas. A modern FMS uses the lateral flight plan and an accurate aircraft performance model to create the optimal vertical and speed profile, taking into account various types of route constraints (including altitude, speed and RTA).The inclusion of hazard constraints would require an enhancement of the FMS functionality. Furthermore, an airborne predictor of congested areas would also be required as does the communication equipment able to effectively communicate with SWIM and other aircraft. Considering autonomous airborne surveillance, the presence of a weather radar, Enhanced Ground Proximity Warning System (EGPWS) with altitude radar, and air data sensors are indispensable.
- **Separation Management**–Separation Management would require an ASAS tool-set containing ADS-B, with the ability to send and receive both state and Intent information, CDTI for Situation Awareness (SA), CP, CD, CR and preferably also the use of clustering and complexity modules. Automated flight is also impossible without a FMS and autopilot.
- **ACAS –** ACAS in conjunction with the Mode S transponder will be used as a backup. The essential task in this context is to define a safe interface between the ASAS application and ACAS to ensure smooth switching from Separation Management mode to ACAS mode.

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[4] Not shown in Figure 9.

6 Trajectory Management (TM)

Although the question could be raised why to consider long-term trajectory management within the autonomous aircraft concept, the absence of these functions could considerably reduce the expected benefits of the ASAS concept. In fact, without some longer term adjustment of the trajectories with respect to updated traffic, the need for many tactical manoeuvres could destroy most of the benefits resulting from the trajectory optimization (user-preferred). Furthermore, an optimization of the flight path with respect to the updated weather conditions can considerably reduce resulting flight costs.

The essential question of the iFly concept is the delegation of Trajectory Management.

How and by whom will distributed trajectory management be performed?

There are two basic possibilities:

- **Aircraft** – pure autonomous aircraft concept. There is a substantial drawback if all necessary information must be provided to the aircraft. Also the suitable tools are not currently available on the airborne side (there is only performance-based fuel/timing optimization in the FMS, not optimization of the lateral path).
- **AOC** – AOC already performs this task within the standard flow management process. However, this can already be considered "ground" support.

Another essential question is:

What will be the status of the communicated trajectory within SSAS?

Within trajectory-managed airspace (SESAR) aircraft is responsible to follow the contracted trajectory (3D or 4D) within the specified limits (e.g. RNP). However, this system is based on the compromise where an aircraft agrees to fly less efficiently (obviously flying the contracted trajectory is always less effective than to fly freely using optimum guidance control) but without the necessity of tactical manoeuvres (trajectory is, at least in principle, previously deconflicted).

Depending on the role of FM, the trajectory function could be much more relaxed (maybe even to merely an informative actor) within the SSAS. On the other hand, as the communicated trajectory should be used in CD, it would also be very useful to specify the uncertainty boundary within which it should be executed (3D only or full 4D). There is even the possibility to provide larger boundaries in order to handle the minor tactical manoeuvres without a need to change the broadcasted trajectory intent.

The essential safety requirement is that the trajectory management should not disrupt the ASAS function. Therefore the part of the trajectory considered within the ASAS's CD and CR modules should not be modified by the TM optimization process. For example, if the look-ahead time of 20 minutes is considered by the ASAS function, the TM modifications of the trajectory should affect just the flight more than 20 minutes ahead, otherwise it could interfere with the ASAS actions.

6.1 Long-term Situation Awareness

The function of Trajectory Management requires good medium to long term situation awareness. For that purpose it is recommended to define the **long term awareness zone (LTAZ)**. This part of Self Separation Airspace should be connected to the **medium term awareness zone (MTAZ)**.

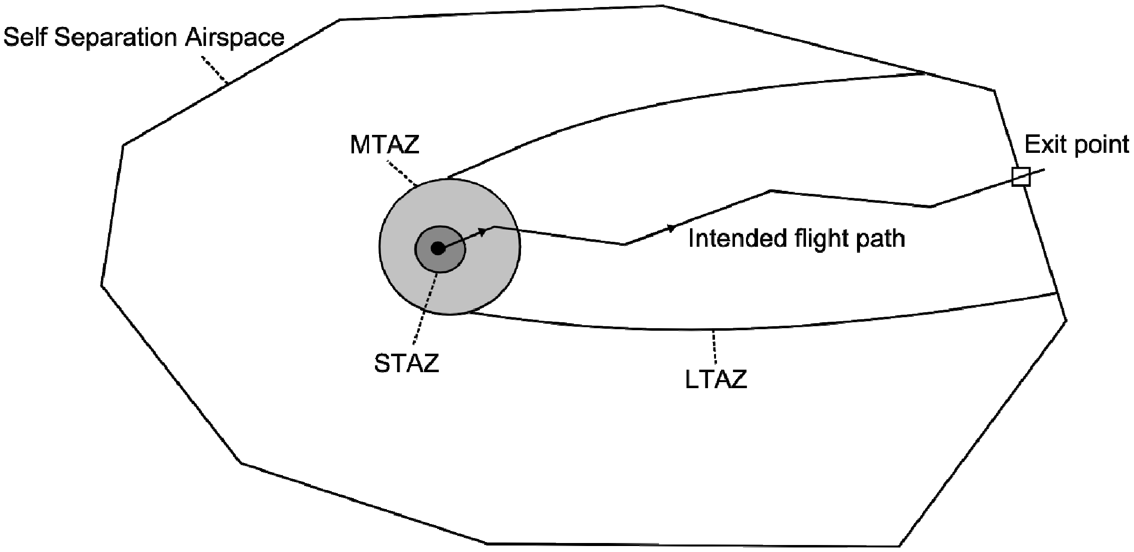

Figure 11: Awareness Zones (Long-Term Awareness Zone (LTAZ), Medium-Term Awareness Zone (MTAZ), and Short-Term Awareness Zone (STAZ)).

The specification of such airspace should fulfil the following requirements:

- Contain the original optimal trajectory of an aircraft from its actual state up to the planned exit point;

- Be spacious enough so that re-planning of the optimal trajectory (by SSAS Trajectory Management) will occur inside this airspace;
- Be small enough so that the aircraft is not overloaded with unnecessary information.

Note that the purpose of this airspace is to delimit the part of airspace for which hazards and other relevant information will be presented.

The relevant information that can not be obtained through onboard systems will be provided by SWIM.

6.2 Traffic Congestion Prediction

Congestion prediction could be a useful function to complement the long term situation awareness in terms of detection (prediction) of congested areas. It can play a role in SSAS trajectory management by preventing the aircraft from entering an area where it would have to manoeuvre too often. It may also play an important role in preventing the conflict resolution algorithms from becoming overloaded, since most of the conflict resolution methods are effective only up to a certain number of aircraft involved. Avoiding conflict situations with too many aircraft is therefore a key element for the success of the free flight concept, otherwise some intervention by a centralized controller would be needed.

Congestion areas prediction is based on the evaluation of traffic complexity (discussed in detail in Section 9) for the entire long term awareness zone. The input of the function should be the intent information of other aircraft. The essential parameter is a complexity threshold value(s) that will be used to make a distinction between congested areas and the surrounding areas, for the purpose of simple computations and display. In order to set the threshold reasonably, the range of the complexity function and the meaning of values the function can take should be known. The output of the function should be a set of polytopes[5] in 4dimensional space (i.e., airspace in time), so that the evolution of such an area can be evaluated in time. Other relevant parameters contain time period and time steps for which complex areas will be computed.

Congestion prediction function for the long term awareness zone should not entirely rely on onboard systems due to limited intent information from distant aircraft. Rather than collecting the intent information from all the traffic and computing the congested areas, it would be more efficient if the complexity function was computed by some ground system. Only the resulting polytopes would be sent to the aircraft to minimize the transmission and storage requirements.

A set of rules is required to define how the information obtained should be used from an operational point of view, since there is interdependency between the traffic intent and the resulting congested and complex areas. If all traffic reacts to such an area by means of an avoidance manoeuvre, the area that was originally predicted as congested/complex will now appear to be clear, which may in turn make all aircraft re-establish their original optimal intent, and the situation may repeat.

This issue should be considered as a motivation for introducing some general rule about avoiding congested/complex areas. For example, a decision regarding congested/complex areas should not be changed once taken and announced to others.

What rules (if any) should be defined for use in complexity prediction?

Due to differences in the prioritization of hazards, different policies and possibly a different implementation of the complexity prediction function, it is not likely that all aircraft would take the same decision regarding a congested/complex area, i.e. either change the path or keep the original intent. Therefore, it may actually pay off for some aircraft to wait until others manoeuvre, and benefit from it. These aspects should be studied carefully before introducing complexity prediction functions and before determining the rules/restrictions for its use.

6.3 Optimal (user-preferred) trajectory generation

A lot of factors are involved in the process of optimizing the (user preferred) trajectory. The performance optimization is currently performed by the FMS (in fact, it was the reason why the FMS was invented) using algorithms that balance the optimization between fuel costs and time. To date there is no actual airborne system for lateral trajectory optimization as this

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[5] In order to avoid misunderstanding, we use the following definition: convex set M is a polytope if there exists a finite set of vectors X such that M is a convex hull of X.

flexibility is not available in the current ATM system (in the current system this is usually taken care of by AOC).

What will be the role of the AOC within the optimal trajectory generation?

Currently, the FMS is not a planning tool and it requires a lateral flight plan and vertical flight constraints as inputs. However, it does have an accurate aircraft performance model; it incorporates wind along the planned trajectory and allows for an effective guidance of the aircraft along the predicted path, while meeting both spatial and time constraints. The FMS is therefore probably best suited for implementation of airborne trajectory management functionality.

What are the changes necessary in current avionic systems (in particular FMS) to ensure Free Flight Trajectory Management?

The generation of a user preferred flight path within the trajectory management function should take into account:

- Weather information both to avoid the hazards and to benefit from the suitable wind conditions,
- Information about the anticipated traffic congestion areas,
- Environmental aspects, which very often coincide with the economical ones.

6.4 Providing the trajectory data to SWIM

There is an ongoing discussion in the ATM community on how best to communicate the information of the intended flight trajectory (intent information) between the ground and the air. The current definition of the intent information that should be transferred via ADS-B is described in the ARINC 702a-3 standard.

What will be the trajectory information (format) communicated with SWIM?

Considering future development there are two essential approaches:

- All information needed by the ground trajectory predictor to predict the intended trajectory is transferred. This approach typically requires some kind of aircraft performance model within the trajectory predictor.

- The FMS generated trajectory is communicated through ADS-B by means of Trajectory Change Points (TCP) and some kind of interpolation is used to obtain the whole flight path.

Analysis performed within the ERASMUS project showed that even a simple interpolation of the FMS-generated trajectory provides a reasonable accuracy for medium-term time horizon. More complex interpolation (e.g., splines) can be used when additional accuracy is required.

Under which conditions must this information be updated in SWIM?

In fact, there is a direct link between this question and the issue of manoeuvrability boundary limits mentioned in Section 4.1. Ideally, the response should be based on the results of relevant validation experiments.

6.5 Airborne Collision Avoidance System (ACAS)

There is a necessity of a well defined interface between the ASAS application and the collision avoidance function in the role of safety backup. There should be a definition of the threshold where the TCAS system takes over the control of the CR advisories.

How the ASAS/TCAS interface should be designed to ensure the continuation of the CR advisories?

Should the CR algorithms be part of the FMS, TCAS or an independent box within the airborne system?

7 Separation Management

7.1 Medium/Short-Term Situation Awareness

A **Medium/Short Term Awareness Zone (MTAZ and STAZ)** needs to be defined with regard to the SA requirements for medium term look-ahead time (5–6 to 15–20 minutes) and short-term look-ahead time (up to 5–6 minutes approximately). This airspace can be regarded as a “sliding window” in time, e.g. the focus moves along the own ship movement.

Will the awareness zone be defined by distance, or by time needed by the aircraft to reach its borders?

The most straightforward way of defining the airspace is by distance, i.e., borders of such airspace will be described by shape and dimensions, which could be the same for all aircraft or individually designed according to aircraft speed. On the other hand the definition of the airspace could also be based on time, i.e. defining the straight-line distance according to aircraft’s current speed. Benefits and drawbacks of those solutions should be carefully assessed.

Noteworthy is the fact that if it is necessary to provide the aircrew with information concerning its MTAZ, it would be necessary to receive intent information from every aircraft approaching from the opposite side.

In more detail: Consider two aircraft, both flying with a speed of 520 kts (which actually is the capability of A380) on opposite tracks; the distance could be 260 NM. To provide the aircrew with enough information to achieve a high level of SA for the suggested period of time, e.g. up to 15 minutes, it is required to receive the information from traffic 30 minutes away. This distance however might be out of ADS-B range. In those cases the usage of some ground service like Traffic Information Service – Broadcast (TIS-B) or satellite infrastructure (e.g., ADS-C) is necessary.

7.2 Conflict detection (CD)

A conflict is defined as a predicted minimum distance within the look ahead time, which is less than the required minimum separation distance. The purpose of a CD algorithm is to detect conflicts, so that appropriate action can be taken. Conflicts can occur between aircraft; however, also interactions with non-traffic hazards (weather, terrain, SUA) need to be considered.

In general, there are two approaches to conflict detection: the first one is based on predicting conflicts as intersections of the trajectory of the relative motion of one aircraft, with the protected zone of the other aircraft. The second approach uses the Alert Zone (AZ) and a conflict is detected when the intruder enters into the AZ.

CD based on trajectory intersections

In a traffic conflict, the CD function uses predicted trajectories of both aircraft to predict a loss of separation with the protected zone. If intent is unavailable, projection of the current state into the future is computed in order to obtain a trajectory for the time period of interest (the so-called state-based approach). However, such trajectory is only usable for short-term (i.e., 5 minutes) prediction period due to low reliability

This basic variant is a deterministic approach, i.e. computing with deterministic trajectories. If there is an intersection of a trajectory, within the look ahead time, with the protected zone, a conflict is detected and the point of first contact, the closest point of approach, together with their times, can be computed. This information can then be used for alerting (e.g., display on CDTI), and conflict resolution.

Although very simple, this method does have some shortcomings in that it does not take into account uncertainty that is inevitably due to wind influence and navigation, surveillance and control errors.

This led to the consideration of stochastic methods that represent the uncertainty by means of random variables with predefined parameters. The prediction of future trajectories is probabilistic and conflicts are detected when the conflict probability is higher than a given threshold. The threshold must be selected carefully to detect serious hazards, while minimizing the amount of false and nuisance alerts. A credible method of determining the threshold for alert is the use of a System Operating Curve (SOC) [Kuchar 1995].

CD based on Alert Zone

The alert zone's boundary is a time-to-conflict boundary. Its shape depends on relative trajectory orientation, rate of closing, and in stochastic cases also on position and trajectory uncertainties.

This method is only suitable for very short term (tactical) conflict detection using the state projection of the other aircraft. Currently it is implemented in the Traffic alerting and Collision Avoidance System (TCAS).

Conflict threat levels

Conflict alerts can be sorted according to their threat level.

a. The lowest threat level is informative, i.e. information about a congested area (see section 7.2) – this is a strategic warning without large requirements for precision.
b. Next level up is the ASAS conflict detection function, which predicts individual conflicts based on trajectory intersections. The time to conflict can be between 1 to 15–20 minutes, dependent on the available intent information.
c. The most imminent threats are detected by penetration of the AZ. TCAS works on such principle. However, it is considered to be more a safety net than a standard CD&R function, and should remain independent of other CD&R systems.

The look-ahead times introduced in this suggestion are based on previous research and on rule of thumb. The most suitable values should be reached through validation in order to provide answers to the following questions:

Up to what look-ahead time should intent-state conflicts be detected?

In case no intent information is available for the other aircraft, up to what look-ahead time is the intent-state conflict detection reliable?

What look-ahead time should be considered for ASAS?

7.3 Clustering

There are two potential applications of the cluster computation within the ASAS self-separation function.

- After a conflict is detected, the cluster of involved aircraft should be determined and provided to the CR module, in order to solve the whole situation at once. This function is missing in the pair wise approach where conflicts are resolved sequentially one by one.
- For tactical resolution manoeuvres it may be of interest to know which of the suggested resolution option will cause least complexity increase in the vicinity of the manoeuvre. Note that by tactical changes of aircraft's path, its own space for manoeuvrability together with the space of manoeuvrability of the neighbouring aircraft may be decreased. This function could be part of the conflict resolution module.

7.4 Conflict Resolution(CR)

With regard to Conflict Resolution the following needs to be addressed:

- Choice of Resolution Manoeuvres,
- Cooperative Strategy:
    - Priority rules
    - Implicit coordination
    - Explicit coordination.
- CR algorithm
- Distributed Decision Making
- Manoeuvre Advisory
- Manoeuvre Execution
- CR process.

7.4.1 Choice of Resolution Manoeuvres

The choice of possible CR manoeuvres can be dependent on the look-ahead time of the CD module. For example, an effective speed-based solution of the conflict typically requires at least medium-term time range (about 10-15 minutes) CD due to the limited size of the aircraft's speed envelope. Furthermore, a flight is typically executed as a sequence of well known flight procedures. Therefore the set of resolution manoeuvres that can be considered could be a subset of these procedures. Alternatively, a manoeuvre can also be defined by specifying a new guidance or trajectory target.

Should the CR manoeuvres be considered separately in the vertical and horizontal planes?

The current ATC-based system basically splits the resolution manoeuvres into vertical, horizontal, and speed changes reflecting the controller's approach to ATM. Within the autonomous operations concept it is possible to preserve this splitting (like in MFF) or to use more complex 3D manoeuvres.

7.4.2 Cooperative Strategy

When aircraft try to solve their conflicts it is necessary to avoid the use of counteracting manoeuvres. One possible solution is represented by priority rules. Priority rules represent a set of rules that determine which aircraft has the 'right of way' and which aircraft is required to manoeuvre. Although it results in a more effective manoeuvre considering the number of necessary actions (in fact, when both aircraft manoeuvre to solve the conflict, very often the individual manoeuvre of any of them is already sufficient to resolve the situation), this approach reduces safety as the success or failure of CR relies just on the action of one aircraft. Therefore it is safer to consider some kind of coordination as there can be more than two aircraft involved in the conflict and it is also not guaranteed that both aircraft detect the conflict at the same time.

Should the priority rules be included in the CR process?

There are two possible types of the coordination:

- **Explicit coordination** via mutual communication,
- **Implicit coordination** by the "rules of the road/flight" or using suitable CR algorithms.

What (if any) will be the roles of the explicit and implicit coordination within CR?

As the explicit coordination requires extra communication between the involved aircraft, it further increases the pilot's workload, it is less robust (possible communication failure), and requires extra time for execution. In this context the implicit coordination is preferred whenever possible. The geometrical CR algorithms (e.g., cross product of speed vectors, some kind of voltage potential) are particularly suitable for implicit coordination.

Within the MFF project a combination of priority rules and implicit coordination (modified voltage CR method) was used to combine the benefits of the two approaches.

7.4.3 CR algorithm

What will be the most suitable CR algorithm(s) for ASAS / Free Flight operations?

A review of existing CR methods is given in the work of J.M. Hoekstra [NLR 2001] and J Kuchar [Kuchar 2000]. For the conflict resolution method three classes of methods were found:

- Geometrical methods
- Genetic Algorithms
- Stochastic methods

Within the NLR projects, the modified voltage potential method, a geometrical algorithm, was used together with priority rules (MFF, Free Flight). On the other hand, NASA Langley uses a genetic algorithm together with manoeuvre patterns in their Autonomous Operations Planner (AOP). A stochastic variant of CR may be very computationally extensive and that is why it may eventually be better to dispense with less reliable deterministic method, possibly defined using three states instead of just two: HAZARD, CAUTION, NO HAZARD.

A more extensive analysis of the available CR methods will be provided within the iFly WP5. In all cases, the selected algorithm should be able to solve the conflict situation of the whole cluster of aircraft en bloc.

7.4.4 Distributed Decision Making

In a previous project dealing with ‘Free Flight concept’, changes to air traffic management style were pointed out [Philip J Smith et al. 1997], explaining the shift from a management by direction, where decision making is assumed by controllers who had the necessary information, to a distributed traffic management and thus of decision making, between ATC (or ATM), crew and AOC’s. Whether it is strategic Decision Making (long term) or Tactical Decision Making (medium/short term, conflict resolution), one of the issues addressed was the need for widely distributed information sharing between system actors.

In the iFly concept, it is assumed that tactical decision making, in the vicinity of a conflicting situation, will be distributed between ‘airborne systems’.

A distributed system [Dilts et al. 199l] is considered as a decentralized collection of autonomous ‘organizations’ that can be logically or physically different to one another, but cooperate with each other to achieve a global goal. The central notion of a distributed system is the pursuit of full local autonomy and the cooperation to achieve a global goal. Referring to this definition, airborne systems are locally and physically different, fully autonomous and each of them with its own goals, but cooperating to achieve a global goal, i.e. conflict resolution.

In this context, airborne systems may be assimilated to a ‘*group*’ of individuals put together to resolve a conflicting situation, but each of them is also trying to achieve its own goal, which might put the individual in conflict with others.

Group decision-making is best defined as a collection of ‘individuals’ having conflicting interests that must be resolved where each decision maker has a unitary interest motivating its decisions i.e. each airborne system has its own trajectory, operational and organisational constrains.

Cooperative ‘social’ decision making was also a studied function of the Decision Maker’s own, and interdependent other party’s gain or loss frame, that is the decision maker’s own representation of their potential outcomes. An own gain frame produced less cognitive activity than an own loss frame and other's loss frame caused more cooperation than other's gain frame only in case of an own gain frame. i.e. cooperative decision making is really effective only in a ‘ win-win’ situation.

In any case, cooperative decision making will require an intensive data exchange between ‘airborne systems’. Based on previous work on the Free Flight concept, Intent and State information was the main new information needed to be shared for efficient conflict resolution and tactical decision-making. In addition, we consider environment and traffic restrictions information as also needed to help the crew in building a sound and safe decision.

Another way to consider ‘co-ordinated’ decision making in conflict resolution may be the **collaborative approach to decision making** where the decision is built collectively from the beginning to the end, without task sharing (as opposed to the cooperative approach described above). In this case, system actors, involved in the conflict situation, need to construct common situation awareness and problem comprehension. Wellens (1993: 272) defined group SA as the sharing of a common perspective between two or more individuals regarding current environmental events, their meaning and projected future.

Data exchange remains one of the main tenets of collaborative decision making, but there is also a need for a common knowledge of the Free Flight system characteristics: operating procedures, rules of priority, terrain/weather or other threats/constraints, etc.

Technology advances, mainly in collaborative work and decision making, can be explored further to confirm the achievability of this approach in conflict resolution. The only question that may arise is the effect of time constraints in a dynamic situation. In other words, a collaborative decision process that would start long ahead before a conflict situation arises would be more thorough and more efficient than a cooperative one. However, a cooperative decision making process probably enables shorter times between the identification of a conflict situation and its resolution (the decision might be of a poorer quality). Thus, the choice between these two approaches of decision making is not just a matter of which leads to the best decision, but a matter of trade-off between the quality of the decision and the time constrains of the situation.

Information sharing aids and automated decision support tools need to assure that all factors are taken into account in the Decision Making process.

7.4.5 Manoeuvre Advisory

It is assumed that all CR manoeuvres that generate new conflict(s) within the look-ahead time are inherently rejected by the CR algorithm. In this context only conflict-free solutions are discussed.

How many CR advisories should be provided to the pilot?

While there are usually more CR manoeuvres that solve the conflict, for execution it is favourable to find the solution that best fits the actual situation. Within the MFF program, it was left up to the pilot to choose between two presented alternatives: vertical or horizontal manoeuvres.

Should the assessment of the CR advisories be a part of the CR process?

Another possibility is that the system chooses the optimum solution (or at least align the available solutions) based on some set of predefined criteria. One of them could be the requirement that the CR manoeuvre should not increase the traffic complexity. In this context an interesting approach is used by NASA in the AOP work where the future manoeuvrability of the aircraft is used for the assessment of the potential solutions.

Which criteria should be considered in the CR manoeuvres evaluation?

7.4.6 Manoeuvre Execution

Besides manual control there are two alternatives on how to perform CR manoeuvres using the automated aircraft control:

- Using the FMS (eventually Mode Control Display Unit (MCDU) as a Human Machine Interface (HMI)), i.e., specifying the additional target within the current flight plan,
- Using the autopilot (through Flight Mode Panel (FMP)), i.e., setting up the new guidance target (heading, altitude, …)

Under which conditions should the CR manoeuvre be performed by the FMS and when manually (or by autopilot)?

Within the ASAS related literature these two possibilities are in general referred to as state-based and intent-based CR (INTENT project, MFF). Very often these variants are linked to the availability of the intent information to the CD module, although there is not a direct relation . In fact, both state and intent based CR can be used independently. It is always possible to either change the track angle directly on the FMP or rather to specify suitable additional waypoint via the MCDU. The FMS based solution is in general preferred as it corresponds to an optimized execution of the manoeuvre and the FMS automatically considers the needed speed changes to meet the applicable time constraints (e.g., in the SSAS exit point). A small drawback of this choice is some delay (typically several seconds) in manoeuvre execution (the autopilot mode may be used when this latency could cause some problems). Any change of intent will have to be communicated to other users and to SWIM.

The solution of the conflict by changing speed can be performed by manual changes of the thrust, or by inserting a suitable RTA in the flight plan managed by the FMS.

7.4.7 CR Process

The model CR process should contain the following steps:

1. CD module detects a possible conflict,
2. The cluster of the aircraft that are involved in the conflicting situation is determined,
3. Priority rules (if applicable) are analyzed for involved aircraft,
4. The possible CR manoeuvres are generated to resolve the cluster as a whole,
5. The manoeuvres are ranked according to the preferences (optional),
6. Several (or only the best one) manoeuvres are presented to pilot,

7. The selected manoeuvre is executed by the suitable mode (FMS, autopilot, or manual).

8 Situation Awareness (SA)

8.1 Situation awareness: basic concept

To assist the aircrew in achieving a high level of situation awareness is a major topic within the Free Flight concept. Due to the fact that many definitions based on different approaches have been developed the main question arises:

Which concept of Situation Awareness meets the demands of iFly?

It is recommended to base the iFly concept on Endsleys' (1988) "Three-Level Theory" approach.

In contrast to other approaches the 3-Level theory focuses more on the cognitive (e.g. perception, memory, knowledge…) than on environmental aspects, or on the question of how specific information is processed. Together with the associated underlying analysis, e.g. Goal Directed Task analysis (GDTA), types of data that might be sought from individuals when achieving situational awareness can be detected easily. Endsley developed an extensive and detailed list of Situation Awareness Information Requirements for En Route Air Traffic Control [Endsley, 1994]. If one considers the fact that pilots take over some of the controller's tasks this approach seems to be even more appropriate and helpful to understand the aircrews' needs in the Free Flight environment.

Based on this theory Endsley describes situation awareness as: "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and projection of their status in the near future", which serves as basis for timely and effective decision making."

SA and its key elements in iFly: working descriptions

Due to the fact that it is hard to achieve total SA, it is important to identify key elements which are related to pilots monitoring activity during en-route flight [Uhlarik and Comeford 2002], which in turn forms the basis for appropriate conflict detection and resolution in time.

What are the key elements of Situation Awareness in iFly?

Four key elements were identified to play a major role within the iFly environment. The following paragraphs outline the key components together with the corresponding working definition/description:

Environment awareness

Having knowledge of weather formation (area and altitudes affected and movement; temperature; icing; clouds, ceiling; visibility; IFR vs. VFR conditions; areas and altitudes to avoid; flight safety; projected weather conditions); fuel; flight area; alternates.

Achieving a high level of Environmental awareness forms the basis for strategic planning as well as for tactical decision making. The therefore required information concerning weather (current as well as forecast) should be integrated in existing displays.

Navigation awareness

Having knowledge of the location of one's own aircraft, other aircraft, terrain features, airports, cities, waypoints and navigation fixes; position relative to designated features; runway and taxiway assignments; path to desired locations; climb and descent points; congested areas.

Navigation awareness will become more important due to the fact the ATC will no longer work as a backup system. Strategic planning (on ground or in flight) as well as tactical decision making will mainly rely on aircrews' knowledge regarding the above mentioned sub elements including the information provided by supporting tools.

Mode awareness

Having the knowledge and information, which is necessary to know about the status-quo/mode of automation, the configuration, the current sub processes and their future behaviour. As automation becomes more important in aviation, mode awareness is closely linked.

The aircrew will be supported not only by automated tools calculating optimal trajectories (including more intervening variables in the computations than now implemented) but also by automated conflict detection/resolution tools. Concerning the automated steps it will be necessary to keep the aircrew in the loop by providing as much information as the pilot needs to act as at least a backup in case of a system failure. It is not yet clear to which extent SA may suffer under all forms of automation. Endsley stated that pilots who have lost SA due to being out-of-the-loop may slower detect changes and problems, which would lead to extra time in gathering relevant system parameters to proceed with problem diagnosis and further on manual performance in case of an automation failure. This sounds reasonable when one considers the following factors that result from the "being out-of-the-loop" – stage: loss of vigilance, receiving information passively instead of actively processing information and loss of or changes in feedback concerning state of the system [Endsley & Kirsis, 1995].

Traffic awareness

Having the knowledge and information which is necessary to obtain, maintain and regain self-separation in the Free Flight environment under normal or non-normal conditions, where successful self-separation is defined as keeping own ship separated from other aircraft by legal separation minima (see 4.2.3).

To achieve a high level of traffic awareness is a new responsibility for the aircrew. To accomplish this goal they need to be supported by appropriate tools. The main focus here will lie in the development of a Cockpit Display of Traffic Information (CDTI), which provides particular necessary information for each situation which will form the basis for accurate decision making in time.

8.2 Splitting of the SA Airspace of Interest

According to the proposed structure of the SSAS ATM there are different forms of SA:

- SA for Trajectory Management (long-term),
- SA for Separation Management (medium/short-term).

The relevant information can be classified according to the spatial allocation of the appropriate hazards (traffic, weather, …) to the corresponding spatial zones shown schematically in Figure 11 in page 38.

8.3 Human Machine Interface (HMI)

To enable the Free Flight Airborne Cognitive System (capable to make dynamic decisions that keeps the aircraft in a safe proximity to other aircraft) it will be necessary to provide the aircrew with sufficient information at the right time.

The main goal is the development of a comprehensive feature set based upon the information needs of the tasks identified in previous work, and incorporating features of human-machine interfaces developed in previous projects that have been favourably rated by the flight crews.

Which information has to be provided to the aircrew to enable high level of Situation Awareness in iFly?

Weather information

To enable the aircrew to make strategic changes to their predetermined flight trajectories during en-route phase of flight as a result of weather it is necessary to provide accurate information. This could for example include information about Area affected, Altitudes affected, Conditions (snow, icing, hail, rain, turbulence), Temperatures, etc. But most importantly this information has to be presented in its further evolution, to allow accurate decision making. To display this information will be the most difficult task. Severity or even different conditions could be colour coded, or severity might be coded by numbers. Areas affected could be displayed as polyhedrons – whereby a mix-up with displayed congested areas must be avoided if depicted on the same display.

This decision making process could be supported by a tool which helps to find the optimal route according to prioritization.

If weather information is included into conflict resolution algorithms, can we assume that every aircraft has the same information about the weather? Is it necessary to provide additional information by means of text?

Terrain

The necessity to display terrain information during en-route Free Flight will be dependant on the definition of the Self Separation Airspace. Assuming that the SSAS will be located in high altitudes, bounded by transition layers, where ATC will regain responsibility for separation and safe guidance in emergency, it will not implicitly be necessary to provide the aircrew with terrain information on a display. But if so it could be realized in the style of new GPS systems including high-resolution terrain database, e.g. Integrated Navigation (INAV) as a part of the Primus EPIC Integrated Avionics System; Enhanced Ground Proximity Warning System (EGPWS), which is a terrain and proximity warning tool supporting the aircrew identifying terrain as a hazard.

Conflict Detection

If a conflict is detected by the conflict detection algorithm it is important to catch aircrews' attention. It might be necessary to depict the aircraft involved and the time left to loss of separation. Alternatives for visual and aural alerts have to be studied.

Conflict Prevention (CP)

Conflict Prevention tools should help the pilot in the decision making process. The system predicts which manoeuvres will lead to a conflict before these manoeuvres are executed. Several studies have shown the usability of such a system in the form of “no-go” bands on speed, heading and vertical speed tape. Other implementations include FMS integrated prevention systems that poll for conflicts on the modified route. Stated improvement suggestions should be integrated in the design process.

Traffic Information

The information which will be displayed on a CDTI should be clear, well organised, easy to understand, should not allow space for interpretation, symbolism must be explicit, head down time should be kept at a minimum, multiple display ranges and filter methods should be considered, etc. Visual and aural coding techniques should assist the aircrew in maintaining high level of traffic awareness.

It has to be made sure that all the solution advisories and possible alerts do not conflict with each other and do not lead to a confusing situation for the aircrew.

Congested areas

It will be important to clearly distinguish congested areas from for example weather information in the kind of representation on the display. It is recommended to apply colour coding to differentiate between several levels of severity. Polygons could be used as a symbol to depict such areas.

Additional Requirements

- Changes in the transmitted information of other aircraft need a clear presentation.
- Rules have to be defined regarding priority for resolution advisories.
- It needs be examined if it is useful to display information horizontally as well as vertically.

What are the recommended design guidelines for the development of iFly supporting tools ?

Concerning the design of supporting tools and its HMI it is recommended to follow the guidelines as stated in the ICAO circular 249-AN/149:

- The human must be in command
- To command effectively, the human must be involved
- To be involved, the human must be informed
- Functions must be automated only if there is a good reason for doing so
- The human must be able to monitor the automated system
- Automated systems must, therefore, be predictable
- Automated systems must be able to monitor the human operator
- Each element of the system must have knowledge of the other’s intent
- Automation must be designed to be simple to learn and operate

8.4 Information Required

8.4.1 Intent

By intent information is meant the predicted path of an aircraft (other that purely state information) for some look-ahead time. There are several ways to format the data, but it should be easy for any system receiving such information to interpolation between points and to reconstruct the 4D trajectory efficiently. It is not desirable to simulate the flight of other aircraft on-board, even though the prediction accuracy will be improved by providing aircraft type, actual weight and flight control settings.

The intent information can be communicated by means of Trajectory Change Points (TCP). These points are those points at which the trajectory changes some of its characteristics.

Whatever method is used, emphasis should be put on the simplicity of constructing the trajectory. Wind influence should be incorporated in the intent, so that the receiving aircraft does not have to speculate about it, even if it had accurate meteorological information for the other aircraft position.

Another important piece of information regarding intent is the conformance boundary of the intent trajectory. All aircraft should automatically monitor the surrounding traffic and compare their actual state with the available intent information. In case that some aircraft violates the conformance envelope of its planned path, an alert should be issued and this particular aircraft should be attended to. The tolerance of the allowable deviation should be specified.

8.4.2 State

By state information it is meant the basic set of data provided by an ADS-B Out state vector message. It should serve as a backup in case intent information is unavailable, or in case aircraft do not conform to their intent. It should also give the crew information about the other traffic existence so that the crew may ask SWIM for intent information specifically for this traffic.

8.4.3 Hazards

There can be many other types of hazards, obstacles and necessary information that should be processed by the underlying algorithms/functions:

- Special use airspace (possibly with activation or de-activation times, if applicable)
- Weather phenomena (thunderstorms, icing, clear air turbulence)
- Volcanic ash
- Congested areas
- Terrain

- Wake vortex
- Self Separation Airspace borders with the transition zone and possibly with the waypoints for entry/exit

Many of them are natural phenomena whose behaviour is complex and stochastic by nature. However, for the purpose of communicating, displaying and avoiding it is desirable to discretize them so that the result can be presented in form of 3D or 4D polyhedron, or a set of polyhedrons of different kinds and different levels of severity. The discretization and classification of severity should in most of the cases be performed by the sender's automated ground centre.

The exception is wake vortex that could be predicted or detected by on board functions, which require state information as well as input for wind speed, temperature and other aircraft's:

- Gross weight
- Wing span
- Turbulence

Besides hazards, common meteorological information should also be provided to the crew. It may be of interest as to why e.g. the suggested optimal trajectory is not straight, and the answer may lie in the presence of favourable tail winds.

8.5 Non-Traffic Situation Awareness

The awareness issues addressed below have been identified through a systematic analysis within iFly D2.1. Most awareness aspects already play a key role in current operation.

8.5.1 Aviation

Avionic Technology Awareness

Because there will be more reliance on the aircraft's avionics (in particular) and other equipment in general (e.g., engines, air conditioning, pressurization) iFly flight crews will need a high situation awareness of the status of the relevant technologies relative to the safe and efficient operation of the aircraft in its current environment. Therefore, iFly operations will require that the flight crew be provided with the information relevant to the development of that understanding. The awareness must be at a level that will allow the crew to know not just that the equipment is operating, but also the degree of operation (e.g., the kind and magnitude of potential failures or errors it could make).

Fuel Awareness

With the volatile and high price of fuel steadily becoming a larger fraction of the operations cost for any aircraft owner and operator, the iFly systems will need to make the flight crew aware of other information, like weather and/or traffic that is important for the crew to make an optimal fuel usage decision.

Overall Financial Awareness

The vast majority of the iFly aircraft flying will be done to either directly make a profit on each passenger carried (e.g., an airline) or indirectly reduce some other cost (e.g., a corporate jet that allows as executive to have more effective use of their time). As a result, professional pilots are being tasked with the responsibility to meet defined financial goals established by their employer. While the fuel cost issue has already been addressed the flight crew may have the responsibility to bring a flight in at, or under, some overall cost. For example, the most efficient fuel cost may be completely wiped out by the cost of rerouting passengers or the cost of per diem for those who complete miss their connections. Therefore an effective iFly system will need to support the financial requirements of its users. This does not necessarily mean support each individual aircraft’s needs all the time, but rather that the overall costs are held low, and so that one segment of the airspace users’ is not systematically always the least efficient.

Environmental awareness

As environmental issues gain more and more scientific, political and popular support, the flight crew will have the responsibility to make sure their operation conforms overall particulate emissions, with geographically based limits (e.g., sound limits may be more strict over a densely populated area than a lightly populated area) and temporal limits (e.g., particulate emissions limits may be more stringent during temperature inversions than in other metrological conditions).

Temporal Awareness

In an iFly environment pilots will have the responsibility to meet posted temporal restrictions, e.g., RTAs. The flight crew will need to be aware not only of the RTA but also the probability (not just the mathematical probability) of meeting the RTA, as well as a sense of the major variables that are involved and their relative impact on the overall requirement. iFly will need to provide effective 4D navigation performance required of the aircraft, as well as clear and intuitive 4D comprehension on the part of the flight crew.

Weather Awareness – current and forecast

iFly will need to support the ability of the flight crew to establish and maintain the necessary level meteorological awareness so they can effectively use meteorological information (both current and forecast) to meet their system level objectives. For example, selecting the side of a front that provides a tail wind to either make up lost time or burn less fuel could positively impact the overall performance of a flight. Being able to set the aircraft up for such a manoeuvre an hour ahead of time may even further enhance overall performance. In addition, using this type of knowledge to reduce turbulence could also enhance the reputation of the airline in the eyes of customers in terms of more comfortable flight with less time spent strapped in a seat. In airline type operations this would very probably involve the airline's operational centres.

Structural Awareness

The functional life of the different physical components can vary significantly as a function of operational environment to which they are exposed. For example, every minute an engine is run at maximum thrust may cause the same wear as the engine would experience when being run at 85 % for five minutes. Likewise, airframe fatigue may be 10% higher during moderate turbulence than during flight in calm air. In addition, there are interactions between the variables, e.g., the impact of turbulence on airframe life will vary with current gross weight and/or airspeed. Again, the ideal awareness for the flight crew would be not only be a recognition of the change in lifetime but again how one can modulate the different variables to obtain a mission specific optimal outcome. What is the maximum freight it can haul in this condition versus the temporal limits e.g., how will it impact length of the times between certain structural inspections.

Geographic Awareness – current and future

The flight crew will have greater responsibility for using geographical information. The selection of a route or a deviation could be impacted by the type of terrain flown over. For example, in certain types of operation that may be a requirement to be able to glide clear of certain area (e.g., large body of water or mountains). Having foreknowledge of these issues during a deviation could allow for a safer trip and a more efficient use of their resources. For example, the most time efficient path over the undesirable terrain could be selected.

Awareness of emergency or diversion airport(s)

There are a number of reasons that could require a diversion to a non-planned airport, e.g., equipment problems, passenger or crew health, severe weather or geographical conditions (e.g., ash from a volcano). The crew will need the ability to quickly and accurately select the most appropriate diversion airport within the constraints of the mission, aircraft, personnel on board, and the phenomenon causing the diversion can be critical.

Passenger Awareness

The flight and the cabin crew will need to understand any special needs of their passengers as function of where they are in their mission and all relevant exogenous conditions.

Flight area Awareness (e.g., airspeed, noise, weather conditions)

Because legal requirements of a particular piece of airspace will vary as a function of time, e.g., noise requirements at night and pollution requirements as a function of weather conditions) the flight crews will have more responsibility to meet those requirements without the assistance of ATC.

Circadian Desynchronosis Awareness

It is a well-known fact that changing time zones by flying to the east or to the west will cause desynchronization of the circadian cycles (of biological and psychological functions) of the flyers, which affects their physiological and cognitive capabilities and needs time for resynchronization and full restoration of working capacity to occur. The flight and cabin crew will have an awareness of their circadian state so as to understand and control any circadian desynchronosis induced by deviations from the original planned mission.

Sense and avoid awareness in IMC

Current aviation regulations defining the "safe avoidance of other aircraft" assume either VMC or ATC. In iFly operations it will be necessary for the flight crew to operate using sense and avoid in the cockpit when the aircraft is operating under Autonomous Flight Rules (AFR) rules in IMC. The flight crew will have the responsibility to know how to effectively use the sense and avoid technology within the operational criteria for the flight to create and maintain their awareness of other airborne traffic in their vicinity.

8.5.2 Airlines[6]

Pre-Awareness of next mission

Flight crews often have very short turnaround times on their connecting flights. Crews often have only 45 minutes between flights (have you noticed that the flight crew are often off the airplane before you are?). There is general concern that the flight crews sometimes do not have adequate time to develop a good mental model of the next mission that includes desirable outcomes and potential mission changes. As a result, there is a critical need for technology to assist the iFly flight crew to quickly obtain 1) a correct mental model and 2) the goals of the next mission segments and 3) to provide

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[6] The airline specific issues were generated with the assistance of a retired Delta Airlines dispatcher who the author has known for many years. He remains professionally active as a dispatch consultant and as a leader in the dispatcher's international professional organization.

the flight crew “cognitive support” in the iFly decision making process through out the mission.

Freight Awareness (e.g., military weapons, export controlled items) into airspace were it is not allowed

Airlines carry freight beyond the passengers’ baggage and flight crews will be responsible for navigation around traffic and weather. Therefore the flight crews on missions will need to not only have an awareness of what freight they are carrying but also how it might potentially impact mission decisions that might involve diversions into the “wrong” airspace.

8.5.3 Unmanned Aerial Systems

While the basic SA needs for the UAS operator will be the same as airline flight crew they will be modified along several dimensions, which seem to imply major challenges [iFly D2.1] The most obvious is the remote operation, which creates a slightly less intense psychological state knowing that you are not in the blunt end of the aircraft. Thus, while you may be embarrassed, you will probably not be physically hurt! Second, busy airspace remote operation may induce an ATCo-like worldview in the UAS pilot, again mentally pulling that operator out of the individual UAS cognitive workspace.

Awareness of State of Data Link

The UAS operator must maintain an awareness of the data link. When flying in crowded airspace the consequences of either a degraded control or complete loss of control will increase and thus the necessary awareness of the UAS operator. When the UAS operator is the sole operator of multiple UASs (which is predicted) the UAS operator will be responsible to be continuously aware of state of the data link to/from each UAS under his/her control.

Sense and Avoid Awareness

While sense and avoid is becoming more available on traditional aircraft (e.g., TCAS, ADS-B) and has proven itself to be very useful, using it as the sole means of being maintain awareness when operating multiple UASs may significantly increase workload and thus potentially negatively impact overall situation awareness when mental rotations and/or translations are required. In UASs in particular the data will need to be presented in a way that meets normal human capabilities for 3D orientation so that the crew can quickly switch from one UAS to another and instantly and intuitively gain the awareness of the UAS being directly controlled.

Awareness of Each UAS Being Controlled

The higher the number of UASs being controlled (and there will be more than one) by one ground operator, the higher level of workload will grow, along with the normal degradation of operator performance when workload levels surpass optimum.

Awareness of Personal Circadian Desynchronosis

Circadian desynchronosis may be a more significant issue for operations crews of UASs that are used to haul freight (which is usually done at night). Currently freight pilots tend to have much higher rate of addictions and other physiological conditions than do other commercial pilots. Combine this with the less “exciting” world of remotely controlling aircraft when the operators are in desynchronosis and the design challenge to keep the UAS operator sufficiently aware of each UAS to effectively and safely control it. There is significant data on problems associated with traditional ATCos operating under desynchronosis, which could most probably be applicable to UAS operators. In addition, there is a large amount of data currently available for the air crews that flight only at night carrying freight.

Awareness of freight

Dispatchers have noted that flying controlled materials (e.g., military weapons, export controlled items) into airspace where it is not allowed is becoming a bigger and bigger issue around the world on all types of aircraft. Again, it is probably related to a possible emergency landing or a diversion into an area where such cargo is not allowed to be shipped. When the flight crew has more than one aircraft to attend to, the crew needs to not only know what freight each UAS is carrying but also have a high enough level of awareness of that fact to be able to understand how it might impact future mission decisions for each UAS, e.g., an emergency diversion into “the wrong kind of airspace.”

8.6 Flight rules

- Special item to ICAO flight plan about Free Flight (FF) capability.

  Operators of FF approved aircraft shall indicate the approval status by inserting the letter “x” in Item 10 of the ICAO flight plan form, regardless of the requested flight level.
- Additional communications requirements.

  FF crew is able to communicate other aircraft, regional ATCo and AOC via data link or similar means.
- Additional requirements for separation of aircraft.

  FF separation minima for different FF conditions have to be established and the responsibility of the crew for keeping the separations has to be stated.
- New phraseology.

  New phraseology should be introduced about
  - (a) FF capability
  - (b) FF separation manoeuvres
- Step-wise implementation of the FF procedures.
- Every FF regulatory activity should follow the principle of gradual development in order to guarantee a safe and controllable integration of FF in the airspace.

8.7 Responsibility distribution

8.7.1 Air crew role

- Separation responsibility.

  FF air crew has the responsibility for maintaining separation.
- Monitoring of communication channel (frequency changes? Via data link?)

  Less frequency changes, in the best case these will be automated.
- Position reports.

FF crew reports AOC about the situation on board (for safety, security reasons)

9 Complexity Prediction

Complexity prediction is not simply detecting clusters of potentially conflicting aircraft and counting them, because the number of aircraft itself does not say much about whether the situation is really problematic or not. There are other factors, such as headings and speeds that contribute to the resulting nature of the traffic. However, there is no strict definition of air traffic complexity, and various aspects can be described and understood by this term, according to the specific purpose it should serve.

How can air traffic complexity for airborne self separation be defined?

Although complexity prediction is a well established topic in air traffic management research, it mainly aims at reducing controllers' workload by which the capacity is mainly limited in controlled airspace. A well known concept for this purpose is called dynamic density [Masalonis et al. 2003], which is based on summation of various metrics weighted according to their influence. But majority of metrics used in dynamic density is not applicable to free flight scenario.

The main difficulty is that "complexity" is in fact a subjective notion. It is tightly connected to the way that the situation is interpreted and/or resolved. In this context, the existing complexity metrics typically reflect the level of the controller's workload, especially its capability to detect, interpret, and solve dangerous situations. However, the autonomous aircraft concept based on a decentralized approach requires considerably different assessment of the complexity. In particular, complexity is determined in this case by the capabilities and methods to detect, interpret and resolve a situation of the CD and CR applications.

It brings a second important issue that there are effectively three different applications of the complexity notion within the proposed ATM scheme, each of them having different requirements on considered metrics:

- **Congestion prediction** (long-term) is based on the intended trajectories (Reference Business Trajectories in the SESAR terminology) stored in SWIM. It has typically two main goals:
    - Prevent an overloading of the ASAS self-separation application,

    - Optimize the plan path by avoiding needs of many tactical manoeuvres during Separation Management phase.
- **Clustering** (medium/short term) – is a function tightly related to the CD and CR modules. It aims to determine the group of aircraft that are involved in the detected conflict situation (it does not mean necessarily that all are in conflict). This information is provided to CR algorithm that looks for the conflict-free solution with respect to the whole cluster. This function is usually missing for pair wise CR algorithms where just a conflict between two aircraft is resolved at once.
- **Complexity prediction** (medium/short term) is closely connected to the CR application (in fact, it is not shown in Figure 9 as it is considered to be part of the CR module). It should form a part of the CR advisory generation process by assessing how the generated manoeuvres contribute to the complexity of the new traffic situation.

Some of the latest research efforts search for so-called intrinsic complexity, such as Kolmogorov entropy [Delahaye 2000] and Lyapunov exponents' computation [Puechmorel 2007], but the research is not mature yet and more work in this area is needed, including vast testing and comprehension. The main drawback of this approach is a lack of the application-related specificity discussed above.

10 Operational Hazards

Which methodology can be used for identification of hazards?

The identification of high-level hazards is the first phase of the Operational Hazard Assessment (OHA). OHA is a part of the ED-78A process, in particular of the Operational Safety Assessment (OSA) which itself is a part of the Coordinated Requirements Determination. The latter includes an OHA and an Allocation of Safety Objectives and Requirements (ASOR). The inputs to the OSA are derived from the Operational Services and Environment Definition (OSED). The OHA is a qualitative assessment of the operational hazards associated with OSED. The ED78A guideline has been assessed by the Safety Regulation Commission as Acceptable Means of Compliance (AMC) with Eurocontrol Safety Regulatory Requirements (ESARR4).

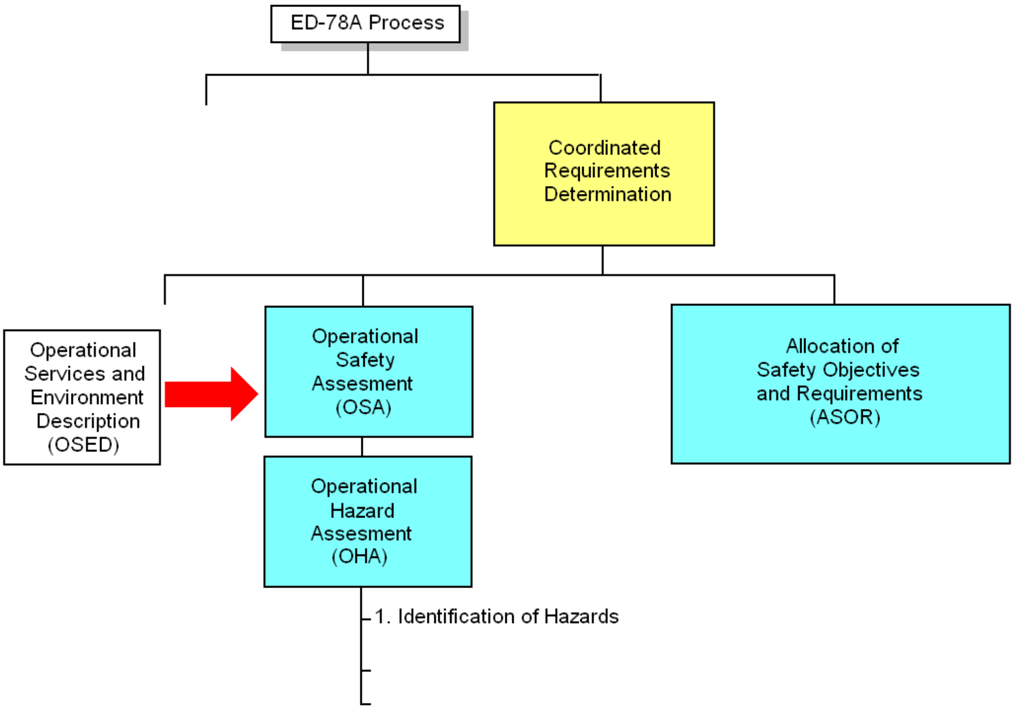

Figure 12: Methodology for identification of hazards

Which inputs are necessary?

There is a main standard input to OHA (by ED78A): OSED. So it is necessary to assume that the next work for OHA will comply with the requirement and a current inventory of hazards is preliminary and not exhaustive.

Which structure of hazards can be used?

At this stage, hazards will be expressed. These categories are not disjoint (there are several points of view and a one hazard event can belong to more hazard categories). The considered hazards categories are:

a) Weather hazards
b) Traffic hazards
c) Aircraft internal hazards
d) Land hazards
e) Human factors hazards
f) Data hazards
g) Implementation hazards

Which hazards should be considered?

The hereafter list of hazards (the hazard categories) is compiled from iFly related projects and deduced by brainstorming activity.

a) Weather hazards

- Clear-Air-Turbulence
- *Wake vortices*
- Aircraft icing
- Thunderstorms
- Other meteorological hazards for which well-tried warning mechanisms already exist (Volcanic ash)

b) Traffic hazards

- Congested Airspace
- *Wake vortices*
- Interfaces hazards (interface between MAS and UAS)
    i) There are not fulfilled requirements (for example ETA) for a transition from UAS to MAS

ii) Responsibility from a ground to an airborne (or vice versa) is handed over insufficiently exactly or by a confusing way

- Civil-military coordination
- Special use airspaces
- Insufficiently equipped aircraft in UAS
- Aircraft with an unpredictable behaviour and/or not communicating in UAS

c) Aircraft internal hazards

- Planning (an incorrect flight plan)
- Incorrect or inaccurate configuration
- Aircraft systems fail
- Incorrect or inaccurate instruction implementation
- Vertical crossing
- Penetration of a hull
- Cabin decompression
- Constraints (for example flight envelope) are not taken into consideration
- Situation awareness and Conflict prevention phase
  - Aircraft makes (or aircrew decides to make) a manoeuvre that leads to conflict
- Conflict detection phase
  - Aircrew is not alerted or misinterprets alert
- Priority determination phase
  - Incorrect or loss of priority determination
  - Inconsistent priority indication
  - Misinterpretation of priority
- Conflict resolution phase
  - Loss of resolution
  - Delay of resolution
  - Incorrect resolution (conflict is not solved or other conflict is induced)
  - TCAS alert is inconsistent with other information (ASAS information)

d) Land hazards

- Terrain
- Obstacles

e) Human factors hazards

A responsible person detects an illusory problem or does not find out a real problem or there is a delay in reception.

- Information congestion
- Non-distinction between an important information and/or event and a non-important one

f) Data hazards

- Data availability is corrupted
- Data integrity is corrupted
- Data authentication is corrupted
- Data confidentiality is corrupted (i.e. wrong data confidentiality is shown)

g) Implementation hazards

- Interdependencies (undesirable interactions) between new applications
- Interdependencies (undesirable interactions) between new and old applications (especially TCAS)

Which hazards probably may not impact the iFly operations?

Let us remark that some hazards may not impact the iFly operations and their analysis should not be in the scope of iFly. Now, it is possible to expect a set of these hazards only:

- Aircraft icing
- Penetration of a hull
- Cabin decompression
- Obstacles
- Data confidentiality is corrupted

11 Involved Technologies

11.1 On-board technologies

11.1.1 Existing Equipment

FMS

FMS is a core airborne system that plays an essential role in our concept. Its key functionalities include:

- FMS controls/allows the tuning of all the appropriate aircraft receivers via the communication control units.
- Accurate lateral and vertical navigation. All modern FMS are certified for the RNAV/RNP capability allowing an accurate and reliable navigation independently on the airways and navigation aids structure.
- Performance based optimization of the flight (via cost index scheme). Based on the inserted lateral flight plan with the required vertical constraints, FMS generates the optimized vertical and speed profiles taking into account the balance between the fuel effectiveness and the time constraints. For these purposes FMS contains highly accurate aircraft performance model.
- Accurate guidance along the generated trajectory.
- Accomplishing of the time constraints (RTA) at the specified point(s).

The current FMS functionality may be sufficient for providing the own intent information to the CD module. It can also be used to execute a CR manoeuvre and to resume the specified flight path.

TCAS

TCAS (actually version II) is a standalone application that works as a backup to the ATC separation management to prevent air-to-air collisions. Within the SSAS it should play a similar role. It is based on the information from the Mode S transponder. The typical time scale when TCAS provides advisories to the flight crew is about 40 s up to 1 minute to the conflict. The TCAS display modes are often considered as the starting point for the CDTI design.

Weather Radar

Weather radar has been used in the avionics for about 40 years. It uses radar signals, which may be reflected from clouds or terrain. Modern weather radars also use Doppler processing to detect turbulence and wind shears. Considering the typical ranges, e.g., Honeywell RDR-4B weather radar has following modes:

- Up to 320 NM for weather and map,
- Up to 40 NM for turbulence,
- Up to 5 NM for wind shears detection.

Enhanced Ground Proximity Warning System (EGPWS)

EGPWS is the application intended to avoid flight into terrain. It may use radar altimeter, worldwide terrain database together with navigational information. The actual aircraft intent is compared with the terrain database and based on the proximity of the terrain the warning (colour graded) is presented, typically on the navigation display. In addition the corresponding audio warning is also provided.

Communication

Communication is the key enabler of the airborne ATM functionality. In fact, the ASAS application cannot work without the information about surrounding traffic. In this context, the implementation of ADS-B/C and TIS-B are of particular importance.

The intent information communicated via ADS-B message is defined in the ARINC 702 standard. The most recent version of this document (already implemented in A380) is A702-3.

11.1.2 New Required Equipment

ASAS Application

Description of the expected ASAS functioning is given in the chapter 14.1.1.3. While the CD and CR modules are obligatory, the complexity handling is optional.

Trajectory Builder

As it was described in the Chapter 6, the current FMS is not able to generate the complete optimal flight path. This application should be able to generate the trajectory that avoids any hazardous areas (congestions, weather hazards, restricted airspace, …)

typically expressed in the form of polyhedrons. It should be also able to optimize this path with respect to the beneficial weather conditions (e.g., tail wind) and other user preferences. The result may be provided in the form of updated flight plan (with additional constraints, such as RTA at the SSAS exit point(s)). Preferably, the trajectory builder functionality should be implemented directly into (future/enhanced) FMS. An alternative solution is to introduce it as a stand-alone module.

Congestion Predictor

This functionality is in the current ATM system provided on the ground by CFMU (Central Flow Management Unit). It should consider the known intended trajectories of the aircraft in the LTAZ, and predict areas with probable congestion problems. The output could be represented, e.g., in the form of polyhedrons.

11.2 System Wide Information Management (SWIM)

SWIM – System Wide Information Management – is the SESAR information sharing system that enables access to diverse and distributed information within the air traffic system, enabling Technologies and Infrastructure for collaborative information Interchange. SWIM was designed to incorporate the full capability of technology while maintaining maximum flexibility of both installation and operation. The data of a large Air Traffic Service (ATS) is typically distributed over a wide area and archived in a variety of databases and file systems. Enabled access to such information is crucial to an aircraft, however, this is not easy, due to:

- ✓ A model of the relevant information is not available
- ✓ There is no simple way to access the information without being knowledgeable about various computer data formats, file systems, and networks.

Such data could be stored in different repositories such as databases and file systems including those that contain multiple media. Elements to be developed within the Concept of Operations are the description of the functionalities for the SWIM, apart from the details of the implementation and extensions planned for the future.

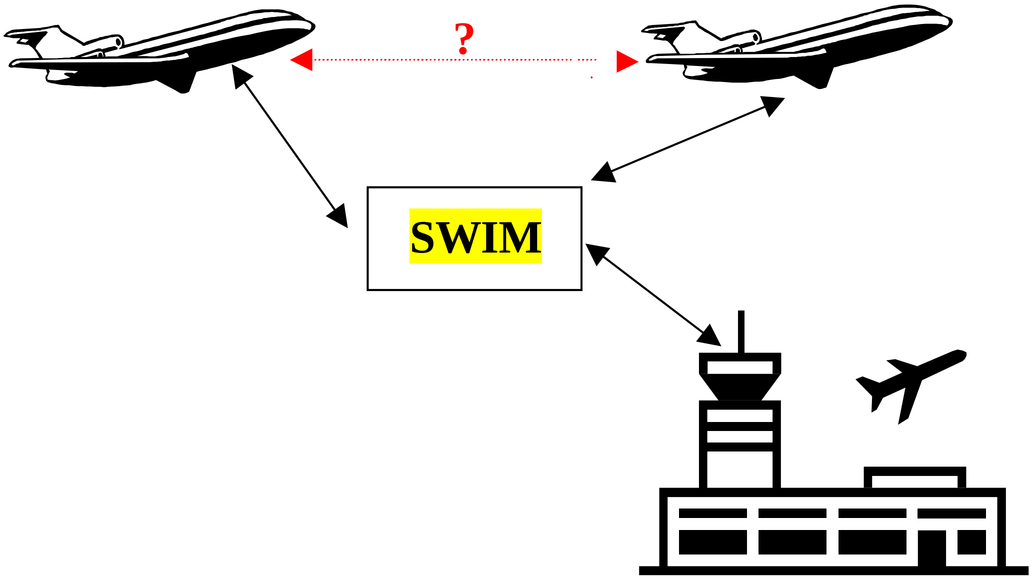

Figure 13: Information sharing system (SWIM) scheme.

The system should facilitate the exchange of information between aircraft and ground under a collaborative environment. The transmitter and receiver in the chain are principally aircraft and centres of the ATS, and their communication is often hampered by the incompatibility of the various systems involved. It would be necessary to know the design, installation and operation parameters of SWIM, low latency (time required for a system to respond to an input) being crucial.

An ideal latency zero element (when time required for a system to respond to an input is zero) of the concept should be the base in order to make progress in en-route autonomous aircraft operation, where all information is made instantly available throughout the ATS. This is applicable in environments with rapidly changing operation conditions that are best evaluated with up-to-the-minute information, ATS constantly manage a wide range of activities, including flight and flight crew scheduling, aircraft maintenance, and services. Unpredictable weather changes or equipment failures often require adjustments to departmental operations throughout the system.

Rapid dissemination of information can improve efficiency, reduce operating costs, and increase customer satisfaction. Unfortunately, this information is often available only through multiple independent units employing a heterogeneous mix of application systems.

11.2.1 Types of Communication

New air-air, ground-ground and air-ground data communication systems will be necessary for those actors who need to communicate on en-route phase of flight in the Free Flight environment:

- ✓ Pilots
- ✓ AOC

Data link communication should, according to the level of importance, be implemented in the form of:

1) Text
2) Voice
3) Images (pictures/video)?

Implementation of new communications components complementing VHF Data Link Mode 2/3/4 and common network transport mechanism is needed to support various data-link technologies, where integration issues may play an important role.

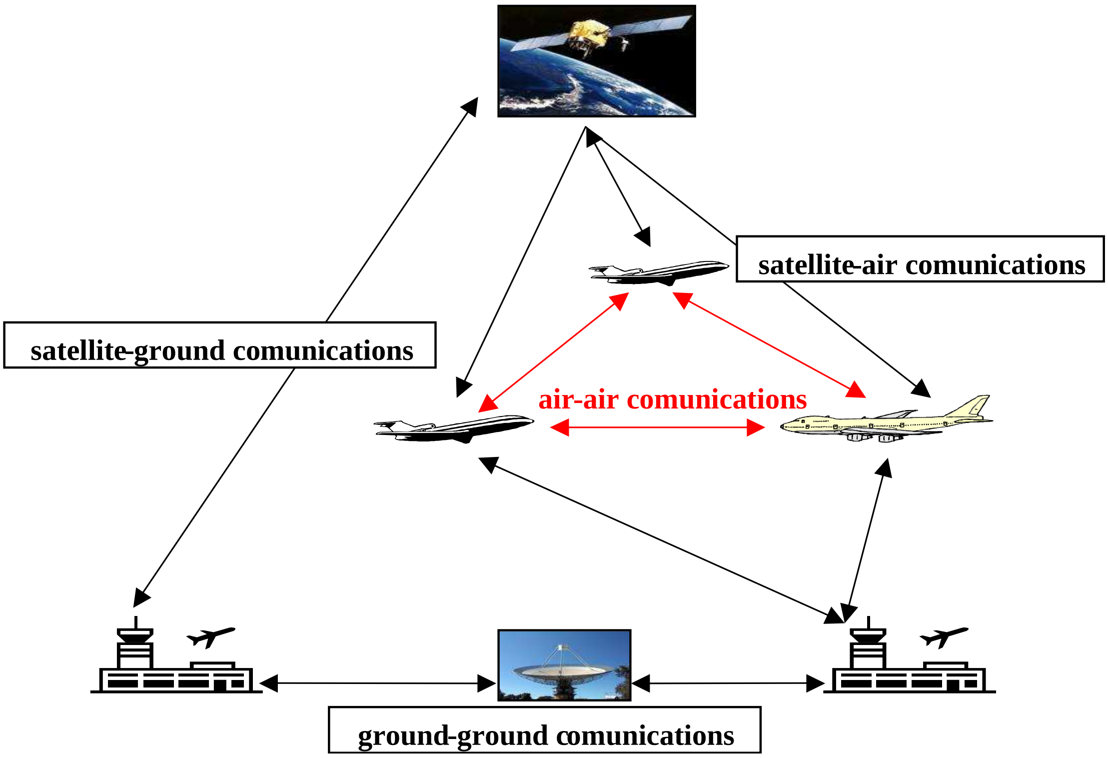

Figure 14: Communications scheme.

Delegation of some conflict resolution, spacing and separation tasks to the pilot will result in a reduction in air/ground communications. But this would increase air–air information transference needs, requiring long range of communications not only for routine operations (when systems are working in normal operation mode).

Some of the technologies for air–air communications could be:
(i) Narrowband Loudness Discomfort Level,
(ii) Appraisal Management and Communications System,
(iii) B-AMC (Broadband VHF),
(iv) Wideband Code Division Multiple Access.

Due to the fact that communications systems can fail, actions for system recovery and for keeping up the aircraft operation, developing contingency actions (when systems or part of the systems fail, systems are working in degraded operation mode) and emergency operations will be necessary.

12 Glossary of terms

4DT	4D Trajectory
A^3	Autonomous Aircraft Advanced
ACAS	Airborne Collision Avoidance System
ACNS	Advanced CNS
ADS-B	Automatic Dependent Surveillance/Broadcast
ADS-C	Automatic Dependent Surveillance/Contract
AMC	Acceptable Means of Compliance
AMFF	Autonomous Mediterranean Free Flight
ANSP	Air Navigation Service Provider
AOC	Airline Operation Control
ARINC	Aeronautical Radio, Incorporated (US)
ASAS	Airborne Separation Assurance System
ASOR	Allocation of Safety Objectives and Requirements
ATC	Air Traffic Control
ATCo	Air Traffic Controller
ATFM	Air Traffic Flow Management
ATM	Air Traffic Management
AZ	Alert Zone
CD	Conflict Detection
CDM	Collaborative Decision Making
CDR	Conflict Detection and Resolution
CDTI	Cockpit Display of Traffic Information
CFMU	Central Flow Management Unit
CNS	Communication, Navigation and Surveillance
ConOps	Concept of Operation
CPDLC	Controller Pilot Data Link Communications
CR	Conflict Resolution
CTA	Controlled Time of Arrival
EADI	Electronic Attitude Director Indicator
EC	European Commission
EGPWS	Enhanced Grounds Proximity Warning System
E-OCVM	European Operational Concept Validation Method
EPIC	Emergency Procedures Information Centre
ESARR4	Eurocontrol Safety Regulatory Requirements
FF	Free Flight
FFACS	FF Airborne Cognitive System
FFAS	Free Flight Airspace
FMS	Flight Management System
GA	General Aviation
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPWS	Ground Proximity Warning System
HF	Human Factors
HL	High Level
HMI	Human Machine Interface
IAF	Initial Approach Fix
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
I-I C	Intent-Intent Conflict
IMC	Instrument Meteorological Conditions
INAV	Honeywell's Integrated Navigation
I-S C	Intent-State Conflict
KPA	Key Performance Areas
LTAZ	Long Term Awareness Zone
MAS	Managed Airspace
MCDU	Multi-Function Control and Display Unit

MFF	Mediterranean Free Flight
MTAZ	Medium Term Awareness Zone
MTC	Mid Term Collision
NM, nm	Nautical Mile (1.852 m)
OHA	Operational Hazard Assessment
OSA	Operational Safety Assessment
OSED	Operational Services and Environment Definition
PASAS	Predictive Airborne Separation Assurance System
PAZ	Protected Airspace Zone
RA	Resolution Advisory
RBT	Reference Business Trajectory
RNAV	Area Navigation (OACI)
RNAV/RNP	Required Navigation Performance for Area Navigation
RNP	Required Navigation Performance
RTA	Required Time of Arrival
RTCA	Radio Technical Commission for Aeronautics
RTD	Research, Technology and Development
RVSM	Reduced Vertical Separation Minimum
SA	Situation Awareness
SESAR	Single European Sky ATM Research
SM	Separation Minima
SSAS	Self Separation Airspace
STAZ	Short Term Awareness Zone
STC	Short Term Collision
SUA	Special Use Airspace
SWIM	System Wide Information Management
TA	Traffic Advisory
TBO	Trajectory Based Operations
TCAS	Traffic Alert and Collision Avoidance System
TCP	Trajectory Change Points
TIS-B	Traffic Information Service - Broadcast
TM	Trajectory Management
UAS	Unmanned Aerial Systems
VFR	Visual Flight Rules
WP	Work Package

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http://www.atm-erasmus.com/pageoverview.html

FREE FLIGHT, Free Flight with Airborne Separation Assurance.
http://hosted.nlr.nl/public/hosted-sites/freeflight/

HYBRIDGE, Distributed Control and Stochastic Analysis of Hybrid Systems Supporting Safety Critical Real-Time Systems Design.
http://hosted.nlr.nl/public/hosted-sites/hybridge/

MFF, Mediterranean Free Flight Programme.
http://www.medff.it/

NEXTGEN, Concept of Operations of Next Generation Air Transportation System.

RESET, Reduced Separation Minima.
http://reset.aena.es/

FlySAFE project.
http://www.eu-flysafe.org/Project.html
http://www.eu-ysafe.org/EU-Flysafe Public/Project.html

RVSM, Reduced Vertical Separation Minimum project.
http://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/enroute/rvsm/

14 Appendices

14.1 Appendix A: High Level review of SESAR and NextGen regarding airborne self separation

Although there are naturally some differences between the concepts of the next generation ATM systems in Europe (SESAR) and in the US (NextGen), the key elements that affect the development of new ASAS applications are nearly the same:

- SWIM (System Wide Information Management) provides the traffic-related information to all involved users. This results in net-centric overall ATM system. The enhanced situation awareness is a cornerstone for any new aircraft's ATM responsibility and in this context an implementation of the global information sharing system with appropriate communication channels (datalinks) is a key enabler of all ASAS applications. Actually the biggest effort is put into the preparation of the standards and the implementation and validation plans for wide use of ADS-B Out and In. Several validation activities are already performed worldwide (Australia, Alaska, Sweden (NUP)).
- Trajectory-Based Operations (TBO) – an extensive use of the 4D trajectory (4DT) contracts. As it is discussed in Section 4.1, the extensive use of TBO outside of SSAS can simplify the transition between the managed airspace and SSAS.
- New airborne-delegated separation management modes (ASAS).

Considering the new separation management modes, they can be split to two classes[7]:

- ASAS applications used within the ATC-managed airspace together with non ASAS-capable aircraft.
- ASAS applications used within the separate part of airspace (so-called Self Separation Airspace – see Chapter 4) reserved just for the ASAS-capable aircraft.

The first class is characterized by a limited responsibility of the airborne side (delegation just for a specific manoeuvre and/or separation management just with respect to one (or more) appointed aircraft) and consequently simpler future implementation of these applications to

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[7] There are 4 ASAS applications usually discussed in literature: Air Traffic Situation Awareness, ASAS Spacing, ASAS Separation, and ASAS Self-Separation. As we consider the situation awareness more an enabler of the autonomous flight concept, just the remaining three applications are discussed in the text.

the existing ATM. In this context the timescales anticipated for the introduction of this type of ASAS applications are considerably shorter than for establishing of SSAS.

As iFly is based on the study of the second type of ASAS applications, just a short description will be given about the first ASAS class. Two main applications are usually considered in this context:

- **Merging and Spacing:** Aircraft is instructed to merge behind a designated lead aircraft and maintain a given spacing in time or distance. The responsibility for spacing may be on the ASAS or on the controller (both cases are considered). This procedure should be used essentially in the terminal area as its benefits within the en-route phase are disputable.
- **Airborne (or Delegated) Separation Procedures:** Controller delegates responsibility to perform specific separation operations to capable aircraft. The latter may be: passing, crossing, climbing, descending, and turning behind another aircraft. Again the two alternatives are considered with the responsibility in the air and on the ground, respectively. The NextGen’s notion of the Delegated Separation is slightly more general than SESAR’s Cooperative Separation discussed below, as it can include some procedures that involve several aircraft responsible for separation from each other.

The second type of ASAS application, which is usually referred as the ASAS self-separation, is the main subject of the iFly project**.** Note, that within SESAR it is considered that the ASAS self-separation could be used by designated aircraft also within the managed airspace. However, this (introducing the mixed equipage problem) is out of scope of the iFly project and will not be discussed here.

14.1.1 SESAR

SESAR ConOps is based on 14 concept elements. iFly’s primary aim is to provide important contributions to two of them:

- New Separation Modes;
- Improved Situation Awareness.

However, the scope of the work is also closely interconnected with other elements (list may not be exhaustive):

- ATM Organization;

- Airspace Management;
- Information Management;
- Trajectory Management;
- Collaborative Decision Making;
- Controller Task Load Reduction.
- Maximize utilization of capacity.

Considering the performance-based approach which is the main driver of the SESAR ConOps, the iFly project addresses mainly (but not exclusively) the following ICAO Key Performance Areas (KPA):

- Safety;
- Capacity;
- Flexibility;
- Efficiency;
- Cost Effectiveness.

14.1.1.1 New Separation Modes

SESAR considers two types of new separation modes:

- **Cooperative Separation** – in which the role of the separator is temporarily delegated to the aircrew to assure separation with regard to other aircraft under specific circumstances;
- **Self-Separation –** in which the aircrew are the designated separator for a defined segment of a flight during which they shall assure separation from all other aircraft.

The corresponding manoeuvres are considered as a temporary deviation from the **Reference Business Trajectory** (RBT – intended user-preferred and contracted trajectory) to be renegotiated (in the managed airspace) and resumed once the aircraft is conflict free.

It is not anticipated that all the separation modes will be deployable by 2020 in medium or high-density area of managed airspace. In particular considering the self-separation, it is not even envisioned to be available for most of the users within the

2020–2025 timeframe. Nevertheless, it is considered that for low-density traffic self-separation can be used by 2020 to increase ATM system capacity and flight efficiency in areas or flight segments where this is feasible.

14.1.1.2 ATM Capability Levels

In order to describe the anticipated deployment of the ATM capabilities along the SESAR timeframe, the ATM capability levels 0–4 were defined:

- **ATM capability level 1 (ATM-1)** corresponds to the existing systems and those that are delivered up to 2012/2013.
- **ATM capability level 2 (ATM-2)** corresponds to the systems delivered and in-service from 2013 onwards but which do not meet the full 2020 needs. Expected new functionalities include:
  - Regional air-ground data link;
  - Uplink/downlink of meteorological data;
  - Uplink of constraints and clearances;
  - Lateral containment of RBT;
  - Multiple time constraints;
  - Air to air position/vector exchange;
  - ASAS Spacing (Merging and Spacing application)
- **ATM capability level 3 (ATM-3)** corresponds to the main capabilities required by the key SESAR target date of 2020. Expected new functionalities include:
  - Altitude containment of RBT;
  - ASAS Separation.
- **ATM capability level 4 (ATM-4)** corresponds to advanced capabilities that potentially offer the means to achieve the SESAR goals. The expected timeframe and availability is 2025 and beyond. Expected new functionalities include:
  - Longitudinal containment of RBT;
  - Trajectory exchange;
  - ASAS Self-Separation.

14.1.1.3 ASAS Self-Separation

Within SESAR it is considered that the self-separation mode could be used not only in the separate part of airspace but also by the delegated aircraft within the ATC managed airspace. In this case, the contract between the aircraft and ATC should specify the 4D trajectory together with some manoeuvrability limits for the ASAS conflict resolution solutions. The responsibility for separation of this aircraft from other (including ATC managed) traffic should lie on the airborne side.

The envisioned structure of the European airspace is shown in Figure 15.

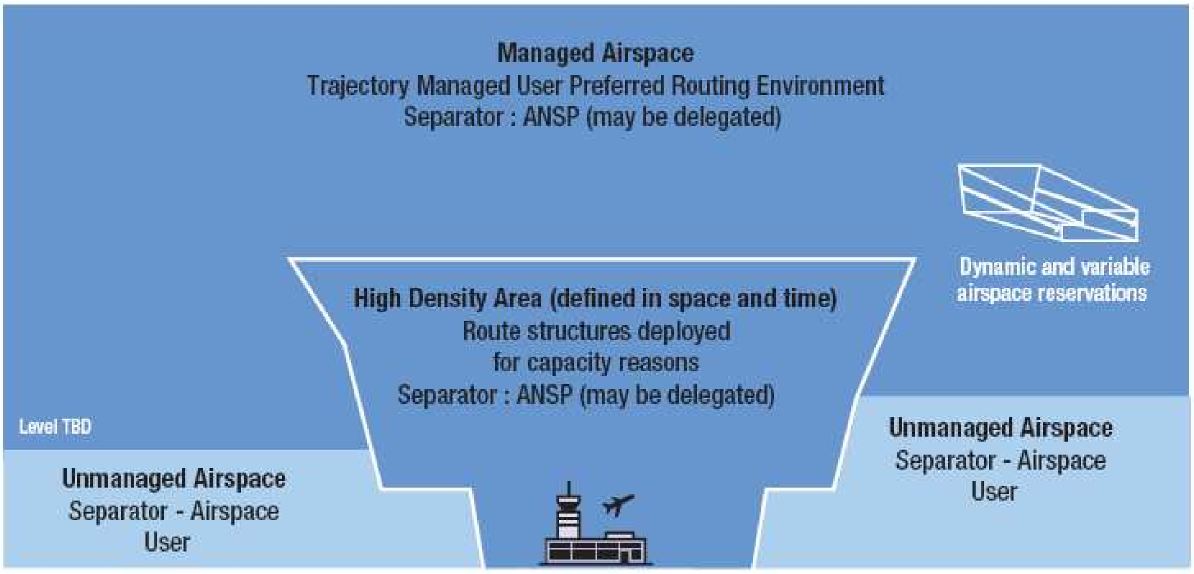

Figure 15: SESAR Airs pace Structure.

14.1.2 NextGen

The ASAS self-separation notion within NextGen is nearly the same as in SESAR and also the implementation timeframe is very similar. The earliest implementation of self-separation is expected in oceanic and remote airspace, possibly with separation standards between current procedural standards and actual radar-based standards.

The anticipated global airspace structure is shown in Figure 16.

Figure 16: NextGen Airspace Structure.

14.1.2.1 Flow Corridors

Besides, the NextGen introduces the concept of so-called "flow corridors" for the super dense traffic conditions typically experienced in the terminal areas:
"When demand is very high, the ANSP may implement "flow corridors" for large numbers of separation-capable aircraft travelling in the same direction on very similar routes (see Figure 17). Flow corridors consist of long tubes or "bundles" of near-parallel 4DT assignments, which consequently achieve a very high traffic throughput, while allowing traffic to shift as necessary to enable more effective weather avoidance, reduce congestion, and meet defence and security requirements. The airspace for aircraft operating in flow corridors is protected; aircraft not part of the flow do not penetrate the corridor".

It is anticipated that the airborne self-separation will be used also within these corridors.

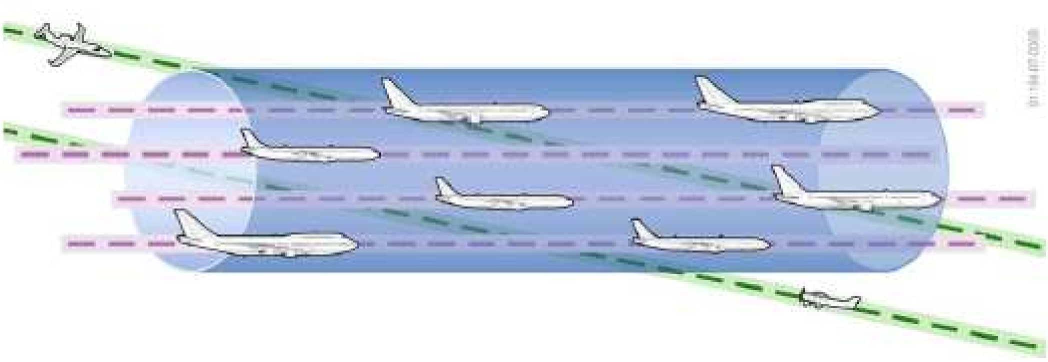

Figure 17: NextGen Flow Corridors.

14.1.2.2 Possible ASAS Implementation Steps

Within ASAS-TN2 one possible approach for implementing ASAS within NextGen was presented:

Phase A – Situation Awareness Tool

- Tool that advises pilot of available altitudes for altitude changes
- Advisory information only (low certification requirements)

Phase B – ADS-B In-Trail Procedures

- Altitude changes allowed based on cockpit derived data
- No delegation of separation authority

Phase C – Enhanced ADS-B In-Trail Procedures

- Limited delegation of separation authority to cockpit during a manoeuvre
- On-board system monitoring of separation during manoeuvre

Phase D – Airborne separation corridor

- Aircraft allowed to self-separate in designated corridor
- All aircraft properly equipped (conflict detection & resolution)

14.2 Appendix B: Input previous R&T projects working repository

In order to select the most interesting inputs or candidate elements of the concept among a large list of projects proposed from the previous state-of-the-art aeronautics research results and be able to define a "baseline" operational High Level (HL) concept and alternatives, common criteria among all partners involved have been defined. After technical discussions, it was agreed that useful projects should include references to the following key words or questions:

a. Autonomous Aircraft

b. Conflict Prediction

c. Separation Minima

d. Complexity Prediction (Clustering)

e. Free Flight procedures and implementation options, i.e. conflict resolution based on priority rules or on co-operative actions, level of coordination between aircraft, etc.

f. Conflict Resolution: ASAS (Airborne *Separation* Assurance System), ACAS (Airborne *Collision* Avoidance System), etc.

g. ASAS-TCAS (Traffic Alert and Collision Avoidance System) interaction

h. Conflict resolution algorithms, i.e. solving multiple conflicts one by one or according to a full concurrent way

i. Distribution of Conflict Resolution responsibility (automation/human, ground/air)

j. Human factors and goal settings of pilots and of airlines.

k. Identification of elements such as pilots flying/non-flying, systems components and entities (like the aircraft's position evolution and the Conflict Management Support systems), air traffic controller, global navigation and surveillance equipment (like the communication frequencies and the satellite system), etc.

l. Current and future technological issues, equipment performance and airborne requirements for Free Flight: air-ground communication (e.g. TIS-B), air-air communication, systems, displays, etc. Focused on functionalities more than on the description of the technology.

m. Merging and Spacing

n. Free Flight Airspace (FFAS), Free Route Airspace and Restrictions for Free Flight on European airspace

o. Airspace Division

p. Risk & Safety Assessment as a function of traffic density increase. Does the selected project/paper tackle the Free Flight risk assessments weaknesses detected?

q. Benefits & Cost Assessment, impact on economy caused by organisational and institutional issues derived of the introduction of the autonomous aircraft advanced operations en-route.

r. Overall Air Traffic ConOps

Taking into account this agreed set of topics relevant to the ConOps, the iFly team has built a repository of existing research and technology projects as a working matrix to offer an overview of the projects identified. A project is considered as a relevant input if it:

- is able to introduce something new about the topics listed in the agreed common criteria, or
- offers an evaluation of some methods already developed.

PROJECTS IDENTIFIED	NAME-DESCRIPTION	THE PROJECT INTRODUCES SOMETHING NEW TO THE TOPICS RELEVANT TO THE ConOps	THE PROJECT EVALUATES SOME METHODS ALREADY DEVELOPED	(Y/N)	POTENTIAL ELEMENTS IDENTIFIED
AFAS	Aircraft in the Future ATM System The AFAS and MA-AFAS projects were designed to be complementary. Both are taking into account the activities of other related Fifth Framework Programme projects	YES			
ASAS-TN2	Airborne Separation Assistance Systems Thematic Network 2	NO	Annual overview (maturity report) of the results of ASAS-related projects	**YES**[8]	**A.** (Review of the ASAS related projects)
CARE-ASAS	Action Plan on Airborne Separation Assurance Systems. Although CARE-ASAS was conducting R&D activities related to ASAS, it could not be considered as an R&D project on ASAS. The main goal of CARE-ASAS was to help the organisations working on ASAS R&D to speak the same language and to work together: it provides general considerations for airborne self-separation as well as widely accepted terminology. Project concluded in 2004	Provides general considerations for airborne self-separation as well as widely accepted terminology Define principles of operation for different categories of ASAS application. Category 4 is "Airborne Self-separation Applications". Includes general considerations and provides some terminology which is widely accepted. CARE-ASAS proposed grouping of ASAS applications into packages. This approach was endorsed by ICAO. "Package III" includes "Airborne self-separation application (i.e. PO-ASAS category IV applications) in medium/high-density airspace." i.e. the iFly WP1 concept would be a "Package III" application.		**YES**	
C-ATM	Co-operative ATM Implementation of co-operative systems and processes aimed at optimising system resources and task distribution between air and ground and supported by the sharing of common data across the system, in order to dramatically improve the efficiency of the overall Network, providing a more reliable and predictable service to airspace users	**F. Conflict Resolution: ASAS** ASAS will be used to support situation awareness, to perform delegated spacing tasks and to ensure better adherence to ATC separation minima in en-route, terminal, and approach airspace and on the airport manoeuvring areas. Separation management responsibilities remain unchanged: the pilot is ultimately responsible for aircraft safety at all times; **J. Human Factors** Airborne spacing procedures may be applied en-route to exploit the pilots ability to manage the agreed 4D trajectory whilst, for example, the pilot maintains his specific spacing in a traffic flow. The controller will be responsible for transitioning traffic to new trajectories and amending 4D plans in the event of scenario changes being implemented by the traffic flow manager and/or local traffic manager. There is a change in both pilot and controllers roles and perspective towards a strategically managed rather than tactical system that enhances the overall network and airspace users' business objectives. **L. Current and future technological issues** It is expected that future aircraft avionics will permit both surface and flight navigation and management on the basis of *Network Operations Plan* (NOP) incorporating the gate to gate airspace user demand as a set of 4D plans for anticipated flights. The 4D plan is represented in the aircraft by the Flight Management System trajectory and in ground system by trajectory calculations in flight data processing systems. Collaborative processes will integrate all stakeholders into the ATM system. C-ATM relies heavily on the implementation of *System Wide Information Management* (SWIM) to enable		**YES**	***CONFLICT RESOLUTION*** **PE1. Airborne Separation Assistance System (ASAS) procedures** ***FREE FLIGHT PROCEDURES & TECHNOLOGICAL ISSUES: COMMUNICATIONS*** **PE2. Network Operations Plan (NOP):** it will provide an up to date overview of the European airspace situation through all the phases of the layered planning process. Traffic managers, air traffic services, airports and airspace users and military operators' will access and extract data from the plan to support their operations and to build their own actual operations plans. For an individual flight in the NOP its plan becomes the agreed 4D trajectory. **PE3. 4-D Flight Management System (FMS) capabilities and trajectory planning** **PE4. Air-Ground data-link communications** **PE5. Flight Data processing** **PE6. Flow Management** **PE7. Collaborative Decision Making applications** **PE8. System Wide Information Management (SWIM)** enables information management and services ***AIRSPACE ORGANIZATION*** **PE9. Airspace Network Management:** provision of capacity through the activation of flexible and dynamic airspace structures to meet users' needs. The network management process is supported by the Network Operations Plan. ***SEPARATION MINIMA*** **PE10. Advanced tools to support Separation Management**

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[8] as a link to other projects

PROJECTS IDENTIFIED	NAME-DESCRIPTION	THE PROJECT INTRODUCES SOMETHING NEW TO THE TOPICS RELEVANT TO THE ConOps	THE PROJECT EVALUATES SOME METHODS ALREADY DEVELOPED	(Y/N)	POTENTIAL ELEMENTS IDENTIFIED
		information management and services. 4D plans and pre-departure trajectory co-ordination or 4D trajectory re-planning will be provided or amended where feasible via data exchange through Controller/Pilot data link communications. Nevertheless, Radio telephony remains the primary communication channel for delivery of time critical clearances. **O. Airspace Division** *Airspace Network Management*: The goal of Network Management is the provision of capacity through the activation of flexible and dynamic airspace structures to meet users' needs. The network management process is supported by the NOP. Dynamic (modular) sectorisation will be implemented through sector configurations, pre-designed and adapted to the main traffic flows predicted over each day of operation. **E. Free Flight procedures and implementation options** When issued, the 4D plan represents the agreement between traffic flow manager, air traffic services and airline operations centre as to how the flight should proceed. The NOP, which is developed during the layered planning phases, will provide an up to date overview of the European airspace situation through all the phases of the layered planning process: Strategic, Pre-Tactical, and Tactical. Traffic managers, air traffic services, airports and airspace users and military operators' will access and extract data from the plan to support their operations and to build their own actual operations plans. Collaborative processes will integrate all stakeholders into the ATM system **Q. Economic Benefits** Improvement of the efficiency and stability of operations. Shared 4D plan will improve predictability and therefore safety, and reduce "bottlenecks" whilst improving aircraft and fleet management efficiency.			
Free Flight	Free Flight with Airborne Separation Assurance	YES	YES	**YES**	YES
FREER	Freer Flight is the historic name of ASAS activities at EEC. The FREER project began with consideration of autonomous or self-separating aircraft. The project evolved in the direction of delegation of tasks from the ground to the air. During the early "autonomous aircraft" part of the project a concept was developed, which was not dissimilar to that subsequently adopted by AMFF, i.e. priority rules, resolution of individual conflicts. Since 2002, the project has been (re)named **CoSpace**. CoSpace - Towards the Use of Spacing Instructions	Provides conflict resolution algorithms of possible interest. Some conflict resolution algorithms used or developed during the early part of the project include: GEARS, this algorithm can be used to solve an initial conflict and to avoid conflicts with surrounding aircraft - provided their trajectories are known. http://richard.irvine.free.fr/gears/Gears.pdf A review of different approaches based on force fields for airborne conflict resolution http://www.aiaa.org/content.cfm?pageid=406&gTable=mtgpaper&gID=19351		**YES**	
G2G	Gate-to-Gate Programme Gate-to-Gate planned to study ASAS Package 1 applications.	**F. Conflict Resolution: ASAS + M. Merging and Spacing** ASAS applications and Delegation of tasks to the flight crew. Among the four ASAS applications categories defined, G2G considers that two of them are within the time frame: *Airborne Traffic Situational Awareness* (ATSAW) applications, giving the flight crew enhanced situational awareness and *Airborne Spacing* applications, requiring the flight crew to achieve and maintain a given spacing with	G2G programme uses TORCH as a first basis, in co-ordination with other programmes (AFAS, MA-AFAS, NUP and MFF) The G2G IOC especially comprises a consolidation of the so-called cluster concepts: Flow and Capacity Management; En-route and Layered Planning; Extended	**YES**	***FREE FLIGHT PROCEDURES: BETTER PLANNING & COLLABORATION*** **PE1. 4D Trajectories** **PE2. Layered Planning:** to accomplish this, it is mandatory to establish **timely information sharing (PE2.1)** and to apply **Collaborative Decision Making (PE2.2)** in all phases of planning and in all phases of flight. **PE3. 4D-Flight Monitoring System (4D-FMS):** ATM

PROJECTS IDENTIFIED	NAME-DESCRIPTION	THE PROJECT INTRODUCES SOMETHING NEW TO THE TOPICS RELEVANT TO THE ConOps	THE PROJECT EVALUATES SOME METHODS ALREADY DEVELOPED	(Y/N)	POTENTIAL ELEMENTS IDENTIFIED
		designated aircraft. **O. Airspace Organization and Management (AO&M)** AO&M is required to provide sufficient airspace capacity and routes to be able to cope with expected demand. The re-organization of airspace is addressed e.g. by the Single European Sky initiative, and this will lead to a breakdown of airspace in Europe in Functional Airspace Blocks (FABs) **I. Distribution of Conflict Resolution responsibilities: Air-Ground integration** A general driver behind the G2G IOC is *layered planning*, and to accomplish this, it is mandatory to establish timely information sharing and to apply *Collaborative Decision Making* (CDM) in all phases of planning and in all phases of flight. ATM support is provided by the planning, control and guidance capabilities of the aircraft by use of its 4D-Flight Monitoring System (4D-FMS). Enhanced air-ground interoperability as well as high precision navigation performance can contribute to support executive control to obtain increase capacity and efficiency and at the same time to preserve the required levels of safety. **K+J. Identification of elements: roles and tasks of ATM actors** G2G IOC is based on better collaboration between ATM actors (mainly Airline Operation Centre (AOC), Central Flow Management Unit (CFMU), all Air Navigation Service Providers (ANSPs) concerned by the flight, Airport Operators and Aircraft) and better planning. **Q. Benefits & Cost Assessment**	TMA and TMA Management		support is provided by the planning, control and guidance capabilities of the aircraft by use of its 4D-FMS ***CONFLICT RESOLUTION*** **PE4. Airborne Traffic Situational Awareness (ATSAW) applications** **PE5. Airborne Spacing applications** ***AIRSPACE ORGANIZATION*** **PE6. Functional Airspace Blocks (FABs)**
INTENT	The Transition towards Global Air and Ground Collaboration In Traffic Separation Assurance It aims at defining a road map of new technologies to increase air traffic capacity. In this context it deals with intent information presentation of other traffic in the cockpit.	Intent-based airborne CD&R (en-route)	YES (state-based ASAS)	**YES**	**A.** The scenario involves airborne sep. ass. with free routes; **B, F, H.** Intent based CD&R; **E.** Interaction between intent-based mode and state based-mode; **J.** Pilots workload models.
MA-AFAS	More Autonomous Aircraft in the Future ATM System http://www.ma-afas.com/ MA-AFAS developed and flew an advanced avionics system that supported Cockpit Display of Traffic Information, station keeping and autonomous crossing, sequencing and merging procedures End Date: 2003-07-31 Update Date: 2005-06-09	**A. Autonomous Aircraft** Greater level of autonomy for the individual aircraft, i.e. getting more Air Traffic Control (ATC) functionality out of the control tower and into the plane. **F. Conflict Resolution: ASAS** ASAS is a potential component in the solution together with other CNS (Communication, Navigation and Surveillance) technologies that shift the emphasis to the airborne element. Validation of ADS-B with airborne display of traffic (CDTI) and airborne separation assurance (ASAS) algorithms **L. Current and future technological issues** Digital data links are the key to today's new surveillance systems. The data link considered by MA-AFAS is VDL Mode 4 **G. Benefit and Cost Assessment** Description of the economic benefits and certification requirements of key airborne elements of CNS	To establish the common concept, the project validated selected CNS (Communication, Navigation and Surveillance) technologies against a range of ATN scenarios. The AFAS and MA-AFAS projects were designed to be complementary. Both are taking into account the activities of other related Fifth Framework Programme projects.	**YES**	***AUTONOMOUS AIRCRAFT & CONFLICT RESOLUTION*** **PE1. Autonomous crossing, sequencing and merging procedures** **PE1.1. ASAS:** A common operational concept for European ATM is required which includes a greater level of autonomy for the individual aircraft. ASAS is a potential component in the solution together with other CNS (Communication, Navigation and Surveillance) technologies that shift the emphasis to the airborne element. ***TECHNOLOGICAL ISSUES*** **PE2. Cockpit Display of Traffic Information (CDTI):** evaluation of flight deck HMI to support operation in a more autonomous environment **PE3. VDL Mode 4:** digital data links are the key to today's new surveillance systems. ***FREE FLIGHT PROCEDURES*** **PE4. 4D flight path generation and integration** with ground based flight path planning
MFF	Mediterranean Free Flight Programme. Moving closer to Free Flight in the Mediterranean *D211 – MFF Operational Concept & Requirements.pdf*				

PROJECTS IDENTIFIED	NAME-DESCRIPTION	THE PROJECT INTRODUCES SOMETHING NEW TO THE TOPICS RELEVANT TO THE ConOps	THE PROJECT EVALUATES SOME METHODS ALREADY DEVELOPED	(Y/N)	POTENTIAL ELEMENTS IDENTIFIED
NUP, NUPI & NUP IINUP II+	North European ADS-B Network (NEAN) Update Programme: * NUP - OPERATIONAL ENVIRONMENT DEFINITION (OED). *NUP WP8: Pilot Delegated In-Trail Procedure (ITP) in Non- Radar Oceanic Airspace* * NUP - OPERATIONAL ENVIRONMENT DEFINITION (OED). *NUP WP2: Delegated Airborne Separation Approach and Climb-Out Stockholm-Arlanda* * NUP - OPERATIONAL ENVIRONMENT DEFINITION (OED). *NUP WP2: Delegated Airborne Separation Cluster Control (DAS-CC) En-Route Maastricht UAC*	NO	YES (A lot of concepts enabled by ADS-B infrastructure)	**YES**	**Validation results (NUP II)** for Delegated Airborne Separation **(I)**: En-route **(F)** Explicit definition of cluster by controller, **(M)** In-trail spacing, Approach spacing **(M)**, ADS-B (VDL Mode 4) surveillance. Besides, there are the **Operation Environment Definitions** for various DAS procedures already mentioned in the project description (NUP I).
3FMS	Free Flight - Flight Management System This project aimed to provide new capabilities, such as separation assurance algorithms, and aimed to further develop existing capabilities such as terrain and weather databases. The simulation of technologies such as ADS-B, CPDLC and advanced Human Machine Interfaces (HMIs) were used to provide useful indications of the required performance of these technologies.	YES (Free Flight FMS architecture design)	NO	**YES**	**L** (FMS, Human-Machine Interface) - development and evaluation.
AATT	Advanced Air Transportation Technologies AATT addressed some of the most difficult air traffic management issues, including operations in complex airspace and the implementation of distributed air/ground responsibilities for separation. Honeywell was an active participant on the AATT program several years ago, so they should be able to gather reports, insights from people who worked on this program. The main person to contact is Bill Corwin	YES	NO	**YES**	**A, B, E, F, H, I, J, K, N, Q, R** – very complex project! The most interesting areas are: - NASA Langley's work concerning the AOP (an airborne DST covering complex CD&R tasks, and obstacle avoidance – both intent- and state-based). - DAG-TM considers several relevant concept elements (RTO41): Free Manoeuvring with ASAS respecting the traffic flow management constraints; Trajectory negotiation; Collaborative decision Making; Merging & Spacing. - The tasks related to the en-route air-ground data exchange (EDX – RTO27).
ACAST	The intent of ACAST (Advanced CNS Architectures and System Technologies) is to provide technologies to enable increases in capacity, efficiency, mobility and flexibility for users of the NAS.	Just indirectly related to iFly	YES (CNS)	**YES**	**K.** Multi-function, Multi-mode Digital Avionics architecture and business analysis; **K.** Screening of the technologies for future aeronautical communication (frequency ranges); **K.** UAS bandwidth requirements study; Benefits analysis of the reduced separation minima in the oceanic area (without radar coverage).
ACCAS	Airborne Collision Avoidance System	See Mode S/ACAS	See Mode S/ACAS	**NO**	See Mode S/ACAS
ADS-MED	ADS Mediterranean Area Deployment Programme Study This studied the impact of introducing ADS in the flight plan and surveillance data processing systems			**NO**	
ADS-MEDUP	The ADS Mediterranean Upgrade Programme has strict relationships with other European ADS-B related programmes like MFF, NUP and MA-AFAS.	Not new but useful to know historically	Extensive automation of Air Traffic Management Increased integration of ground and cockpit activities irrespective of aircraft location Delegation part of ATM tasks and responsibility to the cockpit	**YES**	The main goal of ADS-MEDUP is the construction of a pre-operational infrastructure serving a large portion of the Mediterranean airspace, which includes key Ground (fixed) and Airborne (mobile) CNS/ATM elements based on satellite navigation and VDL Mode 4 data link as enabling technologies.
ALO	Development of UAVs (Unmanned Aircraft Vehicles): lightweight observation air vehicle			**NO**	
ARDA	Aviation Research and Developments Activities.	The Aviation Research and Developments Activities	Of many ARDEP domains two seem	**YES**	Some projects from mentioned subdomains may be of

PROJECTS IDENTIFIED	NAME-DESCRIPTION	THE PROJECT INTRODUCES SOMETHING NEW TO THE TOPICS RELEVANT TO THE ConOps	THE PROJECT EVALUATES SOME METHODS ALREADY DEVELOPED	(Y/N)	POTENTIAL ELEMENTS IDENTIFIED
	As part of the ARDEP web site, ARDA offers information about Aviation R&D projects undertaken by research bodies and service providers that are conducting major R&D activities in Europe and in USA.	(ARDA) part of the ARDEP web site contains information about Aviation R&D projects undertaken by research bodies and service providers that are conducting major R&D activities in Europe and in USA. The ARDEP web-site contains background information about European ATM R&D, and specific project information is regularly updated on the web. The scope of ARDEP is to provide an as accurate as possible picture of the ATM R&D activities carried out each year. The following projects may be of some interest: in subdomain CNSC: CEC138, DLR039, DLR041, ENA032, EUR096, EUR388, SIC021 in subdomain STUD: EUR186, SIC022 in subdomain TECN: CEC145, EUR336. Most of the projects have been covered in parallel in several subdomains.	relevant for iFly ConOps identification process with their following subdomains. These are: 1. Domain OVA (Overall and system-wide ATM Topics) Subdomain CNSC (ATM concepts and scenarios) with 46 projects currently 2. Domain INV (Innovative ATM concepts and new technologies) Subdomain STUD (Innovative concepts studies) with 9 projects currently Subdomain TECN (Assessment of New Technologies for ATM) with 11 projects currently		partial interest to some iFly WPs. Several projects included into the present review are listed in the mentioned ARDEP subdomains
ARTAS	ATM suRveillance Tracker And Server			**YES**	**Utility for iFly** The new concept of free flight will require from each aircraft overlying the intended airspace to be "updated with the most accurate picture" of the surrounding traffic, as well as an anticipated awareness of the approaching **aircraft vectors**. This "accurate" picture, based on **processed radar data reports** to form a best estimate of the current Air Traffic situation, is provided to all Users interested in air traffic. Data provided by ARTAS could be considered as an input to the Aircraft flight management systems, and the planned conflict management system.
ASSTAR	Advanced Safe Separation Technologies and Algorithm		YES When DSNA set up the ASSTAR project, the goal was to progress on ECLECTIC ideas and concepts, basically, the extrapolation of the visual separation clearance to an airborne separation clearance for crossing supported by ADS-B and ASAS. Thanks to ASSTAR, the ASEP (Airborne SEParation)-Lateral Crossing procedure progressed in several important directions: -operational procedure with phraseology and clarification on the delegation of responsibility for separation -airborne algorithms to support the ASAS procedure, with demos on CDTI -airborne architecture (functional) -safety assessment	**YES**	
ASTP	ADS Studies and Trials Project ASTP supports the validation of ground and airborne surveillance applications enabled by ADS (Automatic Dependent Surveillance) and TIS (Traffic Information Service) technologies. ADS Technology Assessment activity of the EUROCONTROL ADS Programme. The objective of ADS Technology Assessment is to evaluate existing and future ADS candidate technologies and make technical recommendations for technology selection		Extensive performance and capacity assessments of the three main ADS-B data link technologies (i.e. 1090 MHz Extended Squitter, VDL-4, and UAT) and developed models for performance estimation. Development of a trials platform known as AVT (the ADS-B/TIS-B Validation Testbed), which is used to validate the physical and functional surveillance system architecture proposed by the EUROCONTROL CASCADE Programme.	**NO**	
Australian UAP	ADS-B Upper Airspace Program Airservices Australia is currently deploying ADS-	NO	YES (Implementation and validation of ADS-B (1090ES) based surveillance for	**YES**	**L.** (just as an example of the real ADS-B implementation) – the implementation is not completed

PROJECTS IDENTIFIED	NAME-DESCRIPTION	THE PROJECT INTRODUCES SOMETHING NEW TO THE TOPICS RELEVANT TO THE ConOps	THE PROJECT EVALUATES SOME METHODS ALREADY DEVELOPED	(Y/N)	POTENTIAL ELEMENTS IDENTIFIED
	B ground stations across Australia providing almost nationwide air traffic surveillance capability at flight levels above FL300. The objective of the program is to provide ADS-B equipped aircraft with increased safety and operational flexibility in non-radar airspace.		upper airspace (above FL300 levels).		yet (at the final stage, the 28 ground stations should cover the Australian airspace).
AVIZOR	It is an extension of the SIVA project		Taking SIVA as a starting point, AVIZOR enhances present capabilities	**NO**	
BASILE	Basic Aircraft SImulator for Logic Evaluation	NO (Trajectory generator – aircraft dynamics + FMS model)	NO	**NO**	**L.** Simplified FMS model
CAPSTONE	The FAA Capstone Program is a technology focused Safety Program in Alaska which seeks near term safety and efficiency gains in aviation by accelerating implementation and use of modern technology	NO	YES (implementation and validation of ADS-B (UAT) based surveillance	**NO**	**L.** Validation results of UAT ADS-B surveillance. Not finished yet.
CASCADE	The CASCADE programme addresses the next generation of data link applications and services to improve further the air traffic control sector productivity and ATM performance	Autonomous aircraft lies beyond its scope. Performance requirements for ADS-B transponders are under development i.e. not available now.		**NO**	
CESAR	Concept of Electronic Separation Assurance in Realtime environment Project launched around 1996!!!		The CESAR project developed a real-time demonstrator for ASAS applications, evaluating the pilots and controllers acceptability of the ASAS Crossing Procedure (ACP)	**NO**	
CRISTAL program	This European program has collected a lot of data on actual ADS-B performance	NO	YES (Validation for CASCADE program)	**YES**[9]	**L.** The only publicly available results are based on the CRISTAL UK activity.
DADI II	Datalinking of Aircraft-Derived Information The EC DG XIII project DADI has evaluated the concept of the use of airborne derived data in ground systems: http://cordis.europa.eu/telematics/tap_transport/research/projects/dadi.html DADI II will support the implementation of data link applications into ATM in the 2003-2005 time frame. This will focus on automatic downlink of airborne data	NO	NO Directly (mainly Air to Ground Communication – ADS-B derived data usage on the ground)	**YES**[10]	**L.** Air-ground communication + ground tools.
ECLECTIC	Electronic separation Clearance Enabling the Crossing of Traffic under Instrument meteorological Conditions 2002-2004	**G. Conflict Resolution: ASAS (Airborne Separation Assurance System), ACAS (Airborne Collision Avoidance System), etc.** Assessing operational feasibility and acceptability of ASAS Crossing Procedures (ACP) Contingency in case of “ASAS unavailability” * The ACP abortion does not mean immediate risk of collision * ATC should be able to recover * ATC may use half vertical separation as a last resort * ACAS *The ASAS application of ECLECTIC (ASAS Crossing) and all related work has been taken over by the ASSTAR project*	**H. Conflict resolution algorithms** CENA a déjà mis en œuvre sur un PC des algorithmes de croisement ASAS et la logique TCAS version 7. Cette machine sert de base au démonstrateur.	**YES**	***CONFLICT RESOLUTION*** **PE1. ASAS (Airborne Separation Assurance System) Crossing Procedures (ACP)**: procedures which allow the flight crew to provide separation with respect to one aircraft designated by ATC; the controller remains responsible for separation of other aircraft; Airborne Separation Minima values may be different from the radar one, may depend on the equipment. **PE2. Contingency procedures in case of “ASAS unavailability”**
EGNOS TRAN	EGNOS (European Geostationary Overlay Service) Terrestrial Regional Augmentation Network	**L. Current and future technological issues** EGNOS data are made available to the user via terrestrial networks to fill the geostationary coverage gaps due to urban environment and high latitudes. VDL Mode 4 technology not only extends the coverage of EGNOS signal, it provides Communication, Navigation and		**YES**	***TECHNOLOGICAL ISSUES: COMUNICATIONS*** **PE1. EGNOS (European Geostationary Overlay Service) Data:** terrestrial networks to fill the geostationary coverage gaps due to urban environment and high latitudes

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[9] but just few results available

[10] but probably more relevant for refinement of the A^3 ConOps

PROJECTS IDENTIFIED	NAME-DESCRIPTION	THE PROJECT INTRODUCES SOMETHING NEW TO THE TOPICS RELEVANT TO THE ConOps	THE PROJECT EVALUATES SOME METHODS ALREADY DEVELOPED	(Y/N)	POTENTIAL ELEMENTS IDENTIFIED
		Surveillance (CNS) capability in these difficult regions efficiently. The critical operations that are being evaluated and explored as part of EGNOS TRAN are APV-I precision approach and surface movement surveillance and guidance.			
EGOA	Enhanced General aviation Operations by ADS-B	Not directly, but it has some virtual value for iFly	1. Evaluation and validation of ADS-B and FIS-B for general aviation pilots 2. Evaluation and validation of ADS-B in a mixed radar and ADS-B environment from a ATC perspective	**YES**	**1.** An interesting example of technology evaluation and validation in field trials. **2.** The project suggests to use ADS-B on general aviation aircraft, military aircraft and UAVs to make them "visible" for ATC
EMERALD	EMErging RTD Activities of reLevance to ATM concept Definition	Not new but useful to know historically		**YES**	**1.** Assessment of ADS-B techniques for ASAS **2.** ASAS application for Autonomous Aircraft free flights **3.** Use of Extended Flight Rules (EFR) concept from FREER project (1997)
EMERTA	Emerging technologies opportunities, issues and impact on ATM			**YES**	**Utility for iFly** Provided the assurance that all relevant elements of data link network(s) and sub-networks (such as a satellite sub-network) are properly coordinated and interoperable, the applicability of **data links** to support air traffic services (ATS) **as largely replacing voice communications** is becoming more acceptable and spread. The use of this concept will enhance the safety of free flight aircrafts. Introduction of Automatic Dependent Surveillance-Broadcast / **Airborne Separation Assurance System (ADSB/ASAS)**
ERASMUS	En Route Air Traffic Soft Management Ultimate System	YES (Strategic speed-based CR)	Validation of the implemented strategic CR (not finished yet)	**YES**[11]	Strategic speed-based CR
FACES	FACES: a Free flight Autonomous and Coordinated Embarked Solver	Distributed algorithm, which provides an order of priority for aircraft in a cluster. A one against many algorithm is then applied in the given order.		**YES?**	
FALBALA	First Assessment of the operational Limitations, Benefits & Applicability for a List of Airborne Surveillance (AS) Applications (CARE/ASAS description of a first package of ground surveillance /airborne surveillance applications (package I)) Project ran from July 2003 to July 2004!!!	**G. Conflict Resolution: ASAS (Airborne Separation Assurance System)** It was recognised there is a need to know what will be the minimum avionics requirements for ASAS, and what level of aircraft equipage needs to be reached before the anticipated benefits can be gained. The need for clear operational requirements and procedures for use of ASAS was restated and the issue of cost of retro-fitting aircraft avionics was raised. **L. Current and future technological issues** The project brings elements for consideration by the future CDTI (Cockpit Display of Traffic Information) designers. These elements should also help defining required performances of an Airborne Surveillance and Data Processing system in the European airspace. The analysis of the maximum numbers of visible aircraft has also demonstrated the need for traffic filtering onboard the aircraft. **N. Airspace Organization** Qualitative analysis of the runway use, the use of radar vectoring to optimise the runway capacity while merging the arrival flows, the use of holding patterns to delay aircraft, the ordering of aircraft in the landing sequences	Validation and Assessment of the possible operational benefits brought by the three airborne surveillance applications selected from CARE (Co-operative Actions of ATM Research and Development in Eurocontrol)/ASAS description of a first package of ground surveillance /airborne surveillance applications: * Enhanced traffic situational awareness during flight operations (ATSA-AIRB) * Enhanced visual separation on approach (ATSA-VSA) * Enhanced sequencing and merging operations (ASPA-S&M)	**NO**	Project scope delimitated for TMA phase of flight

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[11] when the validation results will be available

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		and the spacing between successive aircraft in an arrival sequence. **M. Merging and Spacing** Some of the traffic characteristics were also addressed from a quantitative perspective, like the case for the spacing between aircraft in each arrival flow. **J. Human factors** The study concluded that there are potentially many benefits of sharing traffic information with flight crew via a CDTI if the clutter and head down time issues can be resolved. One of the few potential disadvantages identified may be a tendency for pilots to question or hesitate over controller instructions, although this is difficult to anticipate for real operations.			
FARAWAY II	An extension of Faraway (Fusion of Radar & ADS Data)	Not new but useful to know historically	Enhancement of ground surveillance and aircraft navigation by the use of ADS/TWDL.	**YES**	Expected benefits: **1.** For the Controller, a decrease in workload due to automated dialogue with the aircraft **2.** For the Pilot, a better contract negotiation with ground/air, improved situation awareness, lower cost to fly
Flight Deck Merging and Spacing	Hazard analysis that includes hazards similar to the ones iFly will be dealing with.	YES (Merging & Spacing)	YES (related to CoSpace)	**YES**	**F.** ASAS M&S application focused mainly on the optimization of airlines operations **I.** Shift of some responsibility from the ATC to the AOC (namely providing the traffic-to-flow and spacing info) **J.** Human factors involved in the hazard analysis **M.** Development and testing of M&S algorithms.
FlySAFE	FlySAFE designs, develops, implements, tests and validates a complete Next Generation Integrated Surveillance System (NG ISS), going a generation further than the emerging integrated safety systems. The project is the "strategic" follow-on to the ISAWARE and ISAWARE II projects in which the emphasis was more on "terrain and traffic" information presentation to the pilot	J,L,P, Weather Information System	B,J,L	**YES**[12]	Next Generation Integrated Surveillance System (NG ISS) Weather Information Management Systems (WIMS)
FRAP	Free Route Airspace Project: Eight States Free Route Airspace Project	**N. Free Flight Airspace (FFAS), Free Route Airspace and Restrictions for Free Flight on European airspace Airspace Organization** Free Route Airspace Concept. It recognises the need for airspace management and system adaptations and also identifies new needs. The Concept of Operations describes the operational procedures for General Air Traffic (GAT), Operational Air Traffic (OAT) and Air Traffic Management (ATM). **J. Human factors and goal settings of pilots and of airlines** Analysis of impact on Air Traffic Controllers: potential conflicts, instead of occurring at known points, will be widely dispersed among numerous random points. **L. Current and future technological issues** In February 2002 a FRAP report on Free Route Airspace Concept: System support will need enhancements in the areas of FPPS (Flight Plan Processing System) and FDPS (Flight Data Processing System). Additional system supports in providing controller tools are likely to be necessary to fully	**P. Risk & Safety Assessment** Review of the process undertaken and discussion on the lessons learned for further phases of work on the safety assessment of the FRAC, and for ATM safety assessment in general. Differences between Free Routes and the current Fixed Routes structure: * A comparative approach is useful in the early stages of safety validation, as it eliminates many of the uncertainties involved in making absolute judgements. * A comparative approach is necessary in order to demonstrate that the new system meets the ATM 2000+ objective that risk should not increase and, where possible, decrease.	**YES**	***AIRSPACE ORGANIZATION*** **PE1. Free Route Airspace (FRA):** the principal aim of the FRA concept is to remove the constraints imposed by the fixed route structure and through the optimised use of all the airspace obtain benefits of capacity, flexibility, flight efficiency and cost savings, while maintaining safety standards. Within FRA, Airspace Users shall be able to plan user-preferred trajectories. **PE2. FRA sectors, and FRA sector design** ***TECHNOLOGICAL ISSUES*** **PE3. Additional (air and ground) system supports:** system support will play a major role in enabling the FRA to be implemented, i.e. **PE3.1: Real-time Airspace Database** ***SAFETY ISSUES*** **PE5. Safety Requirements (even in failure conditions):** If these safety requirements can be practically and effectively implemented, the implementation of FRA concept is expected to meet the principal Safety Objective of ensuring that risk does not increase and where possible is reduced.

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[12] but the project is not finished yet, i.e. just limited results

PROJECTS IDENTIFIED	NAME-DESCRIPTION	THE PROJECT INTRODUCES SOMETHING NEW TO THE TOPICS RELEVANT TO THE ConOps	THE PROJECT EVALUATES SOME METHODS ALREADY DEVELOPED	(Y/N)	POTENTIAL ELEMENTS IDENTIFIED
		exploit the advantages of Free Route Airspace. In a complex airspace, MTCD (Medium Term Conflict Detection) tools are expected to be prerequisite			
HYBRIDGE	Distributed Control and Stochastic Analysis of Hybrid Systems Supporting Safety Critical Real-Time Systems Design The HYBRIDGE project has developed innovative approaches to handling uncertainty in air traffic management. iFly can be considered a follow-on to the Hybridge project. At the end of (and following) Hybridge an autonomous aircraft concept (AMFF) was assessed *WP9: Risk assessment for a distributed control system.*	YES	YES	**YES**	YES
IAPA	Implications on Airborne Collision Avoidance System (ACAS) Performances due to Airborne Separation Assistance System (ASAS) implementation	YES (G – methodology to study ASAS/ACAS interaction)	YES (G – ASAS/ACAS Interaction Study, P)	**YES**	**G.** The recommendations of IAPA project about the ACAS / ASAS interaction should be respected. **G, P.** The IAPA methodology has proven successful in assessing the ACAS / ASAS interaction issue and would equally benefit to any future investigation of the interaction between ACAS and ATM changes in the provision of separation.
INOUI	INOUI focuses on developing roadmap documents and know how to provide a path for integrating UASs (Unmanned Aircraft Systems) into the future ATM System. INOUI aims amongst other on supporting SESAR in its task of creating a master plan, including a research and development plan, up to the year 2020.	No information available	No information available	**NO**	No information available
ISAWARE II	Increasing Safety by enhancing crew situation AWAREness The project is largely based upon information available on-board of aircraft, to pre-process this information, to prioritise and to present the results in visual and oral ways consistent with the natural perception of the crew. The concept developed is an Integrated Situation Awareness System (ISAS). This ISAS concept not only intends to greatly improve the situation awareness of the crew, but also should quicken their reaction	J (Human Machine Interface, unfortunately mainly considering approach and landing, the terrain awareness, and taxi; smart alerting system).	J (Validation of the HMI)	**YES**	**J.** Human Machine interface (including Synthetic Vision System)
MEFISTO	Modelling, Evaluating and Formalising Interactive Systems using Tasks and interaction Objects It intends to contribute to the design of user interfaces for safety critical interactive systems with special reference to Air Traffic Control (ATC) applications			**NO?**	**Utility for iFly** In its main objective (the design of new interfaces for controllers), Mefisto is probably not relevant: we can NOT expect to turn pilots into controllers, thus tools developed for controllers can not be integrated into cockpits. However, the design methods developed in the first steps of the project might be interesting for IFly since these methods as well provide ways to validate the usability and safety requirements.
Mode S/ACAS (MSA)	Secondary Surveillance Radar Mode Select (SSR Mode S) is a development and enhancement of 'classic SSR'. Aircraft Collision Avoidance System (ACAS) improves air safety by acting as a "last resort" method for preventing mid-air or near collisions between aircraft.	NO	NO (Implementation programs, the Mode-S and TCAS II functionalities must be considered within the ConOps)	**YES**	**F.** The European policy regarding ACAS II is to require the mandatory carriage and operation of an airborne collision avoidance system by defined civil aircraft in the airspace of the ECAC Member States. This implementation process is managed by the Mode S & ACAS Program in EUROCONTROL on behalf of the ECAC (European Civil Aviation Conference) States. **L.** The requirements of Mode S EHS apply to IFR flights as GAT by fixed wing aircraft having a maximum

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					take-off mass greater than 5,700 kg, or a maximum cruising true airspeed in excess of 250kt, in the designated airspace of Germany and the United Kingdom from 31 March 2005, and France from 31 March 2007. A 2 year transition period was in place up to 30 March 2007, during which a co-ordinated exemption policy was applied by implementing states, managed through the Mode S Exemption Co-ordination Cell (ECC). **F.** TCAS II, Version 7.0 is the only equipment, which complies fully with ACAS II Standards And Recommended Practices (SARPs), published by the International Civil Aviation Organization (ICAO). Therefore TCAS II version 7.0 is required to meet the ACAS II mandate in the ECAC Member States.
NAAN	North Atlantic ADS-B Network	NO	YES	**NO**[13]	**L.**
NEAP	North European ADS-B Applications Project	NO	YES	**NO**[14]	**L.**
NEXTGEN	Concept of Operations of Next Generation Air Transportation System (Joint Planning and Development Office).	YES (ConOps of the overall Air Traffic)	NO	**YES**[15]	**R.** (covering **A, I, L, N, O** but just ConOps)
PHARE	Programme for Harmonised ATM Research in EUROCONTROL	The **P**rogramme for **H**armonised **A**TM **R**esearch in **E**UROCONTROL (PHARE) was European collaborative research programme to investigate a future ATM concept in 1989-1999.	Some projects under PHARE umbrella may still be of partial interest to some iFly WPs.	**YES**	Of some interest to some WPs may be: Flight path monitoring, Conflict solving assistance, Co-operative tools, Airborne human machine interface, Trajectory prediction, Datalink, Operational concepts, PHARE demonstrations
RESET	Reduced Separation Minima	**C. Separation Minima (SM)** Identification per flight phase, feasible SM reductions contributing to safely reaching the traffic increase. Development of methods to safely (fulfilling ICAO/ESARR requirements) and cost-effectively assess the prioritised separation minima reductions. This includes developing a multi-criteria assessment method that will be able to integrate and synthesize results of the Safety, Human Factors, Efficiency and Economy Assessments. State Vector Modelling Approach. **P. Risk & Safety Assessment** Safety assessments for reduced SM and assessment of their impact on technology needs. Evaluation of safety risks for a variety of flight scenarios relating to final approach, landing, and roll-out for parallel and single runways **M. Merging and Spacing** Airborne spacing assumes air-to-air surveillance (ADS-B) along with cockpit automation (ASAS). No significant change on ground systems is initially required Airborne spacing involves a new task allocation between controller and flight crew envisaged as one possible option to enhance the management of arrival flows of aircraft. **J. Human factors and goal settings of pilots and of airlines** Identification of what traffic growth and reduced SM mean for pilots and controllers roles, tasks and responsibilities.	RESET uses the C-ATM Phase 1 Concept as staring point to address Separation Minima (SM) as constraining physical factor limiting capacity growth and the operational concept improvements required to deliver extra capacity, brought about by new technologies, evolving controller & pilot roles and changing tasks and procedures **C. Separation Minima** Separation Minima List, a table self-explanatory that contains information of the standards laid in regulations down. Review of existing standards and practices related to aviation safety minima and target level of safety **P. Risk & Safety Assessment** Overview of Techniques, Methods, Databases, or Models that can be used during a Safety Assessment	**YES**	***SEPARATION MINIMA*** **PE1. Separation Minima (SM) reductions** ***HUMAN FACTORS*** **PE2. New task allocation between controller and flight crew**
ROSALIE	Required Off-line Simulator for ASAS Logic	Did not get into private area of the website, but according	The Technical review from CENA gives a	**?**	ASAS

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[13] Consider NUP instead
[14] Consider NUP instead
[15] The concept of future traffic organization over the US

PROJECTS IDENTIFIED	NAME-DESCRIPTION	THE PROJECT INTRODUCES SOMETHING NEW TO THE TOPICS RELEVANT TO THE ConOps	THE PROJECT EVALUATES SOME METHODS ALREADY DEVELOPED	(Y/N)	POTENTIAL ELEMENTS IDENTIFIED
	Implementation and Evaluation	to the acronym the scope of the project could be too narrow to consider directly useful for iFly ConOps	nice overview of the ASAS for beginners		
RTCA SC 186	RTCA, Inc. is a private, not-for-profit corporation that develops consensus-based recommendations regarding communications, navigation, surveillance, and air traffic management (CNS/ATM) system issues. RTCA functions as a Federal Advisory Committee. Its recommendations are used by the Federal Aviation Administration (FAA) as the basis for policy, program, and regulatory decisions and by the private sector as the basis for development, investment and other business decisions	NO	NO	**YES**[16]	**L.** Minimum Operational Performance Standards: 1090ES ADS-B and TIS-B (DO-260A); UAT ADS-B (DO-282A); **L.** Minimum Aviation System Performance Standards: ADS-B (DO-242A), TIS-B (DO-286A); Description of the concept of the Airborne Conflict Management (DO-260A); and CDTI: Guidance for implementation (DO-243), and Application Descriptions (DO-259).
SAFE FLIGHT 21	Safe Flight 21 The Safe Flight 21 program is developing and evaluating the use of Automatic Dependent Surveillance – Broadcast (ADS-B) capabilities	Last Operational Evaluation in 2000! project closed? documents and papers? **L. Current and future technological issues** The technologies on which this program is based include the Global Positioning System (GPS), Automated Dependent Surveillance - Broadcast (ADS-B), Flight Information Services (HS), Traffic Information Service - Broadcast (TIS-B), and their integration with enhanced pilot and controller information displays		**YES**	***TECHNOLOGICAL ISSUES*** **PE1. ADS-B (Automated Dependent Surveillance - Broadcast)** **PE2. CDTI (Cockpit Display of Traffic Information)**
SAFEE	Security of Aircraft in the Future European Environment The overall vision for SAFEE is the construction of an advanced aircraft security system designed to prevent on-board threats. The main goal of this system is to ensure a fully secure flight from departure to arrival destination whatever the identified threats are	**L. Current and future technological issues** SAFEE airborne elements: Emergency Collision Avoidance System (EAS) and Flight Reconfiguration Function (FRF). ISDEFE contributions to EAS: * IO 31221 within D3122: Sections 7.5,7.6, 7.7, 7.8 * D3124: Sections 3.6, 3.6.1 * D3.2.3.1: Sections 3.3.1.5.2.2, 3.3.2.5.2.2 **J. Human factors, responsibilities and liabilities** The novelty of SAFEE creates new perspective of pilot in command authority. When the aircraft is not controlled by the pilot in command, who is responsible then?	SOFIA project is proposed as the continuation of the SAFEE works on Further Route of Flight (FRF), the system to automatically return the aircraft to ground	**NO**	
SASS-C	Surveillance Analysis Support System-Centre The SASS-C is a software toolbox developed by EUROCONTROL to provide standardised methods and tools for assessing the performance of Surveillance infrastructures.	Seems irrelevant to iFly, but maybe the reviewer has mistaken?	SASS-C is an ATC-Centre based Surveillance Analysis (software) workbench for ATC Radar Plot Analysis and Tracker Performance Measurements	**NO**	
SEAP	South European ADS-B Project Large Scale European ADS Pre-implementation Programme. Project proposed to implement new operational concepts, equipping a large number of aircraft with an ADS system, upgrading current air-traffic control centre systems and installing ADS ground stations	**P. Risk & Safety Assessment**	SAND (Safety Assessment for New Designs) is being applied to produce the safety deliverables of the SEAP project with a link to the standardisation of ADS-B supported services. The production of SEAP safety deliverables are the first step to the establishment of standards for ADS-B supported applications (link with Requirements Focus Group)	**NO**	
SIVA	Development of UAVs (Unmanned Aircraft Vehicles): integrated aerial surveillance system Base para el desarrollo del sistema TUAV (Tactical Unmanned Air Vehicle) LA del Ejercito Sistema Demostrador SIVA (Sistema Integrado de Vigilancia Aerea) propuesto como "puente" para la introduccion de sistemas operacionales			**NO**	

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[16] Standards, guidelines

PROJECTS IDENTIFIED	NAME-DESCRIPTION	THE PROJECT INTRODUCES SOMETHING NEW TO THE TOPICS RELEVANT TO THE ConOps	THE PROJECT EVALUATES SOME METHODS ALREADY DEVELOPED	(Y/N)	POTENTIAL ELEMENTS IDENTIFIED
	en el Ejercito				
SMAA	Study of the Mediterranean and Adjacent Areas for ADS. Analysis of the infrastructures existing in the Mediterranean area, its limitations and the possible solutions offered by ADS		identification of findings with regard to benefits introduced by ADS	**NO**	
SOFIA	Safe Automatic Flight Back and Landing of Aircraft It is a response to the challenge of developing concepts and techniques enabling the safe and automatic return to ground in the event of hostile actions. SOFIA project is proposed as the continuation of the SAFEE works on Further Route of Flight (FRF), the system to automatically return the aircraft to ground.	**L. Current and future technological issues: air-ground communication and air-air communication** Architectures design for integrating the FRF (Further Route of Flight) system into several typologies of avionics for civil transport aircraft. The flight plan can be generated in ground (ATC) or in a military airplane and transmitted to the aircraft, or created autonomously at the own FRF system. The execution of the new flight plan is autonomously performed by FRF without any control from ground. Additionally, SOFIA will investigate the integration of such solution into different airspace environments: current ATM, ASAS/ADS-B, automation of ground functions, airspace with/without radar coverage, CDM, 4D trajectory negotiation. **P. Risk & Safety Assessment** (not as a function of traffic increase) Safety assessment of FRF at aircraft and operational (ATC) levels (applying ESARR)		**YES**	***TECHNOLOGICAL ISSUES: NAVIGATION*** **PE1. Further Route of Flight system (FRF)** and its integration into different airspace environments
SUPERHIGHWAY	Development of an Operationally Driven Airspace Traffic Structure for High-Density High-Complexity areas based on the use of Dynamic Airspace and Multi-Layered Planning	**O. Airspace Division** Development of an innovative airspace traffic structure based on the simplification of the route network around the major European traffic flows. Elaboration of a set of Operational Concept Scenarios **B. Conflict Prediction** Improvement of the situational awareness arising from the use of Collaborative Decision Making (CDM) procedures and technological enablers **I. Distribution of Conflict Resolution responsibility (automation/human, ground/air)** ATM efficiency enhancement by decreasing controller workload per aircraft, ensuring on time performance, positive impact on the Capacity and the Economy high-level objectives.: * moving task to the pilot (ASAS) * moving task to the ATC (automation concept) * improving the airspace design D1.2 performs an extensive review of the existing literature related to the SUPER HIGHWAY concept.	*A simplified airspace environment should result in easier to attain situational awareness*. This assumption is based partly on direct observations and partly on the results obtained from the GATE-TO-GATE project.	**YES**	***AIRSPACE ORGANIZATION*** **PE1. Innovative airspace traffic structure vs. classical sectorised airspace.** The new airspace structure will make full use of the Operational Concept Document principles, and in particular of *Layered Planning*, *System Wide Information Management (SWIM)*, and *Distributed Air and Ground responsibilities*, to increase available ATM en-route capacity in the high-density areas. The traffic structure will be located on the Single European Sky functional blocks of airspace. **PE1.1. Dynamic Airspace** **PE1.2. System Wide Information Management (SWIM)** **PE1.3. Multi-Layered Planning** ***CONFLICT PREDICTION*** **PE2. Collaborative Decision Making (CDM) procedures**, applied to Airspace Management SWIM. To increase predictability the use of CDM is also proposed to reconcile **4D air and ground data (PE2.1)**, and for **provision of conflict free routes (PE2.2)** **PE3. Segregation of traffic flows,** **PE4. Improvement of planning horizons,** are some of the several solutions identified for safety improvements, that highly depend on an increase in awareness for the controller as well as for the pilot. This is based on the knowledge of the surrounding traffic. ***CONFLICT RESOLUTION*** To reduce the probability of conflict three separate solutions are proposed: **PE5. ASAS**

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					PE6. Trajectory based procedures **PE7. Application of pilot delegated separation management** ***TECHNOLOGICAL ISSUES*** **PE8. Technological enablers**: communication, navigation and surveillance technologies. The improvement of ATC advanced tools such MONA or MTCD should be considered as well as human factor issues.
VDL Mode 4	Eurocontrol-VDL Mode 4 is a VHF data link technology, standardised by ICAO, and designed to support CNS/ATM digital communications services	**L. Current and future technological issues: air-ground communication and air-air communication** The very high frequency (VHF) digital link (VDL) Mode 4 provides data service capabilities. The data capability is a component mobile subnetwork of the aeronautical telecommunication network (ATN). VDL Mode 4 is considered in as: * a candidate point-to-point data link in support of advanced applications with strict Quality of Service (priority, time critical etc.), when such applications will be operationally required; * a candidate ADS-B data link (in complement to 1090 ES) to support Package 1+ type of applications. Possible future element of the Mobile Network Service (MNS). The crucial issues for positioning VDL Mode 4 in aeronautical communication and surveillance are: * definition of frequency planning criteria * airborne co-site interference assessment * capacity/performance analysis		**YES**	***TECHNOLOGICAL ISSUES: COMMUNICATIONS*** **PE1. VHF Data Link Mode 4 (VDL-4):** a very robust data link that guarantees that critical data (aircraft's position, speed, direction and intent) is received at all nearby airborne and ground locations. VDL Mode 4 uses a protocol (STDMA) that allows it to be self-organizing, meaning no master ground station is required.

14.3 Appendix C: List of projects reviewed

3FMS	Free Flight - Flight Management System
AATT	Advanced Air Transportation Technologies
ACAST	Advanced CNS Architectures and System Technologies
ADS-MEDUP	ADS Mediterranean Upgrade Programme
AFAS	Aircraft in the Future ATM System
ARDA	Aviation Research and Developments Activities
ASAS-TN2	Airborne Separation Assistance Systems Thematic Network 2
ASSTAR	Advanced Safe Separation Technologies and Algorithm
Australian UAP	ADS-B Upper Airspace Program
CARE-ASAS	Action Plan on Airborne Separation Assurance Systems
C-ATM	Co-operative ATM
CRISTAL Program	
DADI II	Datalinking of Aircraft-Derived Information
ECLECTIC	Electronic separation Clearance Enabling the Crossing of Traffic under Instrument meteorological Conditions
EGNOS TRAN	EGNOS (European Geostationary Overlay Service) Terrestrial Regional Augmentation Network
EGOA	Enhanced General aviation Operations by ADS-B
EMERALD	EMErging RTD Activities of reLevance to ATM concept Definition
EMERTA	Emerging technologies opportunities, issues and impact on ATM
ERASMUS	En Route Air Traffic Soft Management Ultimate System
FACES	Free flight Autonomous and Coordinated Embarked Solver
FARAWAY II	An extension of Faraway (Fusion of Radar & ADS Data)
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EMERALD	EMErging RTD Activities of reLevance to ATM concept Definition
EMERTA	Emerging technologies opportunities, issues and impact on ATM
Flight Deck Merging and Spacing	Flight Deck Merging and Spacing
FlySAFE	
FRAP	Free Route Airspace Project: Eight States Free Route Airspace Project
FREE FLIGHT	Free Flight with Airborne Separation Assurance
FREER	Freer Flight Since 2002, the project has been (re)named CoSpace - Towards the Use of Spacing Instructions
GATRE TO GATE	Gate-to-Gate Programme
HYBRIDGE	Distributed Control and Stochastic Analysis of Hybrid Systems Supporting Safety Critical Real-Time Systems Design
IAPA	Implications on ACAS Performances due to ASAS implementation
INTENT	The Transition towards Global Air and Ground Collaboration In Traffic Separation Assurance
ISAWARE II	Increasing Safety by enhancing crew situation AWAREness
MA-AFAS	More Autonomous Aircraft in the Future ATM System
MFF	Mediterranean Free Flight Programme

Mode S/ACAS (MSA)	Mode S/ACAS (MSA)
NEXTGEN	Concept of Operations of Next Generation Air Transportation System
NUP, NUPI & NUP IINUP II+	North European ADS-B Network (NEAN) Update Programme:
PHARE	Programme for Harmonised ATM Research in EUROCONTROL
RESET	Reduced Separation Minima
RTCA SC 186	RTCA, Inc. is a private, not-for-profit corporation that develops consensus-based recommendations regarding communications, navigation, surveillance, and air traffic management (CNS/ATM) system issues
SAFE FLIGHT 21	
SOFIA	Safe Automatic Flight Back and Landing of Aircraft
SUPERHIGHWAY	Development of an Operationally Driven Airspace Traffic Structure for High-Density High-Complexity areas based on the use of Dynamic Airspace and Multi-Layered Planning
VDL Mode 4	
RTCA SC 186	RTCA, Inc. is a private, not-for-profit corporation that develops consensus-based recommendations regarding communications, navigation, surveillance, and air traffic management (CNS/ATM) system issues

14.4 Appendix D : WP1 relation to other iFly Work Packages

The constituent elements of the A^3 concept are tightly interconnected with the other iFly work packages. Work undertaken within WP1 have been supported by findings developed by other work packages and conclusions described in this deliverable are expected to be useful for following phases of the research.

Since changes in the air traffic management system as a result of technological advances cause changes in the role of the people involved in that system, WP2 has to identify current and new airborne responsibilities carried out by the cockpit crew during the en-route phase of flight. Human responsibility is a key factor in determining to what extent a system can be automated. To achieve a highly automated air traffic management system, the possibility for assigning more responsibilities to the airborne crew than in the current situation should be explored. WP1 will use the results of the airborne responsibilities analysis performed within WP2 to develop the A^3 ConOps.

After having identified what responsibility issues arise in a highly automated ATM environment, the proposed A^3 ConOps will be assessed within the second part of the human responsibilities analysis performed within WP2 to identify potential bottlenecks with respect human responsibility issues and to investigate potential ways to solve them.

Methods developed within WP3 for timely prediction of potentially complex traffic conditions and avoiding encounter situations that seem to be safe from the individual aircraft perspective, but are actually safety-critical from a global perspective, should take into account the potential support needs identified within the autonomous ATM concept developed in WP1.

The multi-agent situation awareness consistency analysis and assessment of the A^3 concept proposed in WP1 will support the ambitious goals of increasing efficiency of air traffic control. The approach performed within WP4 to develop hybrid models for the multi-agent ATM case and then to develop observers for these distributed hybrid systems is essential to evaluate the procedures proposed in WP1.

Conflict resolution needs of the A^3 concept proposed in WP1 should be identified. Then, the most advanced conflict resolution algorithms that have been developed within the free flight community together with radically novel approaches will be implemented to fulfil the requirements emerging from the autonomous aircraft concept developed within WP1.

In the process of preparing the methodology for the cost-benefit analysis of the iFly operational concept (WP6) it has been determined a set of critical issues closely related to the cost-benefit analysis, which should be addressed by the A^3 ConOps:

1) Definition of the airspace area covered by the iFly concept. The airspace area covered by the iFly constitutes a critical parameter for assessing the associated operational improvements (i.e. capacity increase, flight efficiency, and reduction of Air Traffic Flow Management (ATFM) delay) emerging from the introduction of the A^3 operational concept.
2) Identification of the on-board technologies needed for the introduction of the iFly concept. Any new types of technologies or on-board systems required by the iFly operational concept will definitely affect the overall cost of the iFly operational concept.
3) Specification of the time horizon and the start year of the cost benefit analysis. Both parameters depend on the duration of the development and implementation of the proposed iFly operational concept.

In order to asses what traffic demand can be safely accommodated by the A^3 operational concept developed by WP1 and the efficiency of flights, hazard identification and Monte Carlo simulation on accident risk as a function of traffic demand will be performed within WP7.

During the second design cycle of the new concept of operations proposed by the iFly project, WP8 will refine A3 elements using the innovative methods and architecture implications obtained from WP3, WP4 and WP5. In addition, use is made of feedback from WP2, WP6 and WP7 developing a vision how A3 equipped aircraft can be integrated with SESAR concept.

Finally, in order to describe the airborne safety, performance and system design requirements to support the refinement of the A^3 concept defined in WP8, the A^3 ConOps from WP1 will be used.