Project no. TREN/07/FP6AE/S07.71574/037180 IFLY

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

iFly Deliverable D9.4

Airborne System Design Requirements of Airborne Self-Separation Procedure

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Honeywell

Version: 1.1

DOCUMENT CONTROL SHEET

Title of document: ***Airborne System Design Requirements of Airborne Self-Separation Procedure***

Authors of document: Petr Cásek, Ítalo Romani de Oliveira

Deliverable number: *D9.4*

Project acronym: *IFly*

Project title: *Safety, Complexity and Responsibility based design and validation of highly automated Air Traffic Management*

Project no.: *TREN/07/FP6AE/S07.71574/037180 IFLY*

Instrument: *Specific Targeted Research Projects (STREP)*

Thematic Priority: *1.3.1.4.g Aeronautics and Space*

DOCUMENT CHANGE LOG

Version #	Issue Date	Sections affected	Relevant information
0.1	11.1.2011		1st draft
0.2	21.1.2011	All	2nd draft
1.0	28.2.2011	All	NLR feedback
1.1	30.6.2011	Sections 1,2,3,4, Appendix H	EC feedback

Version 1.0		Organisation	Signature/Date
Authors	Ítalo Romani de Oliveira	HNWL	
	Petr Cásek	HNWL	
Internal reviewers	Henk Blom	NLR	
	Frank Bussink	NLR	
External reviewers	Uwe Voelckers	Independent (EC)	

Table of Contents

1. Introduction

After World War II, the Air Traffic Management system has utilized a concept, where the responsibility for aircraft separation lies solely on air traffic controllers. Aircraft fly along predefined flight paths and each aircraft is monitored by a controller, who has an overview of the situation in his sector and beyond and guides aircraft towards their destinations via a sequence of waypoints.

The motivating idea for airborne self separation is the possibility to overcome the performance limitations of the current system by taking advantage of using distributed control principles and new airborne technologies. In particular, data links will enable aircraft to monitor their surroundings and develop a “big picture” about the traffic and other hazards themselves. It is expected that the information about the surrounding environment will be sufficiently accurate and reliable, so a flight crew will be able to assess the situation, plan the trajectory and avoid conflicts with aircraft or other hazards.

Although during recent years airborne self-separation has been studied through many ATM research projects, most of these studies have addressed less dense airspace. This is rather surprising if one takes into account that airborne self-separation was originally intended to be a possible solution for ATM in high density airspace.

The iFly project picks up the challenge of studying the feasibility of airborne self separation in high density airspace. Instrumental to this feasibility study, iFly aims to develop an advanced airborne self separation design together with a vision how well-equipped aircraft can be integrated within SESAR. Hence iFly does not intend to develop a fully defined airborne self separation design, but aims to investigate the boundaries of an advanced airborne self separation concept of operations.

Through a sequence of studies within iFly, an advanced airborne self separation concept has been proposed under the name of Autonomous Aircraft Advanced (A3) ConOps, and documented in [D1.3]. This A3 ConOps concentrates on the airborne self separation for en-route operations in a net centric environment where only appropriately equipped aircraft fly. The responsibility for airborne self-separation lies entirely on so called autonomous aircraft (combination of airborne system and the flight crew) without ground support from air traffic controllers.

iFly Work Package WP9 builds on the [D1.3] report, firstly with WP9.1, which provided an Operational Services and Environment Description (OSED – D9.1) document of the A3 ConOps, developed in accordance with the guidelines provided by EUROCAE ED-78A/RTCA DO-264. This document provided a sufficiently detailed description of the A3 operations to enable Operational Safety Assessment (OSA – D9.2) and Operational Performance Assessment (OPA – D9.3), performed in WP9.2 and WP9.3, respectively.

Building on the previous deliverables of WP9, the present document defines the preliminary system design requirements for airborne systems to support A3 operations.

1.1 Organization of this report

In the remainder of the document, the operational, safety and performance requirements identified, respectively, in WP 9.1, 9.2 and 9.3 will be combined and, together with the findings of WP6, WP7 and WP8 available to the moment will generate new requirements from a system design perspective for the airborne self-separation (SSEP).

This Section presented the introduction to this Work Package and this report. Section 2 provides an overview of the considered SSEP operations; after this, Section 3 presents a Functionally-Oriented Architecture developed to enable robust, realistic and cost-effective system implementations; finally, this architecture is explored in Section 4 to allocate the system design requirements extracted and developed from the previous iFly deliverables.

To complement the main text, explanatory and detailed reference information is provided in the appendices. Appendix A brings assumptions about System Wide Information Management (SWIM), which plays a key role in A3 communications; Appendix B presents a summary of assumptions from the previous deliverables of the WP9 (D9.1, D9.2 and D9.3); Appendix C summarizes the requirements defined in the OSED (D9.1); Appendix D complements the final remarks of the main body text (Section 5); Appendix E and F briefly describe the results of WP3 and WP5, respectively, and how they are viewed and related with the perspective of WP9; and, finally, there are some listings: Appendix G with the reference documents and publications, Appendix H with the abbreviations, and Appendix I with the parameters used for the description of Conflict Detection and Resolution (CD&R) logic.

2. SSEP Operations Overview

A typical airborne self separation flight may have the following progression: An aircraft takes off from the airport and climbs through the departure TMA, where the traffic flow is controlled by the Air Navigation Service Provider (ANSP) who is responsible for aircraft separation. For each flight there is an agreed and shared flight trajectory (so-called Reference Business Trajectory (RBT)) up to the destination allowing to balance the capacity/demand en-route and at the destination TMA and airport. For this purpose there is a flow constraint associated to the flight at the entering fix of the destination TMA in the form of a 3D point with a Controlled Time of Arrival (CTA) restriction.

When leaving the departure TMA, the responsibility for separation is shifted from the ANSP to the flight crew. The following en-route part of the flight (located within so-called Self Separation Airspace (SSA)) is performed according to SSEP operations. During this phase of flight, the flight crew can modify the SSA-part of the RBT without negotiation with any ANSP (but taking into account the relevant traffic), provided that defined Autonomous Flight Rules (AFR) are satisfied and that the CTA at the destination TMA will be achieved. Nevertheless, if there is a need to modify the CTA constraints, such change must be negotiated with the ANSP at the destination TMA. The aircraft need not to follow any predefined airway or flight level structure.

When the aircraft approaches the destination TMA, the responsibility for separation is shifted back from the flight crew to the ANSP and the self-separation part of the flight is terminated.

The scope of the iFly operational definition (A3 ConOps (D1.3), OSED (D9.1), OSA (D9.2) and OPA (D9.3)) is not to describe the whole self separation flight but to focus only on its part within SSA. Therefore the transitions procedures and operations in the departure and terminal TMA are out of the scope of this document.

In addition to the assumptions from OSED, OSA and OPA, several other assumptions are taken from the outcomes of other WPs. These assumptions may be relevant to delimited parts of the architecture, in which case they are enunciated together with the requirements in subsections of Section 4, or may be relevant to the whole system, in which case they are presented in Section 2.3.

2.1 SSEP Operations According the A3 ConOps

The goal of the self separation operations described in the A3 ConOps is to prevent Loss of Separation (LoS), collision avoidance (preventing a collision in the case of LoS) being handled in the same way as within the ATC-managed airspace. During these operations, the flight crew takes advantage of the onboard equipment, which is monitoring the surroundings and helps the flight crew to detect and resolve potential conflicts. When such a conflict is detected, the onboard equipment proposes a solution(s), which is (are) assessed by the flight crew. Subsequently, the flown trajectory is updated with the solution selected and approved by the flight crew. Note, that **any processes directly influencing (beyond a threshold which should be defined) the flown trajectory may be executed only when approved by the flight crew.**

Within SSA the information exchange among aircraft will primarily be assured through data link, voice communication (for instance, among imminent aircraft) will be limited and used mainly in emergency situations. The aircraft has to continuously broadcast information about its state and if possible intent, to allow other participants to predict its planned trajectory.

In case of a potential conflict, the involved aircraft will not broadcast any additional information and there is neither requirement for any additional individual data exchange among conflicting aircraft. **The coordination of actions among conflicting aircraft is enabled by the set of rules included in AFR, which are binding for all participants.** Based on the set of rules defined in A3 ConOps there are two types of Conflict Resolution (CR) processes:

- (**CR1**) For urgent conflicts (time to predicted LoS shorter than a predefined threshold) all conflicting aircraft must maneuver and the applied maneuvers shall be coordinated through so-called **implicit coordination**. The latter is based on the use of compatible algorithms that generate complementary maneuvers onboard the conflicting aircraft.

- (**CR2**) Conflicts with the time for maneuvering greater than the predefined threshold are solved using the **Priority rules principle** in order to prevent excessive number of maneuvering aircraft. This means that there are predefined rules which assign a priority number to each aircraft and the conflict is actively solved only by aircraft with a lower priority. The aircraft with higher priority simply continues to fly its original trajectory. The priority of aircraft evolves during the flight and is primary determined by the aircraft maneuverability, mission statement and the remaining time to CTA (when aircraft has to meet a time constrains, it has higher priority).

The predefined threshold which allows choosing between CR1 and CR2 is defined as Short Term time Threshold (**STT**).

2.2 Summary of the OSED

This section provides a summary of the SSEP services and environment description, presenting: the definitions of the communications environment (Section 2.2.1); the assumed high level system functional architecture (Section 3); and the model of onboard conflict processing (Section 2.2.2), which is fundamental to many of the subsequent assumptions and requirements. Complementing this information, the operational assumptions, initial performance and safety assumptions identified within the OSED development, and the formal operational requirements, can be found in Appendices B and C.

2.2.1 Communications Operational Environment Overview

The information sharing process is a key enabler of SSEP operation. All information exchange during the SSEP operation may be divided into three main types:

- **Information broadcast** by autonomous aircraft (only ADS-B considered so far).
- **Information provided to/by a ground supporting system (SWIM)**. For the purposes of this document, the System Wide Information Management (SWIM) is assumed to be the main ground-based tool for information sharing. As its structure and capacity is not defined yet, the airborne system requirement definition is based on a set of operational assumptions about SWIM which can be found in Appendix A.
- **Voice communication** will remain the backup means of communication in nonstandard or emergency situations.

As it is possible to envision various implementations of SSA with different performance requirements and different level of ground support, three Service Levels are considered in this OSED:

- **Service Level 1 (SL1)** – all autonomous aircraft are broadcasting only state information.
- **Service Level 2 (SL2)** – all autonomous aircraft conform to SL1 and in addition they broadcast intent information allowing a prediction of the trajectory planned by other aircraft for the Mid-Term Time Horizon (**MTTH**). The MTTH specifies the minimum length (in time) of trajectory that will be possible to rebuild from the broadcast intent information.
- **Service Level 3 (SL3)** – all autonomous aircraft conform to SL2 and in addition there is a ground information sharing (SWIM) support. This level corresponds to the complete system described in the A3 ConOps (iFly: D1.3).

Figure 1 provides an overview of the A^3 communications environment, in which the main communication elements and exchanges are illustrated. In this schematic representation, there are different horizons of communication: the *Air-Air Datalink Range*; the *Medium Term Awareness Zone* (MTAZ), which includes aircraft inside a time range determined by MTTH, and the *Long Term Awareness Zone* (LTAZ), including aircraft in ranges beyond MTTH, up to limits to be determined by ongoing research, and varying according to ground infrastructure to be available.

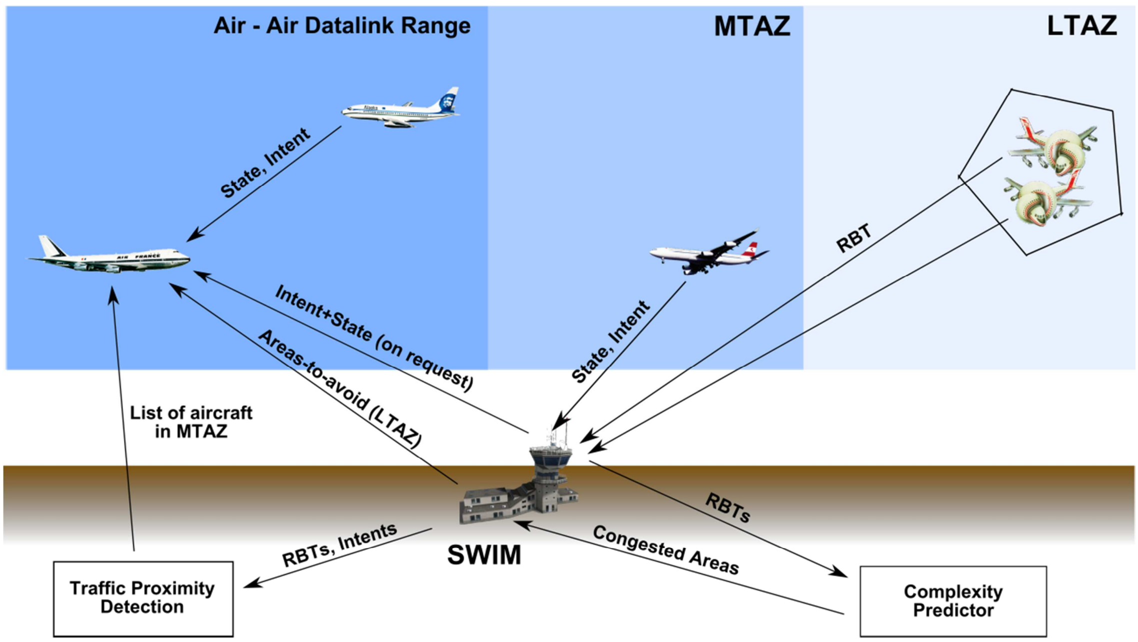

Figure 1: Information sharing process (from D1.3).

2.2.2 Onboard Conflict Processing

The high level description of onboard processing is needed here, in order to make clear the subsequent requirements. The parameters defined in this section are used in the requirements on the airborne system behavior and may vary among different implementations. They are focused mainly on the processing of airborne system inputs (available information) and the generation of system outputs (e.g., CR maneuvers).

The generic model of the onboard conflict processing is shown in Figure 2. After the detection of a conflict, the *event/situation is assessed* and a suitable CR method is chosen. The applicable conflict resolution function then solves the situation based on the *Updated information* and presents a proposed solution(s) to the flight crew. After approval by the flight crew, the solution is initiated (and its execution starts) and at the same time the new intent is broadcast to surrounding aircraft and sent to SWIM (SL3).

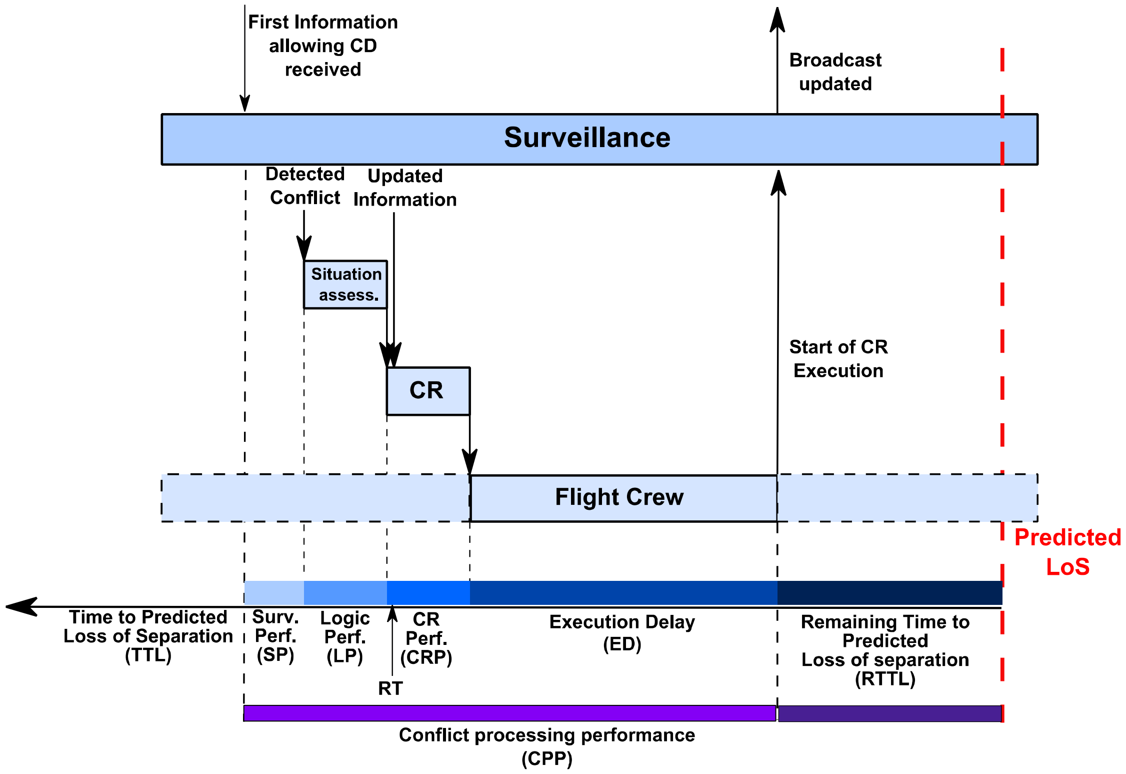

Figure 2: A generic model of onboard conflict processing.

This graph allows for the definition of performance parameters used in the functional and performance requirements development. The model includes the following parameters:

- **Surveillance Performance (SP)** is the time-delay between the moment when the *first information allowing Conflict Detection (CD) was received* and the time when the *conflict was detected*.
- **Logic Performance (LP)** is the time period which is needed for event handling and the choice of suitable type of the conflict solution.
- **Conflict Resolution Performance (CRP)** is the time period needed for generating and presenting the conflict resolution(s) to the crew.
- **Execution Delay (ED)** is the time period between the time when *conflict solution was presented to the flight crew* and the time when an *aircraft starts the conflict solution execution*. Execution delay sums up time needed for
  - human information processing (HIP).
  - maneuver/trajectory initiation (insertion of accepted conflict solution into FMS/autopilot control panel respectively) (MP).

- **Reference Time (RT)** is the time of the traffic situation "snapshot" used in the CR for a generation of the initial conflict solution(s) presented to the flight crew. While there is a possibility to update the presented solution(s) during the flight crew assessment (using the updated information), it remains to be investigated whether such approach would be acceptable for pilots (the proposed solution(s) could be potentially a subject of considerable changes or can even disappear during the assessment). Alternatively, the solution can be frozen at some moment (e.g., only the initial solution being considered). This issue should be validated through extensive human-in-the-loop experiments.
- **Time To predicted Loss of separation (TTL)** the time period spanning between the current time and the Predicted Loss Of Separation (PLOS).
- **Remaining Time To Loss-of-Separation (RTTL)** is the time period between PLOS and the estimated moment when the execution of a conflict solution starts.

For operational definitions, the description of the airborne system (avionics and flight crew) behavior was simplified by considering only the performance of the whole airborne conflict processing (**Conflict Processing Performance (CPP)**). The latter is measured as the time span between the moment when the information about conflicting traffic is received for the first time up to the moment when the execution of a conflict solution starts.

I. Conflict Detection Parameters

Within A3, two independent Conflict Detection (CD) processes are envisioned. The first (with a longer look-ahead time) uses the best available information about surrounding traffic while the second, working as a safety backup, is based only on the actual state information about other aircraft and its extrapolation. To describe such a process, the following two parameters are defined:

- **Mid term Look Ahead Time (MLAT)** – the look-ahead time of the onboard CD based on the best available information (according Service Level) about surrounding traffic.
- **Short term Look Ahead Time (SLAT)** – the look-ahead time of the onboard CD based on the actual state information about surrounding traffic.

II. Conflict Resolution Parameters

The performance requirements on the conflict processing will vary according to the TTL at the moment when the conflict is detected. There are two envisioned forms of a conflict solution (potential system implementations may be based on more advanced splitting):

- **Open maneuver**, solves a detected conflict situation but a consistent continuation of the flight after the maneuver is not considered. This means that an aircraft does not have a consistent RBT when it starts to execute the maneuver. On the other hand, a simpler form of the conflict solution allows shorter conflict processing (computation, pilot's assessment). This type of maneuver is also denominated as **tactical maneuver**.
- **Closed maneuver**, is a conflict solution provided in the form of a consistent RBT update (up to the destination). This solution is preferable both from an operational perspective (more effective information sharing in SL2 and SL3) and considering own flight performance (trajectory optimization). However, such a solution will require longer onboard conflict processing. This type of maneuver is also denominated **trajectory modification**.

The exact choice of the type of conflict solution is based on the conflict processing logic (discussed in the following section), which depends on parameters to be determined in later validation stages. Nevertheless, independently of its form, the solution shall always meet the operational requirements and AFR, i.e., based on the anticipated time of the start of maneuver, the coordination rules (implicit coordination vs. priority rules) shall be applied.

III. Conflict Processing Logic

As described above, onboard conflict resolution requires a decision regarding of the appropriate *form of conflict solution* (open vs. closed) which then, based on the anticipated time of the start of the maneuver, determines the *type of the conflict* (Mid-term driven by priority rules or Short-term with implicit coordination).

Forms of the conflict resolution may (to some extent) vary among different airborne implementations, provided that the operational and interoperability requirements are met. On contrary, the *type of the conflict* is driven by AFR and the operational parameters which must be respected by all aircraft.

The whole process consists of three steps:

1. **The Time-To-LoS (TTL) when a conflict was detected** determines whether the maneuvering of own aircraft is required. In particular, the aircraft shall maneuver if TTL < STT or aircraft has got lower priority number than conflicting aircraft.

2. **Conflict Processing Logic** determines the appropriate form of the conflict solution.

3. **The Remaining Time To Loss (RTTL) of separation** for the selected form of conflict solution determines if the implicit coordination shall be used.

The Conflict Processing Logic thus creates the connection between the TTL when a conflict is detected and the choice of the form of conflict solution. The two performance requirements in terms of **maximum time for conflict processing** (CPP in Figure 2) are considered and associated with the closed and open maneuvers described above.

2.3 Additional Operational Assumptions from Other Work Packages

There are several additional requirements/recommendations on the operational definition of self separation determined in the frame of the iFly project. Some of them are listed below in the form of operational assumptions:

- The human responsibilities and the procedures related to their transition between users are defined according to the recommendations raised by the WP2 [D2.3, D2.4].
- The exchange of information among agents is designed to ensure critical observability as defined in WP4. The following entities can be considered as agents: i) a human operator, for instance a pilot; ii) an airborne system/subsystem, such as ASAS, navigation systems, etc., iii) an ASAS function, as defined below in this document, or iv) SWIM. The independent analysis of the A3 ConOps performed within WP4 and WP9.2 (OSA) demonstrated quite consistent and complementary findings considering the requirements on the information management described in the OSED.
- The hazards identified in Initial Hazard Analysis of A3 ConOps (D7.1b) are taken into account.

3. Development of a Functionally-Oriented Architecture

The system design for ASAS implementations requires the development of a suitable architecture, which should possess the following characteristics:

- Low function coupling and low function overlapping;
- Allow for definition of functional interfaces independently of the internal logic of each component;
- Be compatible with the broader avionic architecture in which ASAS will be inserted, taking into account the technological scenario likely to be in place at the timeframe in which A^3 will require product development.

These qualities are essential to obtain robust, safe and cost-effective implementations and, besides, to shorten the certification cycle with the aviation authorities. This way, it is more likely to achieve the optimistic cost-benefit ratio in scenarios drawn by WP6.

The basis for establishing such architecture was taken from Action Plan 23 (AP-23), Deliverables 3 and 4, and RTCA DO-317. At first place, AP-23 D3 identifies, from the operational perspective, the elementary components of airborne surveillance applications, which have been named *Application Elements*. Each of these elements may appear in several applications, and an application may be composed of some distinct elements. Furthermore, to enable an Application Element, some processes, calculations and monitoring tasks must be supplied, and these are called *ASAS Functions*, succinctly defined in AP-23 D3. Going beyond, AP-23 D4 refines this framework, taking into account suggestions of a broader community, with which better definitions and additional functions were devised (although dropping off one of the functions of D3). However, navigation and communication capabilities are outside the scope of AP-23 and, because defining these capabilities and their relationships with ASAS functions is necessary to elaborate safety and performance requirements in a systemic context, the high-level architecture of DO-317 was used as reference in the OSED, providing additional functions to the architecture herein defined.

Over this background, the present architecture was developed in an iterative process: on one side, the several functions of the architectures above referenced were selected to fulfill SSEP needs, and re-combined to obtain meaningful, non-overlapping and, whenever possible, low-complexity functionality; on the other side, a definition of higher level functional areas was elaborated to facilitate the identification of similar behaviors, communication channels and domains of knowledge amongst functions; finally, the requirements from the previous deliverables were matched to check if they can be properly allocated in the draft architecture and, where necessary, adjustments and new function inclusions were made. The resulting architecture is presented in Figure 3, whose elements are described in the subsequent text sections.

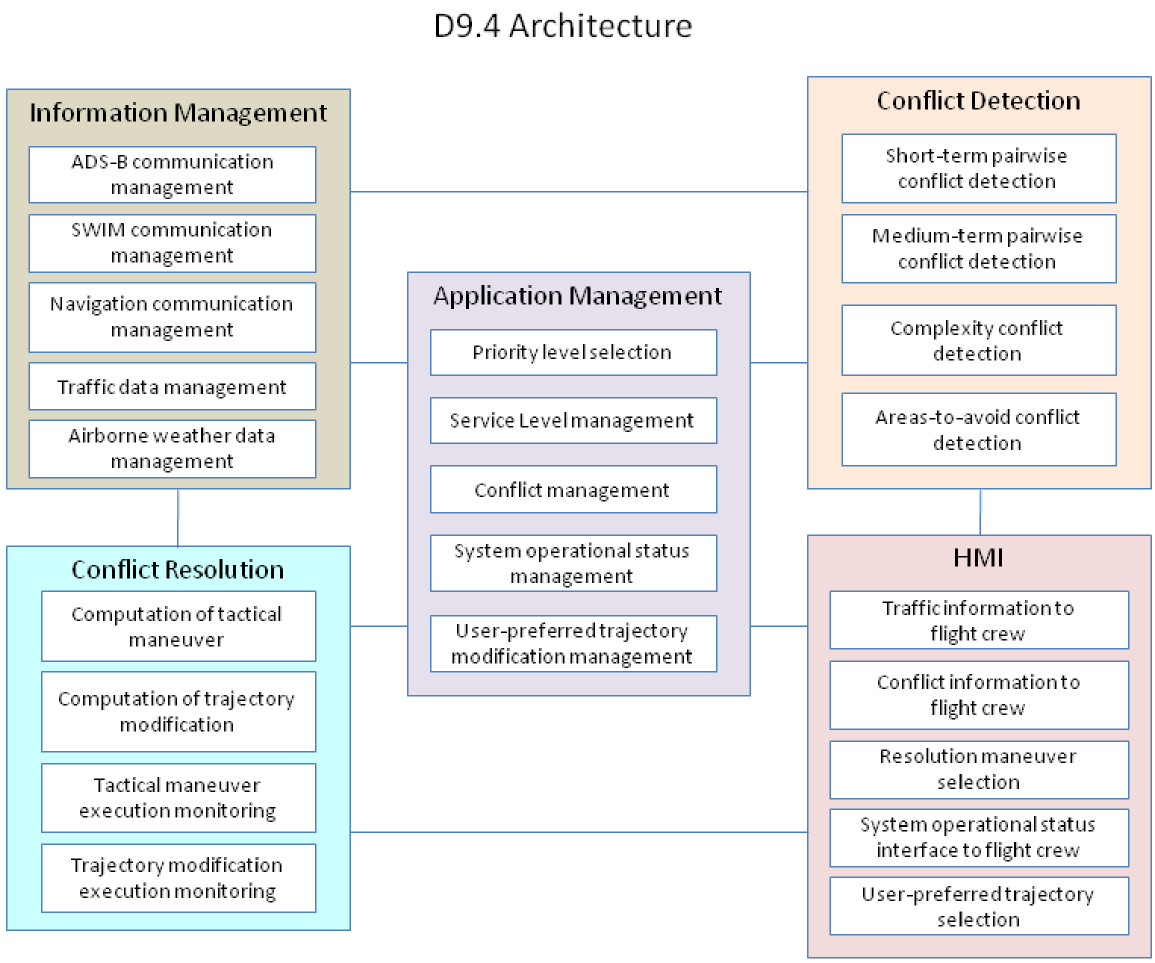

Figure 3: High level view of ASAS architecture.

The description of each Functional Block (FB) and function follows.

3.1 *Information Management Functional Block*

This FB groups functions dealing with information to and from external systems and agents other than the flight crew.

3.1.1 ADS-B Communication Management

- Receives, pre-processes and dispatches information from ADS-B IN function;
- Determines the ADS-B data quality level for each aircraft;
- Pushes information to ADS-B OUT function;
- Processes ADS-B data requests from other ASAS functions.

Required Operational Inputs:

- *ADS-B Reports definition (content + protocol);*
- *ADS-B performance requirements.*

3.1.2 SWIM Communication Management

- Detects whether SWIM is available or not;

- Receives, pre-processes and dispatches information from SWIM;
- Determines the SWIM data quality level for each aircraft, if applicable;
- Transmit information to SWIM;
- Processes SWIM data requests from other ASAS functions.

Required Operational Inputs:

- *SWIM Services definition including the communication means (channels, reports, protocols);*
- *SWIM performance requirements.*

3.1.3 Navigation Communication Management

- Receives, pre-processes and dispatches trajectory information from own navigation systems;
- Determines quality levels for own navigation and trajectory data;
- Alerts other processes about low quality levels of own navigation and trajectory data;

- Processes own navigation and trajectory information requests from other ASAS functions;

Required Operational Inputs:

- *Intent and RBT reports definition;*
- *Trajectory related performance requirements.*

3.1.4 Traffic Data Management

- Acquires and maintains up-to-date traffic information fusing both ADS-B and SWIM data;
- Keeps available information about areas-to-avoid received from SWIM;
- Determines the overall information quality for each detected aircraft;
- Initiates traffic information queries to SWIM and surrounding aircraft, and processes their results;
- Serves traffic information to other ASAS functions.

Required Operational Inputs:

- *Definition of available traffic information sources (primary source, backup(s)) – currently included in the SL definition;*
- *Related performance requirements on these sources.*

3.1.5 Weather Data Management

- Acquires and maintains information from airborne weather sensors and SWIM. This data may be also used to determine areas-to-avoid;
- Processes airborne weather data requests from other ASAS functions.

Required Operational Inputs:

- *Definition of available weather information services in SWIM;*
- *Related performance requirements on the SWIM.*

3.2 Application Management Functional Block

This FB is responsible for the overall function orchestration, global parameter determination, and operational status supervision.

3.2.1 Priority Level Selection

- Determines and monitors the own aircraft priority level in AFR, based on onboard-originated data and, if applicable, on information from SWIM;
- Updates the ADS-B communication management function to broadcast the selected priority level and, when the priority level is not received from SWIM, communicates this information to the SWIM communication management function.

Required Operational Inputs:

- *Priority rules definition in AFR;*
- *Unambiguous definition of the priority number (level), i.e., way how it is determined.*

3.2.2 Service Level Management

- Assesses the pre-requisites for SSEP Service Levels (SL) 1, 2 or 3, and determines the maximum SL allowable;
- Determines the current SL based on the maximum allowable and on input from HMI;
- Propagates SL changes to other ASAS functions.

Required Operational Inputs:

- *Definition of operational SLs and related requirements.*

3.2.3 Conflict Management

- Handles, at any time, relevant events from other functions related to conflict detection and resolution;
- Prioritizes and clusters existing conflicts;
- Determines the need of initiating or reinitiating conflict resolution process;
- Selects the appropriate type of resolution maneuver for each conflict;
- Initiates and manages the execution of conflict resolution maneuvers.

Required Operational Inputs:

- *Definition of AFR;*
- *Operational requirements on CD&R process.*

3.2.4 System Operational Status Management

- Verifies periodically the occurrence of every potential system degrading condition;
- Verifies periodically if all necessary functions are running according the requirements;
- Manages degradation events according to the safety and performance requirements.

Required Operational Inputs:

- *Definition of operational procedures for system degradation in accordance with operational safety and performance requirements (may be included in AFR).*

3.2.5 User-Preferred Trajectory Modification Management

- Check the feasibility and acceptability (e.g., considering AFR) of user-requested trajectory modifications outside the conflict resolution process (e.g. optimization);
- Provides the results of the check to HMI.

Required Operational Inputs:

- *Definition of AFR.*

3.3 Conflict Detection Functional Block

This FB is responsible for the detection of all types of conflicts, their reporting to the conflict management function and, when applicable, to provide conflict information to the HMI.

3.3.1 Short-Term Pairwise Conflict Detection

- Searches continuously over the traffic data for the existence of pairwise conflicts up to STTH, using the extrapolation of state vectors, and considering blunder protection;
- Reports to the conflict management function the existence of any short-term pairwise conflict;
- Keeps available up-to-date data about existing short-term conflicts;

Required Operational Inputs:

- *Definition of STTH;*
- *Definition of blunder protection;*
- *CD performance requirements.*

3.3.2 Medium-Term Conflict Detection

- Searches continuously over the traffic data for the existence of conflicts up to MTTH, considering also blunder protection;
- Reports to the conflict management function the existence of any medium-term conflict;
- Keeps available up-to-date data about existing medium-term conflicts;

Required Operational Inputs:

- *Definition of MTTH;*
- *Definition of blunder protection;*
- *CD performance requirements.*

3.3.3 Complexity Conflict Detection

- Searches continuously over the traffic data for complexity conflicts related to complex traffic situations, which may imply difficulties for separation management task of the own aircraft;
- Reports to the conflict management function the existence of any complexity conflict;
- Keeps available up-to-date data about existing complexity conflicts;

- May be activated on demand to probe user-preferred trajectories under consideration.

Required Operational Inputs:

- *Definition of operational safety performance requirements;*
- *Results of the performance and operational validation of CD&R algorithms.*

3.3.4 Areas-To-Avoid Conflict Detection

- Searches continuously over the traffic data for the existence of conflicts with areas-to-avoid;
- Reports to the conflict management function the existence of any area-to-avoid conflict;
- Keeps available up-to-date data about existing areas-to-avoid conflicts;
- May be activated on demand to probe user-preferred trajectories under consideration.

Required Operational Inputs:

- *Definition of operational procedures considering areas-to-avoid (types of areas-to-avoid, prioritization of conflicts, etc.);*
- *Related performance requirements.*

3.4 Conflict Resolution Functional Block

This FB is responsible for computing conflict resolution maneuvers, and monitoring their execution, whenever solicited by the conflict management function.

3.4.1 Computation of Tactical Maneuver

Computes a set of tactical maneuvers to solve a conflict, respecting given constraints.

Required Operational Inputs:

- *Definition of CPP1 (Conflict Processing Performance for CR1) allowing the determination of the CRP1 (Conflict Resolution Performance) for associated flight procedure (CPP1=CRP1+ED1 where ED1 is the execution delay associated with pilot's decision making process in CR1);*
- *Operational requirements on the CR process.*

3.4.2 Computation of Trajectory Modification

Computes a set of trajectory modifications to solve a conflict, respecting given constraints.

Required Operational Inputs:

- *Definition of CPP2 (Conflict Processing Performance for CR2) allowing the determination of the CRP2 (Conflict Resolution Performance) for associated onboard flight procedure (again CPP2=CRP2+ED2 where ED2 is the execution delay associated with pilot's decision making process in CR2).*
- *Operational requirements on the CR process.*

3.4.3 Tactical Maneuver Execution Monitoring Function

- Once a tactical maneuver has been initiated to solve a conflict, manages the relevant events and measurements associated to the maneuver execution, and informs about them the conflict management function.

Required Operational Inputs:

- *Operational requirements on the CR process.*

3.4.4 Trajectory Modification Execution Monitoring Function

- Once a trajectory modification has been initiated to solve a conflict, monitors the relevant events and measurements associated to its execution, and informs about them the conflict management function.

Required Operational Inputs:

- *Operational requirements on the CR process.*

3.5 Human-Machine Interface (HMI) Functional Block

Considering that ASAS is designed as a pilot's supporting tool and that HMI must perform functions which are not achievable by combining other functions, it must be considered an essential element in ASAS architecture, especially for supporting the sound performance of human responsibilities as recommended in WP2. This FB is setup to account for the main tasks associated to the HMI.

3.5.1 Traffic Information to Flight Crew

- Keeps and shows up-to-date traffic information to the flight crew.

Note: *This information will primarily be shown graphically in the CDTI; however the other supporting means of displaying relevant information are also envisioned.*

3.5.2 Conflict Information to Flight Crew

- Keeps up-to-date conflict information to the flight crew.
- Informs the flight crew about the current conflict resolution process, when there is such one.

Note: *The conflict information may be graphically shown in the CDTI, and, depending on the criticality of the conflict, aural or other alerts may be also provided. Some supplementary means to search for more detailed and precise information are also envisioned. The exhibition of graphical conflict information is dependent of the Traffic Information to Flight Crew function.*

3.5.3 Resolution Maneuver Selection

- Presents the proposed CR maneuvers or trajectory updates to the flight crew;
- Allows the selection and potential modification of the latter.

Note: *For each conflict resolution process initiated, a set of resolution maneuvers will be computed and proposed by ASAS to the flight crew. This function is responsible for the presentation and interaction with the flight crew to select one of the proposed maneuvers.*

3.5.4 System Operational Status Interface to Flight Crew

- Allows the flight crew to consult and change the current SSEP Service Level (SL);
- Displays the current priority level and its source;
- Enables the flight crew to update the priority level, in the extent allowed by the AFR;
- Provides information to the flight crew about ASAS system integrity and degrading conditions;

- Informs the flight crew when pre-requisites for SSEP are not met;
- Allows the flight crew to declare unable to SSEP.

3.5.5 User-preferred trajectory selection

- Allows the flight crew to probe a user-preferred trajectory (e.g. for optimization) for conformance with AFR, potential conflicts and other timing constraints for trajectory modification;
- Allows the flight crew to select a feasible trajectory modification and to follow the onboard trajectory modification procedure.

4. System Requirements Allocation

The requirements identified in the previous WP9 deliverables of (OSED, OSA and OPA) have been reviewed and the functional requirements were formulated according to the architecture developed in the previous section. In addition new requirements have been developed, aiming at providing a complete relation of requirements to guide airborne system design for SSEP. The sections below follow the structure of the architecture of Section 3.

4.1 Notation and Referencing

Each system design requirement is identified by a key code using the notation DR-<FB>[-FF]-<NNN>, where:

- DR stands for Design Requirement;
- FB is a two-letter code identifying the functional block in the architecture of Figure 3 (e.g.: IM refers to Information Management, CR to Conflict Resolution, etc.);
- FF may be present or not, it is a two-letter code identifying the function in the referred architecture (e.g.: inside group IM, AD refers to ADS-B communication management, SW to SWIM communication management, etc.); when FF is not present, the requirement is applicable to the whole functional block;
- NNN is a three-digit number that identifies the requirement inside the functional group or function.

In the body or at the end of each requirement, there may be references to applicable assumptions, requirements or standards. More information about these requirements can be found considering the first letters in the requirement identifying code based on the following guidance:

- ASSUMP-…: Assumptions, refer to Appendix B;
- OSED-…: Operational Requirements from OSED, refer to Appendix C;
- BC-…: Basic Causes refer to OSA, iFly deliverable D9.2;
- EMM-…: External Mitigation Means refer to OSA, iFly deliverable D9.2;
- IMM-…: Internal Mitigation Means refer to OSA, iFly deliverable D9.2;
- SR-…: Safety Requirements refer to OSA, iFly deliverable D9.2;
- PR-…: Performance Requirements refer to OPA, iFly deliverable D9.3;
- DO-NNN: RTCA documents.

Other references are given explicitly to an item in the reference list in Appendix G.

4.2 Information Management Functional Block

Operational Assumptions:

- *The information exchange between air and ground, and from aircraft-to-aicraft, is defined to ensure the critical system observability, as defined in D4.2.*

DR-IM-001:
There is no change in communications as a result of detected short-term conflicts. (OSED-7-OR)

4.2.1 ADS-B Communication Management

Operational Assumptions:

- *Definition of Service Levels (SL) according the Section 2;*
- *For SL 2 and 3, ASSUMP-5-COM;*
- *ADS-B Performance Standards.*

DR-IM-AD-001:
The function shall broadcast by ADS-B Out the data required by actual SL. The broadcast shall meet operational performance requirements.

DR-IM-AD-002:
The function shall be able to receive and process state and intent information about surrounding aircraft through ADS-B In.

DR-IM-AD-003:
For SL2 and SL3, whenever the intent information of an aircraft is changed, a new intent should be broadcast immediately by ADS-B.

DR-IM-AD-004:
Priority level shall be broadcast by ADS-B. (OSED-15-PRD)

DR-IM-AD-006:
The function shall monitor failures in ADS-B In and Out functions, and report detected failures to the System Operational Status Management function.

DR-IM-AD-007:
The function shall determine or receive one or more quality level indicators for ADS-B data of each aircraft.

4.2.2 SWIM Communication Management

Operational Assumptions:

- *Definition of Service Levels (SL) according the Section 2;*
- *For SL 3, ASSUMP-6-COM;*
- *Own aircraft downlink to SWIM: state, intent, RBT;*
- *Periodical uplink from SWIM: the list of aircraft in ownship awareness zone ;*
- *Periodical or event-based uplink from SWIM: areas-to-avoid;*
- *On-demand uplink from SWIM:*
    - *state and intent for requested aircraft;*
    - *list of predicted aircraft in the ownship awareness zone.*
- *State and intent data from SWIM will come each accompanied of one or more quality indicators;*
- *It is possible to detect faults in the communication with SWIM.*
- *Priority level can be determined centrally and communicated to aircraft via SWIM or calculated onboard (depending on the final definition of AFR).*

DR-IM-SW-001:

The function shall transmit to SWIM own RBT as well as the data about accuracy and integrity of the own trajectory information being shared (OSED-1-OR). The operational performance requirements considering update rate shall be met.

DR-IM-SW-002:

The function shall transmit to SWIM state and intent information according the operational performance requirements.

DR-IM-SW-003:
For SL3, the function shall be capable of loading anytime from SWIM the list of all aircraft expected in its awareness zone. (SR-N-2.2)

DR-IM-SW-004:
For SL3, the function shall query SWIM for the list of all expected aircraft in its awareness zone whenever it is not received according the required update rate (operational requirements).

DR-IM-SW-005:
Priority level will be transmitted to SWIM whenever requested by the Priority Level Selection function. (OSED-15-PRD)

DR-IM-SW-006:
The function shall monitor failures in communication with SWIM, and report detected failures to the System Operational Status Management function.

DR-IM-SW-007:
The function shall determine one or more quality level indicators for data about each aircraft coming from SWIM.

DR-IM-SW-008:
For SL3, the function shall be able to query SWIM for information about any aircraft when requested by other ASAS functions (Traffic Data Management).

4.2.3 Navigation Communication Management

Operational Assumptions:

- *Own navigation systems are capable of communicating the up-to-date 4D trajectory information, including:*
    - *the current trajectory itself, and*
    - *one or more quality indicators about the trajectory.*
- *Own navigation systems are capable to update flown trajectory as requested by ASAS application (upon flight crew request).*
- *It is possible to detect faults in the communication with the own navigation systems.*

DR-IM-NA-001:
This function shall continuously update the trajectory information about own flight (RBT, intent) from the own navigation systems together with the accuracy and integrity of this trajectory information. The data shall reflect the actual navigation capability of own aircraft and flown guidance mode (including manual flight).

DR-IM-NA-002:
For SL2 and SL3, the intent obtained from the own navigation systems shall allow a prediction of the aircraft trajectory up to MTTH. (OSED-6-PR)

DR-IM-NA-003:
For SL2 and SL3, this function shall be aware immediately of any change in the intent information occurred in the own aircraft navigation systems, and shall have the most recent intent. (OSED-6-PR)

DR-IM-NA-004:
The function shall provide the appropriate trajectory data to the ADS-B Communication Management and SWIM Communication Management functions.

DR-IM-NA-005:
When the performance of the own aircraft navigation does not meet the minimum requirements for SSEP, this degradation shall be reported to the System Operational Status Management function. In particular, this occurs when either of the performance requirements PR-5 through PR-9, or the safety requirements SR-1, SR-2, are not met. (IMM-8)

4.2.4 Traffic Data Management

Operational Assumptions:

- *All assumptions in 4.2.1 and 4.2.2;*
- *There are established rules to check and assess the quality between SWIM and ADS-B traffic data.*

DR-IM-TD-001:
The function should be capable of maintaining a list of all aircraft from which ADS-B reports are available (received), with their actual states and expected trajectories.

DR-IM-TD-002:
For SL3, the function should be capable of maintaining a list of all expected aircraft in its awareness zones (received from SWIM), with their actual states and expected trajectories. (Adapted from SR-N-2.2)

DR-IM-TD -003:
If the state information about relevant traffic is not updated according to the performance requirements PR-5 through PR-9 (D9.3), the information must be marked as obsolete or invalid. (OSED-7-OR)

DR-IM-TD-004:
For SL2 and SL3, if the intent information about relevant traffic is not updated according to the performance requirements PR-10 and PR-12 (D9.3), the information must be marked as obsolete or invalid. (OSED-7-OR)

DR-IM-TD-005:
For SL2 and SL3, if the valid state information about relevant traffic is not conformant with the intent information (respecting the uncertainty boundaries: SR-1), the intent information must be marked as obsolete or invalid, and the look-ahead time of the predicted trajectory shall be reduced to STTH. (OSED-7-OR, PR.19, SR-1)

DR-IM-TD-006:
For SL3, if the information about relevant traffic (either state or intent) is obsolete or invalid, the airborne system must query the corresponding aircraft[1] and/or SWIM (through SWIM Communication Management function) in search of valid and up-to-date information. (OSED-7-OR)

DR-IM-TD-007:
For SL3, in the case of missing information about an aircraft on the traffic list, the information must be queried from SWIM (through SWIM Communication Management function) or to the corresponding aircraft1. (OSED-7-OR, PR.14)

[1] The means to query directly an aircraft may be a data exchange protocol similar to ADS–C, but performed directly air-air. The execution of this query would be provided by the ADS-B Communication Management function.

DR-IM-TD-008:
For SL3, if there is contradiction in information about an aircraft, between SWIM and ADS-B In sources, and both sources indicate equivalent level of quality, the information with latest time stamp shall be used.

DR-IM-TD-009:
The function shall determine an overall quality indicator for each aircraft data.

DR-IM-TD-010:
Traffic data availability status for ASAS functions shall be provided by the Traffic Data Management function.

4.2.5 Weather Data Management

Operational Assumptions:

- *It is assumed that SWIM provides meteo services, however they will not be ASAS specific, so the related communication means are not explicitly mentioned here.*

DR-IM-WE-001:
The function shall be able to receive, process and combine weather data from different sources (onboard sensors, SWIM).

DR-IM-WE-002:
The function shall determine one or more quality level indicators for weather data.

4.3 Application Management Functional Block

4.3.1 Priority Level Selection

Operational Assumptions:

- *(ASSUMP-1-AD) It is assumed that there may be two options considering the priority level determination (their use may differ according the airspace and applicable SL): the priority can be determined either centrally by a strategic ground based tool and then uplink to the aircraft, or it can be determined onboard based on the predefined rules binding for all self separating aircraft;*
- *In case that the priority is centrally managed, it will be communicated through SWIM;*
- *ADS-B messages are used to transmit the priority number and an emergency flag;*
- *Priority reversal process is not considered [Irvine, Cásek].*

DR-AM-PL-001:
If determined onboard, the priority level shall be identified in function of CTA, the classification of the ownship, and the own mission statement. (OSED-15-PRD, Priority Rules in D1.3).

DR-AM-PL-002:
For SL3, the function should allow the priority level of own aircraft be managed by a central entity, in order to account for strategic objectives in a wider sense. ([D9.3 - Appendix D]; ASSUMP-1-AD).

DR-AM-PL-003:
Priority level shall be provided to the ADS-B Communication Function, so that it can be broadcast to other aircraft. If applicable, it shall be also provided to the SWIM Communication Function. (OSED-15-PRD).

DR-AM-PL-003:
The function shall allow a modification of the priority level by the flight crew in the case of a change in the category of operations and other situations considered in the AFR.

4.3.2 Service Level Management

Operational Assumptions:

- *Definition of Service Levels (SL) according the Section 2;*
- *The information about maximum SL currently available in the airspace is available.*

DR-AM-SL-001:
The function shall allow the setup of SSEP Service Levels (e.g. SWIM availability) by flight crew when entering SSA.

DR-AM-SL-002:
The function shall continuously check whether all the requirements for current SL are satisfied and detect any deviations (e.g., degradation of the SL). The function shall propagate information about such deviations to other ASAS functions.

DR-AM-SL-003:
The function shall allow the flight crew to modify current SL up to the maximum allowable.

4.3.3 Conflict Management

Operational Assumptions:

- *The onboard conflict processing logic according the section 2.2.2;*
- *Assumptions ASSUMP-5-INI trough ASSUMP-9-INI;*
- *Assumptions ASSUMP-1-OTH and ASSUMP-2-OTH;*
- *The trajectory management process follows the protocol described in [D9.3 - Appendix D]).*

DR-AM-CM-001:
The function shall be capable of clustering pairwise conflicts whenever the conflict situation requires treating multiple aircraft simultaneously. (ASSUMP-6-INI, ASSUMP-8-INI, OSED-14-FR)

DR-AM-CM-002:
Once a conflict is detected, conflict situation assessment shall run continuously, until the conflict is solved. (OSED-9-OR)

DR-AM-CM-003:
Once a conflict is detected, the function shall calculate (based on TTL) the Remaining Time To Loss of Separation (RTTL) for Trajectory Modification and Tactical Maneuver and choose the most suitable type of resolution maneuver in order that AFR are satisfied. (PR.26)

DR-AM-CM-004:
Short term conflicts, to happen up to STTH, have priority over mid-term conflicts, to occur after STTH. (OSED-3-OR)

DR-AM-CM-005:
The function shall primary start to solve the most urgent conflict (shortest TTL).

Note: *As the CR algorithms shall generate conflict-free maneuvers/trajectories, the subsequent conflicts should be typically solved as well.*

DR-AM-CM-006:
The function shall not start the execution of any resolution maneuver unless requested through the HMI. (OSED-12-FR, OSED-14-FR)

DR-AM-CM-007:
Once a complexity conflict has been identified, the airborne system shall choose the most suitable type of resolution maneuver, i.e. Trajectory Modification or Tactical Maneuver, based on TTL. (PR.26)

DR-AM-CM-008:
If a trajectory modification of a conflict resolution process started before STT has not been initiated at TTL ≤ STT, the Tactical Maneuvering process shall be started (PR.31).

DR-AM-CM-009:
When the CR process is launched, the Conflict Management function shall instruct the ADS-B and SWIM communication functions to stop broadcasting intent reports until the new trajectory information is available and approved by flight crew. Instead, the appropriate Target State (TS) report (DO-242A) shall be broadcast. (PR.36)

DR-AM-CM-010:
In order to avoid many aircraft maneuvering at the same time, the trajectory modification process will follow the protocol described in [D9.3 - Appendix D]).

DR-AM-CM-011:
Conflicts detected over degraded traffic information will generate advisories through HMI; however they will initiate conflict resolution process only upon flight crew request. (OSA, BC-7b, SR-4)

DR-AM-CM-012:
When a conflict resolution process has already been initiated, and another conflict is detected, the function should respect the restart principles of Appendix D.

DR-AM-CM-013:
The trajectory modification algorithm will be initiated for conflict resolution purposes only if it is required according the priority rules. In case of identical priority levels, an arbitrary procedure (based in the aircraft call signs, for example) will be used to ensure that priority is always unambiguous. (OSED-15-PRD)

DR-AM-CM-014:
For self separation capable aircraft flying in SSA with SL2 or SL3, the search for a Trajectory Modification shall be started at the moment when a Tactical Maneuver is initiated. New conflict-free trajectory shall be initiated within a pre-defined maximum delay from the start of the Tactical Maneuver Execution. (PR.51)

Note: The idea is to have a new conflict-free trajectory and therefore the corresponding intent provided to surrounding aircraft as soon as possible. The initial estimation for the delay parameter can be found in the OPA (D9.3) document.

4.3.4 System Operational Status Management

Operational Assumptions:

- *There is an operational definition of pre-requisites that must be met by aircraft navigation system in order to be allowed to operate in SSA;*

- *There are pre-defined rules considering the system operational status required for SSA operations. There are defined transition procedures for entering and leaving SSA and the transfer of responsibility. Consequently the flight crew is always aware whether aircraft is flying in SSA.*

DR-AM-OS-001:
The function will continuously run health monitoring routines on ASAS to assess if the required functions are properly working. Any detected failure shall be reported to the flight crew, and proper operational measures will be taken by the System Operational Status Management function. (IMM-2)

DR-AM-OS-002:
When a degradation in the own navigation state data is not persistently ceased for a pre-defined threshold time, the System Operation Status Management function shall provide this information to the HMI to make the flight crew aware, indicating that the aircraft is no longer able to continue SSEP operations, as well as to initiate the broadcast of this status through ADS-B and SWIM communication functions. (EMM 4.1)

DR-AM-OS-003:
The System Operation Status Management function shall receive failure reports from other ASAS functions, and shall perform a pre-requisite check regarding SSEP. If some pre-requisite is missing, it shall provide this information to the HMI to display it to the flight crew, indicating that the aircraft is no longer able to continue in SSEP operations, as well as to take operational measures and initiate the broadcast of this status through ADS-B and SWIM communication functions. (EMM 4.1)

DR-AM-OS-004:
The System Operation Status Management function shall monitor the time when the aircraft will enter and/or leave SSA, and communicate it to the HMI.

DR-AM-OS-005:
The System Operation Status Management function shall process the information when the aircraft enters or leaves SSA, indicating this to HMI.

DR-AM-OS-006:
The System Operation Status Management function shall allow the aircraft to be declared unable of SSEP, when requested through HMI, and will broadcast this information through ADS-B and SWIM.

4.3.5 User-Preferred Trajectory Modification Management

Operational Assumptions:

- *Trajectory modifications initiated for performance (optimization) reasons will be performed only beyond MTTH. Any trajectory modification in SSA shall be performed only in accordance with AFR.*

DR-AM-UP-001:
Any kind of conflict-related event has priority over possible trajectory optimization events. (*OSED-3*-OR)

DR-AM-UP-002:
ASAS shall perform validity checks of user-requested trajectory modifications, whenever there is no active conflict. Besides validating the timing constraints of the trajectory modification, ASAS should probe the new trajectory for complexity and areas-to-avoid conflicts. (OSED-11-OR)

DR-AM-UP-003: If there is some type of conflict detection beyond MTTH (areas-to-avoid), ASAS shall probe new trajectories requested by the flight crew for conflicts in this time frame. (OSED-11-OR)

4.3.6 Information Enabling to Flight Crew

Operational Assumptions:

- *Some nuisance conflicts are generated by ASAS, up to a tolerable frequency, to be defined;*
- *There will occur situations where it is needed to prevent information to be shown in the CDTI, such as that the required cognitive workload would pose a higher risk than omitting part of the information;*
- *When filtering information to the flight crew, the information still should be available on request.*

DR-AM-IE-001:
ASAS shall filter the information to be shown to the flight crew so as to avoid nuisance and provide the means to acquire and maintain the highest achievable level of situational awareness without overloading their cognitive capabilities. Therefore, a function of Information Enabling to Flight Crew shall determine which information shall or shall not send to the HMI, according to the current situation.

4.4 Conflict Detection Functional Block

Operational Assumptions:

- *The onboard conflict processing logic of section 2.2.2;*
- *Assumptions ASSUMP-7-INI trough ASSUMP-9-INI;*
- *Assumptions ASSUMP-1-OTH and ASSUMP-2-OTH;*

DR-CD-001:
Conflict detection will run continuously during the SSEP operation, with a minimum pre-determined frequency, and all detected conflicts will be reported to the Conflict Management function. (OSED-7-OR, OSED-8-OR)

DR-CD-002:
For each detected potential conflict, SSEP equipment shall calculate the actual Time To Loss of separation (TTL) (PR.27).

DR-CD-003:
ASAS implementation architecture shall allow that the short-term conflict detection run independently from the intent-based conflict detection. (PR.23)

DR-CD-004:
Any detected conflict will be reported to the Conflict Management function.

DR-CD-005:
Once a potential conflict is detected, this conflict and associated measurements must be tracked and, once it is cleared, its termination shall be reported to the Conflict Management function.

DR-CD-006:
In the case of missing or degraded intent information, the conflict detection will be based primarily on the state information and the look-ahead time will be reduced to Short Term Time Horizon (STTH). (PR.21**)**

4.4.1 Short-Term Pairwise Conflict Detection

Operational Assumptions:

- *The trajectory of autonomous aircraft shall at no time place the aircraft in a state vector conflict (blunder protection) up to a given amount of time, named Blunder Protection Time Horizon (BPTH);*

DR-CD-ST-001:
The function shall continuously perform the short-term CD using the extrapolation of the current position and velocity information about surrounding aircraft. The look-ahead time of this function will be BPTH (Blunder Protection Time Horizon – the initial value is 2 minutes based on the NASA research and similar ATC functions used today). (PR.23)

4.4.2 Medium-Term Conflict Detection

DR-CD-MT-001:
The function shall continuously perform the Conflict Detection using the predicted trajectory of surrounding aircraft and its uncertainty boundaries. The look-ahead time of the predicted trajectory is determined by the received intent information but CD shall not consider the time beyond MTTH time horizon. (PR.21**)**

DR-CD-MT-002:
Any detected mid-term conflict shall be reported to the Conflict Management function.

DR-CD-MT-003:
Once a mid-term conflict is detected, this conflict and associated measurements must be tracked and, once it is cleared, its termination shall be reported to the Conflict Management function.

4.4.3 Complexity Conflict Detection

Operational Assumptions:

- *A conflict detection method based on a complexity measure is defined, such that:*
  - *The conflict represents a predicted intolerable increase in at least one of the following factors:*
    - *the collision risk;*
    - *the flight crew workload;*
    - *passenger discomfort;*
    - *travelling time / fuel consumption (optional).*
  - *If multiple aircraft detect the same conflict, the final result of the corresponding resolution process will not result in new complexity conflicts.*

DR-CD-CC-001:
The function shall continuously perform a detection of the potential situations that could result in overloading of its CR functions or in a serious reduction of own aircraft maneuverability. These situations are denominated as complexity conflicts. (PR.26)

DR-CD-CC-002:
The Complexity Conflict Detection function should be available also to probe user-requested trajectory modifications.

4.4.4 Areas-To-Avoid Conflict Detection

Operational Assumptions:

- *SWIM provides to ASAS relevant information about areas to be avoided by the ownship.*

DR-CD-AA-001:
For SL3, ASAS shall continuously perform a detection of conflicts with areas-to-avoid provided by SWIM.

DR-CD-AA-002:
The Areas-to-Avoid Conflict Detection function should be available to probe user-requested trajectory modifications.

4.5 Conflict Resolution Functional Block

Operational Assumptions:

- *There is no explicit coordination in the conflict resolution process;*
- *The onboard conflict processing logic of section 2.2.2;*
- *Assumptions ASSUMP-5-INI trough ASSUMP-9-INI;*
- *Assumptions ASSUMP-1-OTH and ASSUMP-2-OTH;*
- *The trajectory of autonomous aircraft shall at no time place the aircraft in a state vector conflict (blunder protection) up to a given amount of time, named Blunder Protection Time Horizon (BPTH);*
- *(ASSUMP-2-AD) Some algorithms for tactical conflict resolution may require automated input from ASAS into auto-pilot and auto-throttle.*
- *There will be a suitable definition of ASAS/ACAS interface ensuring the compatible (and smooth) behavior when a potential conflict passes from ASAS to ACAS operational domain.*

DR-CR-001:
ASAS is capable of solving conflicts with one or more aircraft besides the ownship. (ASSUMP-6-INI, ASSUMP-8-INI, OSED-14-FR)

4.5.1 Computation of Tactical Maneuver

Operational Assumptions:

- *For short-term conflicts, the resolution maneuvers are issued in terms of easily understandable maneuvers, for example, a new heading and/or a vertical rate, such that the pilot can easily understand and initiate them in short time.*

DR-CR-TA-001:
The function shall provide, for all current SSEP Service Levels (SL1-3), the Tactical Maneuvering functionality to solve potential conflicts. (PR.28)

DR-CR-TA-002:
The tactical maneuvering algorithm does not rely on any action from other conflicting aircraft than the ownship but it shall be compatible with implicit coordination requirements. (OSED-13-OR)

DR-CR-TA-003:
The proposed conflict solutions with tactical maneuvering follow AFR. In particular, they shall be conflict-free up to or beyond the STTH and, at any moment along the new trajectory the 2-minutes2

extrapolation of the momentary aircraft velocity vector shall be conflict-free as well (blunder protection). (OSED-13-OR, PR.45, PR.46)

DR-CR-TA-004:
The solutions proposed by the tactical maneuvering algorithm shall be valid at expected time of execution, i.e., they have to take into account ED. (OSED-14-FR, PR.48)

DR-CR-TA-006:
The system should use more than one algorithm to calculate tactical maneuvers. (OSA, IMM-3)

4.5.2 Computation of Trajectory Modification

Operational Assumptions:

- *Definition of Service Levels (SL) according Section 2.*
- *The trajectory modification function provides the solution as a consistent update of flown trajectory, i.e., the new intent/RBT information is available for sharing at the time when the execution of the trajectory modification is started.*

DR-CR-TR-001:
The function shall provide, for SSEP SL2 and SL3, the Trajectory Modification functionality to solve mid-term conflicts. (PR.28)

DR-CR-TR-002:
The trajectory modification algorithm relies only on actions of the ownship, and not on any actions from the other conflicting aircraft. (OSED-11-OR)

DR-CR-TR-003:
The proposed conflict solutions with trajectory modification shall follow AFR. In particular, they shall be conflict-free up to or beyond the MTTH and, at any moment along the new trajectory the 2-minutes[2] extrapolation of the momentary aircraft velocity vector, they shall be conflict-free as well. (OSED-2-OR, OSED-05-OR, OSED-11-OR)

DR-CR-TR-004:
The solution proposed by the trajectory modification algorithm shall be valid at time of execution, i.e., it has to take into account ED. (OSED-12-FR)

DR-CR-TR-005:
The system should use more than one algorithm to calculate new trajectories. (OSA, IMM-3)

4.5.3 Tactical Maneuver Execution Function

Operational Assumptions:

- *Only one conflict resolution maneuver is executed each time.*

DR-CR-AM-001:
Once a Tactical Maneuvering solution has been computed by ASAS, its validity shall be monitored until the moment when its execution is initiated, and its parameters shall be actualized. If it loses validity before initiating, the Conflict Management function shall be reported. (PR.50)

DR-CR-AM-002:

[2] Blunder Protection Time Horizon (BPTH), from NASA research and current ATC practice.

Once a Tactical Maneuvering solution has been selected by the flight crew, its actual execution must be monitored, and its parameters must be actualized. The behavior of the own aircraft shall be assessed so as that:

- The Conflict Management function will be informed when the aircraft behavior indicates that it actually has initiated the maneuver execution;
- The Conflict Management function will be reported if the aircraft behavior invalidates the maneuver.

DR-CR-AM-003:
ASAS should be capable of managing the execution of a Tactical Maneuvering solution in a closed loop with the own navigation systems, providing navigation commands when required, and using the aircraft behavior as input for new commands[3]. (ASSUMP-2-AD)

4.5.4 Trajectory Modification Execution Function

Operational Assumptions:

- *Definition of Service Levels (SL) according Section 2;*
- *Only one conflict resolution maneuver is executed each time.*

DR-CR-RM-001:
Once a Trajectory Modification solution has been computed by ASAS, its validity shall be monitored until the moment when its execution is initiated, and its parameters shall be actualized. If it loses validity before initiating, the Conflict Management function shall be reported. (PR.43)

4.6 Human-Machine Interface (HMI) Functional Block

Operational Assumptions:

- *The HMI should keep the false alarm rate under predefined threshold.*
- *There will occur situations where it is needed to prevent information to be shown in the CDTI, such as:*
  - *information overlapping;*
  - *different scales/resolutions of the display will be needed;*
- *The hidden information still shall be available to the flight crew on request;*
- *The display of ASAS and ACAS information is unified in the same display and a consistent symbology allows for their harmonic simultaneous operation.*

DR-HM-001:
The HMI functions shall filter and present the information to the flight crew, so as to avoid nuisance and provide the means to acquire and maintain the highest achievable level of situational awareness without overloading their cognitive capabilities.

DR-HM-002:
The HMI shall allow for decluttering of information on the display based on the flight crew needs.

DR-HM-002:

[3] Some conflict resolution algorithms proposed in iFly (e.g. Navigation Functions) require closed loop control with the own aircraft navigation and guidance systems: A/P & A/T.

The flight crew shall be able to enable or disable the conflict detection and resolution functions.

Note: this requirement needs to be refined.

4.6.1 Traffic Information to Flight Crew

Operational Assumptions:

- *The traffic information is shown to the flight crew in a way that is consistent with other ASAS applications (e.g., ATSA-AIRB, ASPA S&M, etc.).*

DR-HM-TI-001:
Self separation capable aircraft shall have a Cockpit Display of Traffic Information (CDTI) to present the traffic situation to the flight crew. (PR.13)

DR-HM-TI-002:
CDTI is in the primary field of view of the flight crew, and is at the same time the primary output interface of both ASAS and ACAS;

DR-HM-TI-002:
Obsolete or invalid information (when valid is not available) about relevant traffic must be displayed as so to the flight crew. (PR.16, PR.19)

DR-HM-TI-003:
Intent information about surrounding aircraft shall be available in graphical form. (PR.18)

DR-HM-TI-004:
When an aircraft is detected to be in the change mode, and there is valid intent information about it, this intent information shall be shown to the flight crew together with the change status. (EMM 1.4, [D9.3 - Appendix D])

DR-HM-TI-005:
The priority level of all relevant aircraft shall be available to the flight crew. (EMM 1.4, [D9.3 - Appendix D])

4.6.2 Conflict Information to Flight Crew

Operational Assumptions:

- *Conflict information has priority over user-requested trajectory modifications;*
- *Short-Term Conflicts have priority over Mid-Term Conflicts;*
- *There are consistent rules to prioritize conflicts of the same type.*

DR-HM-CI-001:
ASAS equipment of self separation capable aircraft shall provide flight crew with means to gain and maintain situation awareness considering all detected potential threats.

DR-HM-CI-001:
ASAS equipment of self separation capable aircraft shall provide flight crew with means to get a clear understanding of presented solutions (whether in the form of a trajectory or a tactical maneuver). (PR.37)

DR-HM-CI-002:

Information about all detected potential conflicts shall be available to the flight crew. (PR.35)

DR-HM-CI-003:
TTL of the detected potential conflict shall be shown to the flight crew. (EMM 1.4).

Note: it remains to be investigated how to apply this requirement when several conflicts are detected, i.e., if and how to prioritize the parameters to be shown to the flight crew.

DR-HM-CI-004:
ASAS shall allow the flight crew to monitor the execution of a resolution maneuver of the own aircraft.

4.6.3 Resolution Maneuver Selection

For the sake of simplicity, in this section, a *resolution maneuver* stands both for a tactical maneuver or a trajectory modification resolution of a conflict.

Operational Assumptions:

- *There may be more than one resolution maneuver applicable for the same conflict.*

DR-HM-RE-001:
The airborne system shall indicate to the flight crew when a resolution maneuver is being calculated.

DR-HM-RE-002:
When several maneuvers are calculated, each maneuver must be notified to the flight crew as soon as it is available (EMM 1.4).

DR-HM-RE-003:
The airborne system shall graphically depict the computed resolution maneuver.

DR-HM-RE-004:
The airborne system shall allow the flight crew to select one of the maneuvers for execution. (PR.42, PR.49**)**

DR-HM-RE-005:
The airborne system shall provide the flight crew with the time remaining for the initiation of a conflict resolution maneuver. (PR.42, PR.49**)**

DR-HM-RE-006:
The airborne system shall show to the flight crew the remaining validity time of a resolution maneuver. (EMM 1.4).

Note: it remains to be investigated how to apply these last two requirements when several conflicts are detected, i.e., if and how to prioritize the parameters to be shown to the flight crew.

4.6.4 System Operational Status Interface to Flight Crew

Operational Assumptions:

- *Definition of Service Levels (SL) according to Section 2;*
- *Use of priority rules and a priority number according to Section 2.*

DR-HM-OS-001:

ASAS will report any detected system failure or degradation, in itself or from external pre-requisites for SSEP, to the flight crew. (OSA [iFly D9.2], General ASAS failure)

DR-HM-OS-002:
ASAS HMI should allow the flight crew to enable or disable conflict detection and resolution functions, respecting conditions to be evaluated in further analyses.

Note: One envisaged situation is that, when the aircraft leaves SSA, the conflict detection and resolution functions shall be deactivated only manually by the flight crew. This requirement has to be validated.

DR-HM-OS-003:
ASAS HMI shall allow the flight crew to consult and select the SSEP Service Level up to the maximum allowable number determined by the Service Level Management function.

DR-HM-OS-004:
ASAS HMI shall allow the flight crew to consult the current AFR priority level and whether it is originated airborne or not.

DR-HM-OS-005:
ASAS HMI shall allow the flight crew to declare unable to SSEP.

4.6.5 User-Preferred Trajectory Selection

Operational Assumptions:

- *Conflict information has priority over user-requested trajectory modifications.*

DR-HM-UP-001:
ASAS HMI shall provide means to validate a user-requested trajectory modification and, when it is not valid, display the justification.

5. Concluding Remarks

This document concludes iFly WP9, whose main objectives were:

1. To define the preliminary Safety and Performance Requirements (SPR) of the Autonomous aircraft Operations Advanced Concept (the A^3 concept) described in WP1; and

2. To use the results of the SPR process to define preliminary system design requirements for an airborne system to support the A^3 concept.

While the first objective was addressed in the previous WP9 deliverables (OSED in D9.1, OSA in D9.2 and OPA in D9.3), this document focuses on the airborne system design. For this purpose, the outcomes of the previous SPR analysis were integrated in this document into a high-level functional architecture design of an airborne system supporting the A^3 operations. Subsequently, the system design requirements were defined for different parts of the system.

In the pursuit of the WP9 objectives, it became clear that, because of the Advanced aspect of the A^3 concept, many of the considered requirements were related to conceptual questions to be solved - among which several remain open. Actually, the time frame for the A3 ConOps is expected to be 2025+ (beyond the SESAR scope), therefore it is reasonable to expect that not all the questions can be solved already at this stage. In this context it is important to identify the open issues and support thus future follow-up work.

Some of the points that may be considered in providing the final status of the open issues (the aim is not to provide an exhaustive list here but rather highlight important topics) are:

i. The scenarios where SL1 and SL2 are applicable are not yet defined. The core benefits of A^3 will be achieved only with SL3. The main contributing factor to this outcome is the ADS-B performance, combined with the flight crew task performance, which together sum up delays that may turn ineffective the mid-term conflict resolution by trajectory modification (See D9.3, Section 8.1). Staying the scenario as this, SWIM would be very important communication means for mid-term conflict resolution. As in some Oceanic and low-density airspaces the availability of SWIM may not be feasible or cost-effective, it is expected that these would be potential scenarios for SL1 and SL2.

ii. The algorithms for searching conflicts related to complexity / loss of maneuverability, and their subsequent processing logic, will impact the requirements developed in WP9. However this impact could not be assessed for the time being. Therefore, it is just assumed that these conflicts will be detected and processed.

iii. The military operations described in ConOps (Section 8.10) imply in a different set of design requirements for military aircraft in SSA. As it is very likely that this set of requirements will be a subset of the requirements for civil aircraft, this question has not been addressed in WP9.

iv. Centralized versus decentralized priority number determination: the question of whether the aircraft priority number, for the purpose of conflict resolution, should be determined only onboard an aircraft or by a central entity, although relevant for WP9, was not tackled in it. The reason is that the effectiveness of one or another option is subject of still inconclusive mathematical analyses, beyond the scope of this Work Package. The requirements elaborated in D9.4 assume that the priority number can be both determined onboard an aircraft, or managed by a central entity.

v. The restart rules for the conflict resolution process could not be validated. Because of the transmission and processing times during the conflict resolution process, the actual situation may change in the interim so as to invalidate the premises taken to solve a conflict. Appendix D proposes a set of rules to tackle this problem, however those rules have not been validated. As this depends heavily on the conflict resolution algorithm, and on human-in-the loop investigation, this task has not been carried out in WP9.

vi. Some important operational elements such as transition procedures from/to SSA lies out of iFly's scope. These elements must be developed during future development stages of A^3.

Appendix A: System Wide Information Management System (SWIM) Operational Assumptions

Currently, the SWIM structure and capacity is not defined, so only initial performance was performed in the OPA/OSA process. Some of the services (especially performance oriented) described below may be provided by an external provider supported by SWIM (e.g., Flight Operating Center may provide some processing of meteo data, or a long term prediction of areas with high traffic complexity). For our purposes, we include these services in the SWIM description. An illustrative overview of the information sharing process for SL3 (taken from D1.3) is shown in Figure 1.

General Assumptions:

- SWIM will collect and provide access to updated information about weather, and operational restrictions (e.g., restricted areas).
- SWIM will collect information about valid Reference Business Trajectories of all flying aircraft (each aircraft shall immediately provide the information about changes to its RBT).
- SWIM will collect and provide access to updated state and intent information of all aircraft.
- (Optional) There may be additional services provided by SWIM which allow for an increase in flight performance, such as the traffic complexity prediction (generally information about recommended areas-to-avoid), advanced meteo information, etc.

SSA-Based Assumptions:

- SWIM will periodically provide each autonomous aircraft with the following information (push mode):
    - Meteo information
    - Traffic in proximity (update rate TBD in OPA/OSA) – list of aircraft (IDs) relevant to the autonomous aircraft flight up to the Mid Term time horizon (Mid Term Awareness Zone as described in A3 ConOps (iFly: D1.3) may be defined for this purposes).
- SWIM will provide to an autonomous aircraft on its request (pull mode) the latest information about state/intent of any aircraft in its proximity (performance parameters TBD during OPA/OSA).

Appendix B: Summary of Operational, Performance and Safety Assumptions

The following conditions were assumed through the system design development process. Assumptions presented in Tables B-1 and B-2 have origin in OSED (iFly: D9.1); Table B-3 contains additional assumptions and restrictions that have been respected during SSEP OSA development, and Table B-4 contains assumptions taken from interim communications regarding the development of other work packages, which have not been formally published.

Table B-1: Assumptions - Environmental conditions and communication.

Assumption	Description	Location of assumption in OSED (iFly:D9.1)
ASSUMP-1-EC	Only ASAS equipped aircraft – so called "autonomous aircraft" flying under AFR.	Page 9
ASSUMP-2-EC	En-route phase of the flight in so called SSA, the transition procedures (SSA towards MA and vice versa) are not discussed in the iFly framework.	Page 9
ASSUMP-3-EC	User preferred routing without flight levels binding.	Page 9
ASSUMP-4-EC	Airspace boundaries are dynamically allocated.	Page 9
ASSUMP-5-COM	Every aircraft broadcasts its state together with intent, via ADS-B.	ADS-B Initial Performance Assumptions Page 10
ASSUMP-6-COM	Relevant information provided to/by a ground supporting system (SWIM).	SWIM General and SSA-Based Assumptions Page 10
ASSUMP-7-COM	HF voice left mainly for emergency procedures.	Page 9
ASSUMP-8-COM	No explicit communication; Only implicit coordination for short term conflict.	iFly: D1.3 Chapter 8.6

Table B-2: Initial assumptions / performance estimates.

Assumption	Description	Location of assumption in OSED
ASSUMP-1-INI	Quality of broadcast information corresponds to the standard value of RNP required during the en-route phase of flight.	Navigation FB, page 28
ASSUMP-2-INI	Broadcast state information has got a form of State Vector, Mode Status and Air Referenced Velocity Report (DO-260A)	Navigation FB, page 28
ASSUMP-3-INI	MLAT=10min, SLAT=3 minutes	Surveillance FB, page 30
ASSUMP-4-INI	Air-Air datalink range is 90NM (120 NM desired)	Surveillance FB,

		page 30
ASSUMP-5-INI	When a new conflict appears during CR process, the CR should not be interrupted except well defined conditions. ("Restart conditions" defined in OSA Appendix 1: SR-N-4.2).	Events handling FB, page 30
ASSUMP-6-INI	Mid-term conflict resolution algorithm is always able to find a solution.	Trajectory modification FB, page 31
ASSUMP-7-INI	CPP (mid-term) should take no longer than maximally predefined time (first estimation 2 min).	Trajectory modification FB, page 31
ASSUMP-8-INI	Short-term conflict resolution algorithm is always able to find a solution.	Tactical maneuver FB, page 31
ASSUMP-9-INI	CPP (short term) should take no longer than maximally predefined time (first estimation 30sec)	Tactical maneuver FB, page 31

Table B-3: OSA specific assumptions.

Assumptions – others OSA specific	Description
ASSUMP-1-OTH	Priority number determination as stated in iFlyD1.3 used only in case of pairwise conflict
ASSUMP-2-OTH	ACAS is not considered as a part of SSEP and is not a synonym to *Emergency procedure;* SSEP does not modify ACAS procedures
ASSUMP-3-OTH	Only pairwise conflicts – simplified scenarios, no multi-aircraft conflicts will be discussed within SSEP OSA.
ASSUMP-4-OTH	Security issues are outside the scope of this document. The intentional violation of AFR or mischievous acting by flight crew is not considered.
ASSUMP-5-OTH	Technical realization of flight and connected (technology implementation) problems are not investigated. It is supposed that the feasibility of flight is guaranteed.

Table B-4: Additional assumptions – interim inputs from other work packages.

Assumption	Description	Origin WP
ASSUMP-1-AD	The determination of the aircraft Priority Level may be managed by a central entity on ground.	WP5
ASSUMP-2-AD	Some algorithms for tactical conflict resolution may require automated input from ASAS into auto-pilot and auto-throttle.	WP5

Appendix C: Operational Requirements from OSED

A set of Operational Requirements was identified and presented in the OSED (iFly D9.1) document. This section presents the summary of these requirements.

Table C-1: Operational (OR), functional (FR) and performance (PR) requirements together with priority rules determination (PRD).

Requirement	Description	Location in OSED iFly: D9.1
OSED-1-OR	Broadcast information shall include the data about accuracy and integrity of the transmitted trajectory information. The data shall reflect the actual navigation capability of own aircraft and flown guidance mode (including manual flight).	Regular flight stage Page 23
OSED-2-OR	During the initiation stage, the selected action for trajectory change shall conform to Autonomous Flight Rules.	Initiation stage Page 24
OSED -3-OR	During the initiation stage: a) Any kind of conflict has priority over the trajectory optimization. b) Short-term conflicts have priority over mid-term conflicts.	Initiation stage Page 24
OSED-4-OR	During the tactical maneuvering stage: a) CR maneuver shall not generate a new short-term conflict. b) CR maneuver shall be conforming to AFR (implicit coordination if applicable, blunder protection, etc.) c) Tactical Maneuvering stage is followed by the new trajectory generation stage, which generates a new RBT.	Tactical maneuvering stage Page 24
OSED -5-OR	During the new trajectory generation stage: a) New trajectory must be conflict-free at least up to the mid-term time horizon. b) New trajectory shall be conforming to AFR (blunder protection, etc.)	New trajectory generation stage Page 25
OSED -6-PR	The Navigation Functional Block has the following characteristics: a) The broadcast intent allows a prediction of the aircraft planned trajectory up to MTTH (SL2 and SL3). b) Whenever the intent information of an aircraft is changed, a new intent should be broadcast immediately (SL2 and SL3).	Navigation FB

Requirement	Description	Location in OSED iFly: D9.1
OSED -7-OR	For the Surveillance Functional Block: a) If the information about relevant traffic is not updated according to the performance requirements: a. The information must be marked as obsolete or invalid (both for state and intent data). b. If applicable (SL3), this information must be queried from the corresponding aircraft or from SWIM. b) SWIM provides a complete list of aircraft relevant to own flight up to Mid Term Time Horizon – traffic list (SL3). c) (SL3 only) In the case of missing information about an aircraft on the traffic list, the information must be queried from SWIM. d) Conflict detection will run continuously during the SSEP operation and all detected conflicts will be reported. e) There is no change in communications as a result of detected conflicts.	Surveillance FB Page 29
OSED -8-OR	For the Surveillance Functional Block: a) Conflict detection is a continuous process which runs at a given frequency (TBD) with the best information available. b) SP should be maximally TBD seconds/minutes	Surveillance FB Page 29
OSED -9-OR	Situation assessment runs continuously, during the time when conflict information is available.	Events handling FB Page 30
OSED -10-PR	LP – should take maximally predefined time (TBD)	Events handling FB Page 30
OSED -11-OR	Regarding the trajectory modification algorithm: a) The trajectory does not rely on any actions from the other conflicting aircraft. b) The proposed conflict solutions follow AFR, in particular, they are conflict-free up to or beyond the MTTH, blunder protection is considered, etc. c) Optimization process (in absence of any conflict) modifies the RBT only beyond the MTTH.	Trajectory modification FB Page 31
OSED-12-FR	Regarding the trajectory modification algorithm: a) The proposed solution is valid at time of execution (i.e., it has to take into account ED). Flight crew is responsible to take action to solve the detected conflict. System provides only advisories.	Trajectory modification FB Page 31

Requirement	Description	Location in OSED iFly: D9.1
OSED -13-OR	Regarding the tactical maneuver algorithm: a) The algorithm does not rely on any action from the conflicting aircraft b) The proposed conflict solutions follow AFR (implicit coordination if applicable, blunder protection, etc.). c) Conflict resolution makes full use of all information available at time RT (Reference Time, see Figure 2, iFly: D9.1). It remains to be investigated within OSA and OPA how to deal with updated information that is received after RT, whereas the crew has not yet decided what to do.	Tactical maneuver FB Page 31
OSED -14-FR	Regarding the tactical maneuver algorithm: a) Algorithm is able to solve conflicts with multiple aircraft. b) The proposed solution(s) are valid at time of execution (i.e., it has to take into account ED). Flight crew is responsible to take action to solve the detected conflict. System provides only advisories. In other words, the trajectory update is executed only after flight crew approval.	Tactical maneuver FB Page 31
OSED-15-PRD	Priority level utilization: a) Priority rules are applied only to Medium Term Conflict Resolution. b) Priority rules determine the priority level of each aircraft, that means determine which aircraft has got the right way and which aircraft has to maneuver. c) Priority rules will be identical for all aircraft. Priority level considerations are the following d) Priority level will be broadcast so it can be used by other aircraft e) Priority level will be determined based on a. CTA requirements b. Maneuverability c. Mission statement f) Aircraft with lower priority level have to maneuvers to prevent the conflict from becoming a short term conflict. g) In case of identical priority levels, an arbitrary procedure (based in the aircraft call signs for example) will be used to ensure that priority is always unambiguous.	Appendix 2: Priority rules Page 39

Appendix D: Restart Rules for Conflict Resolution

This appendix is based on SR-N4.2 from OSA (D9.2).

When a conflict is detected, Events Handling FB shall identify what type of maneuver and type of conflict resolution algorithm should be used and consequently activate the appropriate conflict resolution process. The conflict resolution should start as soon as possible. A problem arises when new conflict appears while the former one is still being solved, possibly the conflict resolution is still being evaluated by flight crew. The flight crew shall not be interrupted or disturbed too often.

So the set of proposals, when the conflict resolution process shall be restarted, has been formulated:

- The conflict resolution process has not yet proposed the conflict resolution to the flight crew.
- In general: a more serious situation appears and requires instant resolution.
    - A new short-term conflict appeared when mid-term conflict was assessed.
- The conflict resolution proposal has been postponed to the FC assessment but new circumstances appeared. Such a circumstance might be
    - A new intent released by other aircraft would lead to a short-term conflict, if currently proposed solution would be accepted and flown by own aircraft.

A solved conflict is no more a current affair. The flight crew shall be informed, that conflict resolution process has been terminated.

Appendix E: Input from Work Package 3 – "Prediction of complex traffic conditions"

In Work Package 3, methods for predicting complex traffic conditions have been developed and evaluated, aiming at the performance of early actions to avoid air traffic situations that may be over-demanding to the autonomous aircraft design. The first phase resulted in D3.1, which consists in a critical survey of various metrics proposed in the literature for complexity modeling and prediction in ATM. However, as most of the previously existing complexity metrics address ground-based ATM with human Air Traffic Controllers, where aircraft follow predefined routes according to some prescribed 4D flight plan, they were considered restrictive for the advanced autonomous aircraft ATM scenarios.

Therefore, in the second phase, metrics more appropriate for predicting complex conditions in A3 were developed. All of them measure intrinsic traffic complexity, independent of the human operator workload, which is desirable for considered highly automated operations. Due to the high information (communication) and computational requirements of the developed metrics, they are mostly recommended for use within the ground-based centralized tools supporting the self separating aircraft (e.g., by providing complexity maps or high complexity areas-to avoid).

The metrics are presented in D3.2 and summarized in D8.1, both of which serve as reference for the remainder of this Appendix.

E.1 A local flexibility-based approach to long term complexity

This approach is designed to work in a time horizon of more than 30 minutes, and is based on the concept of influence zone of an aircraft. Its main purpose is to identify critical situations with limited maneuverability along the aircraft intended trajectory. The complexity is formulated in terms of the amount of local deviations from a long-term trajectory which do not cause interference with other aircraft but it does not take into account the uncertainties in the aircraft motion.

The complexity is evaluated as function of time along the trajectory and takes as inputs the candidate resolution maneuvers of the considered aircraft together with state and intent information of all the aircraft.

Recommended way of implementation is by central processing on ground.

E.2 A geometric approach to long term complexity

It is built upon a simple idea: to assess whether it would be convenient for an aircraft to be or not at specific place in specific time. For this purpose, it assesses how likely it is that an aircraft will be forced to tactically maneuver at that point. The complexity at a give point of airspace takes into account the relative distance of surrounding aircraft from this point as well as their relative track.

Again, this approach is focused on strategic planning and requires a central processing entity, supported by SWIM (it uses information about RBTs of involved aircraft). There are two operational applications proposed:

- First, it is envisioned that as part of the strategic information for its flight, the automated ground surveillance support makes available to the aircraft the information about the areas-to-avoid, which include areas with high air traffic complexity. This function involves evaluating a suitable complexity metric across the airspace based on the RBTs of all aircraft stored in SWIM and applying some threshold(s) to detect critical areas.

- Secondly, for the purpose of on-board trajectory management, each aircraft needs to upload the complexity map in the vicinities of its current RBT. If the complexity encountered along the RBT exceeds some threshold, then, the trajectory has to be modified.

E.3 A probabilistic approach to mid-term complexity

This method, contrarily to the previous ones in this Appendix, does take into account the uncertainties of the flown aircraft trajectories. The introduced mid-term complexity measure is based on the notion of probabilistic occupancy of the airspace: complexity is evaluated in terms of proximity in time and space of the aircraft in the airspace, determined from their intent and current state, while taking into account uncertainty in the aircraft future position. The correlation amongst the future positions of the various aircraft is neglected.

Similarly to the previous two approaches, operational application of this metric is based on the use of complexity maps, and needs centralized support. In the current version, it is computationally demanding and will require optimization techniques to run in a real environment.

E.4 A dynamical system approach to mid-term complexity

The basic idea comes from the dynamical system theory, where a complexity indicator is obtained by calculating the rate of separation of diverging trajectories which start infinitesimally close to each other. This rate is defined as the Lyapunov exponents of the system which, in more intuitive words, is understood as the level of organization of the air traffic scenario.

This approach is similar to the previous ones in many ways: it uses as input the RBT of all aircraft, and requires centralized processing for determining complexity maps. From the latter the regions of interest can be extracted for individual aircraft. There is a practical benefit comparing to the other discussed metrics that the current version is already fully 3D, and a good degree of parallelism can be achieved in the computation.

E.5 Issues for the implementation of the complexity approaches

The complexity approaches above presented have been tested in limited simulation environments and, in order to be used in real scenarios, need to pass through refinement and validation. Some of the issues to be worked on are the setting of the complexity threshold required to initiate resolution actions, and the coordination (explicit or implicit) of these resolution actions, which must be stable, according to the following reasoning: if all aircraft modify their RBTs to avoid some complex area, they could generate a new complex area, thus making the resolution ineffective. One potential way to avoid this problem is lowering the number of aircraft to maneuver by using, e.g., priority rules.

Another aspect to be worked out is the destabilization created by delays in the decision process, caused by factors such as the human operator performance, and the update rate for the complexity maps.

Appendix F: Input from Work Package 5 – “Pushing the limits of conflict resolution algorithms”

Work Package 5 explored and developed several promising alternatives for onboard conflict resolution algorithm. This Appendix is intended to summarize these alternatives, more details being available in WP5 deliverables, namely iFly D5.3.

It is important to notice that in some of these alternatives, the Detection and Resolution are part of the same iterative process, in an automatic closed control loop. Therefore they should be assessed to determine how they can be adapted to work with the assumption of human operator in the decision loop (see ConOps, Section 9.3.4) used to elaborate the system design requirements.

F.1 Short Term CD&R

F.1.1 Decentralized Navigation Functions

Decentralized Navigation explores the idea of potential fields (force field methods) embedded in navigation functions which allow for convergence to a destination goal and respect to the non-holonomic nature of aircraft dynamics. They enable each aircraft to navigate while avoiding conflict with its neighbors by means of repelling forces. This approach uses a feedback control scheme that provides fast response and is computationally efficient. A comparison between the algorithm's characteristics and the ConOps requirements is given below.

		ConOps Requirements	Proposed Algorithm	Comments
Inputs	Ownship	State, Intent	State, Intent	
	Traffic	State, Intent (opt.)	State	
Outputs		Resolution Manoeuvre	Requirement met; specifically: Speed Climb-descent rate Rate of heading turn	Manoeuvre defined implicitly Constant Speed, bounded climb-descent angle
Lookahead Time		Up to 3 to 5 min	Requirement met, only local sensing for Conflict Detection	
Priority Rules		No	Requirement met, with option of priority rules	
Assumptions		Implicit Coordination ‘1 to N’ resolution No new conflicts	No direct coordination All possible conflicts avoided	

Table F-1: Comparison of ConOps requirements for short-term CD&R and Decentralized Navigation Functions.

F.2 Mid-Term CD&R

F.2.1 MMPC – Multiplexed Model Predictive Control

Model Predictive Control (MPC) is used in this and several other alternatives of CD&R algorithms proposed for Mid-Term, because of its adequacy to air traffic situations. In D5.3, MPC algorithms run in a periodic and distributed fashion, allowing the incorporation of new updated data and information as the conflict scenarios evolve.

For the Multiplexed Model Predictive Control solution, the underlying protocol is that aircraft plan their future trajectories in a predefined cyclic sequence, taking into account plans received from others. Each aircraft involved in an encounter plans its own future trajectory, and then transmits its future plan to the other aircraft. The next aircraft in the sequence does the same. Each aircraft executes the first step in the plan it has announced, until it is its turn to recompute its plan. SWIM in this case is used in order to provide an initial centralized solution to the situation. The algorithm can be robust to communication failure with SWIM, provided its duration is not longer than the Mid-Term CD&R horizon.

F.2.2 MMPC with Disturbance Feedback

This is a refinement of the previous algorithm, where the time affine disturbance feedback is used between policy updates. Thus changes in speed and heading can be applied or not every time step. The scheme involves a single aircraft re-optimizing its policy at any time. In between optimization updates, aircraft apply a fixed feedback policy according to the disturbance they encounter. This modified scheme permits longer prediction horizon lengths than the original MMPC. SWIM in this case is used in order to provide an initial centralized solution to the situation. The algorithm can be robust to communication failure with SWIM, provided its duration is no longer than the Mid Term CD&R horizon.

There are two variants of this algorithm, below described.

F.2.2.1 Fixed order MMPC with Disturbance Feedback

At each update cycle, an aircraft optimizes its trajectory using the plans received from the others. Then, it broadcasts its intent and, with it, the other aircraft perform the same actions in a fixed sequence. Each aircraft can use accurate predicted plans of the other aircraft while planning its own set of moves. This can be implemented according to a fixed or variable timing sequence. Using this restrictive fixed update order enables a higher frequency of policy update. SWIM in this case is used in order to provide an initial centralized solution to the situation. The algorithm can be robust to communication failure with SWIM, provided its duration is not longer than the Mid Term CD&R horizon.

F.2.2.2 Variable order MMPC with Disturbance Feedback

In the previous formulation, aircraft optimize sequentially, one per time step, to ensure feasibility. In this formulation, each aircraft optimizes in parallel for a new plan, conditioned on the other aircraft executing one of their candidate conflict free plans. Aircraft still update their policies in a round-robin fashion, but a variable order of update is employed. The choice of updating aircraft at any given time step is based on satisfaction of some global objective, for instance that which would minimize some total cost of all aircraft. The motivation for performing parallel optimization is to make greater use of time between updates, and to allow aircraft with ‘greatest need’ to re-optimize their policy sooner, for instance in order to respond to strong wind disturbances. SWIM in this case is used in order to provide an initial centralized solution to the situation. The algorithm can be robust to communication failure with SWIM, provided its duration is not longer than the Mid Term CD&R horizon.

F.2.3 Summary of MMPC Algorithms

The algorithms just detailed can be subsumed by the general multiplexed MPC framework, whereby aircraft update their policies in a sequential round robin fashion. All variants require an initial centralized solution enabled by SWIM.

Through the variants of the multiplexed algorithm, the aircraft may apply corrections to their plans (disturbance feedback) in between updates according to wind disturbances they experience, to account the effect of wind. This is done to facilitate feasibility and permit longer prediction horizons to be utilized. Multiplexing is not restricted to employing a specific order of update, and this flexibility can be exploited to achieve system wide objectives by adopting a variable order formulation, as outlined in F.2.2.2. The variant to be chosen may depend on the required amounts of communication and computing.

The main features of MMPC algorithms are summarized in Table F.2.

Feature	ConOps Requirement	Robust decentralized MPC
Look-ahead time	15–20 minutes	Requirement met
Coordination	Not required	Requirement met
Principle of use	Intent	Requirement met
Priority rules	Yes	Requirement not met
Secondary conflict creation	Do not	None created
2-minute state vector conflict	Avoid	Not addressed yet No problem in principle
Type of resolution algorithm	Intent-based	Requirement met
Alternative resolutions	Should provide	Not provided yet

Table F-2: Comparison of ConOps requirements and properties of the robust decentralized MMPC algorithm for mid-term conflict resolution.

F.2.4 MPC combined with Navigation Function

This algorithm works in a similar fashion as the previous ones, in the sense that it still uses MPC for the Mid-Term CD&R, but also takes into account the presence of the Short Term CD&R level, using Navigation Functions in this lower level.

Each aircraft computes its own trajectory and broadcasts its intent to the others, which then take it into account in their calculations. The process is repeated periodically (e.g. every 3-5 minutes). “Priorities” are implicit in the decision of which aircraft computes its solution first in each round. Two schemes are considered:

1) **Fixed priorities**: Each aircraft has a unique priority; as for example discussed in the priority alternatives later on the document. In an encounter the aircraft with the highest priority computes its trajectory first and broadcasts, then the one with the second highest does the same, etc.

Aircraft with lower priority take the trajectories broadcast by the higher priority ones as constraints in their calculations.

2) **Random priorities**: At every round the aircraft draw a random number between 0 and 1 and broadcast it. The aircraft with the lowest number gets the highest priority for the round, computes its trajectory and broadcasts, then the one with the second lowest number does the same, etc. Again lower priority aircraft treat the trajectories broadcast by higher priority aircraft as constraints when calculating their own trajectories.

So far, both schemes lead to resolution. Fixed priorities tend to penalize some aircraft excessively. High priority aircraft get straight paths and low priority ones basically have to go around everyone else, whereas a small deviation from a higher priority aircraft may lead to much better trajectories for the low priority ones. On the other hand, random priorities tend to lead to more "meandering" trajectories. When an aircraft has high priority it heads straight for its destination but in the next round it may have to deviate. What seems to work best is using fixed priorities but penalizing (in the cost function they use in their optimization) high priority aircraft if their chosen trajectories force low priority aircraft to deviate excessively. SWIM in this case can be used to provide a globally optimal solution to the priorities. The algorithm can be robust to communication failure with SWIM, as it can perform in a completely decentralized fashion.

In Table F-3 one finds the main features of this CD&R solution.

Feature	ConOps Requirement	Hierarchical MPC with Priorities
Look-ahead time	15–20 minutes	Requirement Met
Coordination	Not required	Requirement Met
Principle of use	Intent	Requirement met
Priority rules	Yes	Requirement Met
Secondary conflict creation	Do not	Requirement Met
2-minute state vector conflict	Avoid	Not addressed yet
Type of resolution algorithm	Intent-based	Requirement Met
Alternative resolutions	Should provide	Requirement Met Can provide

Table F-3: Comparison of ConOps requirements and properties of the combined MPC&NF algorithm for mid-term conflict resolution.

F.2.5. Hierarchical MPC with Priorities

The previous methods for mid-term conflict detection can deal with priorities implicitly, by taking them into account in the cost function. The A^3 ConOps, on the other hand, demands for a more systematic way to deal with the priorities, in the sense that in medium term conflict situations, lower priority aircraft should maneuver first. In order to accommodate this requirement, a novel method is under development, which can adequately deal with this issue.

This method can be briefly described as following. First, the physical aircraft dynamics are abstracted to simplified ones. Then, a centralized model predictive controller that takes into account the physical limitations of the aircraft, such as input constraints and turning rates, as well as the minimum separation safety constraints among the aircraft is designed. The effects of wind are taken into account, and priorities are assigned to each aircraft. The resulting non-convex optimization problem for all aircraft is centrally solved, by using a standard mixed-integer linear programming (MILP) solver.

After running and analyzing three distinct scenarios for this general scheme, it could be concluded that this approach is, in principle, feasible, and the effect of using priorities is beneficial both for the total extra flown distance as well as for safety indicators. However, the main downside of using priorities is increasing the computing time.

This approach still does not meet important requirements from the ConOps, because it runs centralized and its interaction with the short term conflict resolution algorithms still needs clarification.

Appendix G: List of References

1. iFly deliverable D1.3: Autonomous Aircraft Advanced (A^3) ConOps, 2010.
2. Cásek P., Keinrath C. (2008): Airborne system for Self Separation in a Trajectory-Based Airspace. EUROCONTROL Inovative ATM Research Workshop and Exhibition 2008, p. 25-31, http://inoworkshop.eurocontrol.fr
3. EUROCAE ED-78A/RTCA DO-264: Guidelines for approval of the provision and use of air traffic services supported by data communications, December 2000
4. FAA/Eurocontrol Action plan 23: Long term ADS-B and ASAS Application: D3 – Operational Role of Airborne Surveillance in Separating Traffic, FAA/Eurocontrol cooperative R&D, version 0.3, November 2008
5. FAA/Eurocontrol Action plan 23: Long term ADS-B and ASAS Application: D4 – Draft proposal for a Second Set of GS/AS Applications , FAA/Eurocontrol cooperative R&D, version 0.2, AP23-08-D4-v0.3
6. iFly deliverable D2.4: Potential human factors improvement for A^3 ConOps, version 1.2, May 2009
7. iFly deliverable D3.1: Complexity metrics applicable to autonomous aircraft, version Final 1.0, June 2008
8. DO-317: Minimum Operational Performance Standards (MOPS) For Aircraft Surveillance Application System (ASAS), RTCA Special Committee 186, http://www.rtca.org , April 14 2009
9. DO-242A: Minimum Aviation System Performance Standards For Automatic Dependent Surveillance Broadcast (ADS-B). RTCA, Inc., June 2002.
10. ICAO Doc 9854 AN/458: Global traffic Management Operational Concept, 2005.
11. DO-260A: Minimum Operational Performance Standards for 1090MHz Extended Squitter. Automatic Dependent Surveillance – Broadcast (ADS-B) and Traffic Information Services – Broadcast (TIS-B), RTCA 2003.
12. iFly Deliverable D9.1: Operational Services and Environment Description (OSED) of Airborne Self-Separation Procedure, version 1.3, August 2009.
13. iFly Deliverable D9.2: ED78a/DO-264 based Operational Hazard Assessment and Allocation of Safety Objectives and Requirements of Airborne Self-Separation Procedure (OSA), version 1.3, May 2010.
14. iFly Deliverable D9.3: Operational Performance Assessment (OPA), version 1.3, May 2010.
15. Duong, V. N., Hoffman, E., and Nicolaon, J.-P., "Initial Results of Investigation into Autonomous Aircraft Concept (FREER-1)", Proceedings of the 1st USA/EUROPE Air Traffic Management Research and Development, Saclay, 1997.

16. Irvine, R., "Comparison of Pair-Wise Priority-Based Resolution Schemes Through Fast-Time Simulation", 8th Innovative Research (INO) Workshop, Bretigny, 2009.

17. Alliot, J. M., Durand, N., and Granger, G., "FACES: a Free Flight Autonomous and Coordinated Embarked Solver", Air Traffic Control Quarterly, Vol. 8 (2000), p. 109-130.

18. Idris, H., Vivona, R., Garcia-Chico, J., and Wing, D., "Distributed traffic complexity management by preserving trajectory flexibility", 26th Digital Avionics Conference, 2007.

19. Cásek, P., Brázdilová, S.L., "Priority rules in a Distributed ATM", Air Transport and Operations Symposium, 2010.

20. iFly Deliverable D3.2: Report on timely prediction of complex conditions for en-route aircraft, April 2010.

21. iFly Deliverable D4.2: Report on Observability Properties of Hybrid-System Composition.

22. iFly Deliverable D5.1. Comparative Studies of Conflict Resolution Methods, June 2009/

23. iFly Deliverable D5.2 Analysis of conflict Resolution needs of A3 operational concept.

24. iFly Deliverable D5.3

25. iFly Deliverable D6.4i: Interim report on cost-benefit analysis, 2010.

26. iFly Deliverable D7.1b. Hazard Identification Report.

27. iFly Deliverable D8.1: A3 ConOps Refinement.

Appendix H: Abbreviations

ACAS	Airborne Collision Avoidance System
ADS-B	Automatic Dependant Surveillance - Broadcast
AFR	Autonomous Flight Rules
ANSP	Air navigation Service Provider
AP	Action Plan
ASAS	Airborne Separation Assistance System
ASPA S&M	Airborne SPAcing, Sequencing & Merging
ASSAP	Airborne Surveillance and Separation Assurance Processing
ATC	Air Traffic Control
ATM	Air Traffic Management
ATSA	Airborne Traffic Situational Awareness
ATSA-AIRB	Enhanced Traffic Situational Awareness during flight operations
A/P	Autopilot
A/T	Autothrottle
BC	Basic Cause
BPTH	Blunder Protection Time Horizon
CD	Conflict Detection
CDTI	Cockpit Display of Traffic Information
CPP	Conflict Processing Performance
CR	Conflict Resolution (CR1/CR2 defined in Section 2.1)
CRP	Conflict Resolution performance
CTA	Controlled Time of Arrival
DR	Design Requirement
ED	Execution Delay
EMM	External Mitigation Means
ETA	Estimated Time of Arrival
FB	Functional Block
FOC	Flight Operations Centre
HIP	Human Information Processing
HMI	Human Machine Interface
IMM	Internal Mitigation Means
LoS	Loss of Separation
LP	Logic Performance
LTAZ	Long Term Awareness Zone
MA	Managed Airspace
MP	Maneuver Preparation
MTAZ	Mid Term Awareness Zone (Operational requirements: Information sharing)
MLAT	Mid term Look Ahead Time
MTTH	Mid Term Time Horizon
OPA	Operational Performance Assessment
OR	Operational Requirement
OSA	Operational Safety Assessment
OSED	Operational Services and Environment Description
PAZ	Protected Zone

PFD	Primary Flight Display
PLOS	Predicted Loss of Separation
PR	Performance Requirement
RAA	Restricted Airspace Areas
RBT	Reference Business Trajectory
RT	Reference Time
RTTL	Remaining Time To Loss of separation
SL	Service Level (SL1/SL2/SL3 defined in Section 2.2.1)
SLAT	Short term Look Ahead Time
SP	Surveillance Performance
SR	Safety Requirement
SSA	Self Separating Airspace
SSEP	Airborne Self-Separation
STT	Short Term time Threshold
STTH	Short Term Time Horizon
SWIM	System Wide Information Management System
TBD	To Be Defined
TIS-B	Traffic Information Service - Broadcast
TMA	Terminal Area
TTL	Time To Predicted Loss of separation
WHA	Weather Hazards Areas

Appendix I: List of parameters and CD&R related abbreviations

This list summarizes parameters, which have appeared through the document.
XX stands for no assigned abbreviation.
TBD stands for *To Be Defined*.

Variables used for CD&R

TTL	Time To Predicted Loss of separation	
RTTL	Remaining Time To Loss of separation	

Operational requirements

Thresholds for CD&R parameters		
PLOS	Predicted Loss of Separation	TBD
Thresholds for CR coordination		
STT	Short Term time Threshold	TBD
Information Sharing Parameters		
MTTH	Mid Term Time Horizon	10 minutes
STTH	Short Term Time Horizon	3 minutes
XX	Air-Air data link Range	90NM (120NM desired–Equipage class A3)
XX	SWIM performance parameters	TBD
XX	Meteo information updates	30 minutes

Onboard conflict processing

Conflict detection processes boundaries		
MLAT	Mid term Look Ahead Time	
SLAT	Short term Look Ahead Time	
CD&R Performance parameters: Maximal allowed values		
CPP	Conflict Processing Performance	SP+LP+CRP+ED
SP	Surveillance Performance	TBD
LP	Logic Performance	TBD
CRP	Conflict Resolution performance	TBD
ED	Execution Delay	ED = HIP + MP 2 minutes (Closed maneuver) 30 seconds (Open maneuver)
HIP	Human Information Processing	TBD
MP	Maneuver Preparation	TBD

Other variables and abbreviations

BPTH	Blunder Protection Time Horizon (2 minutes)	
RT	Reference Time (Onboard conflict processing)	
MTAZ	Mid Term Awareness Zone (Operational requirements: Information sharing)	