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iFly

Safety, Complexity and Responsibility based design and

validation of highly automated Air Traffic Management

Specific Targeted Research Projects (STREP)

Thematic Priority 1.3.1.4.g Aeronautics and Space

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Operational Services and Environment Description (OSED) of Airborne Self-Separation Procedure (SSEP)

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1. Introduction

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 investigates 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. Although a crew-less Autonomous Aircraft are not covered by the A3 ConOps, it is expected that a related extension of the concept is quite well feasible.

iFly Work Package WP9 builds on the [D1.3] report starting with WP9.1 which provides the description of the operational environment and the air traffic services required by the A3 concept. In line with this, the intended outcome of WP9.1 is an Operational Services and Environment Description (OSED) document of the A3 ConOps, developed in accordance with the guidelines provided by EUROCAE ED-78A/RTCA DO-264. The main goal is to provide a sufficiently detailed description of the A3 operations to enable Operational Safety Assessment (OSA) and Operational Performance Assessment (OPA) that will be performed in WP9.2 and WP9.3, respectively. For this purpose, a high-level Functional System Description is developed as well as initial performance expectations and technological considerations.

As stated above, the OSED provided in this document is the first step of Safety and Performance Requirements (SPR) process which continues by OSA and OPA. Operational safety assessment will quantitatively asses operational hazards related to autonomous ATM concepts, as well as safety objectives and candidate safety requirements related to identified hazards. Within OSA process the safety objectives will be allocated to involved stakeholders and shared risk mitigation strategies will be developed. Operational performance assessment will provide airborne performance requirements for A3 operations. Results of the OPA and OSA processes will be used for further refinement of the OSED which is provided in this document.

1.1 Organization of this report

In the remainder of the document, the airborne self-separation (SSEP) concept that has been proposed in [D1.3] will be analyzed in more detail.

First, Section 2 provides an overview of the considered SSEP operations.

Next, in Section 3 the environment, as well as all participants and their roles are described. As one of the most important parts of the concept is the exchange of data, an independent subsection is devoted to the communications among aircraft and with ground systems.

Subsequently in Section 4, the description of the processing of different types of conflicts and trajectory changes is provided, followed by a decomposition of the SSEP operations into operational stages. The description of each stage contains an overview of tasks performed within the stage and an initial list of operational requirements.

Sections 5 is devoted to non-normal operations and will be completed based on OSA results.

Since many of the required onboard functionalities run continuously during SSEP and may not be uniquely identified with a single operational stage, a high-level functional description is developed using the concept of *Functional Blocks (FB)* in Section 6 . A functional block is a set of functionalities assuring a group of tasks – such as navigation, surveillance, events handling or conflict resolution. The description of functional blocks includes the list of needed functionalities together with initial performance requirements.

Section 7 provides a brief link with Action Plan 23 deliverables.

Finally, at the end of the document in Section 8, the SSEP operations are illustrated step by step with the help of several sample scenarios.

The summary of important definitions, parameter and operational rules is provided in the Appendices.

- Autonomous Flight Rules (A1)
- Priority Rules (A2)
- ADS-B performance (A3)
- Suggested Automation Levels for an example SSEP implementation (A4)
- List of References(A5) , Abbreviations (A6) and CD&R related parameters(A7)

2. SSEP Operations Overview

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.

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 Constrained 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 structure.

Within SSA the information exchange among aircraft will primarily be assured through data link, voice communication (for instance, among nearby 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. The goal of the self separation operations described in the OSED 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.

In case of a conflict, the involved aircraft will not broadcast any additional information and there is no requirement for any additional individual data exchange. The coordination of actions among conflicting aircraft is enabled by the set of rules included in AFR (see Appendix 1), which are binding for all participants. Based on these rules there are two types of Conflict Resolution (CR) processes, which are based on estimated Time To Loss of separation (TTL) available for maneuvering. For this purpose there is a time parameter defined, Short Term time Threshold (STT), separating the two types of conflict resolution (the value should be determined through the operational validation).

When the time for maneuvering is shorter than STT, 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 for conflicting aircraft.

Conflicts with the time for maneuvering greater than STT are solved using the Priority rules principle (Appendix 2). 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 evolve 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). Ideally, all conflicts should be solved beyond STT, short-term CR serving only as a safety backup.

To ensure separation and onboard trajectory management tasks, the flight crew takes advantage of the onboard equipment, which is monitoring the surroundings and helps the flight crew to detect and resolve conflicts. When a conflict is detected, the onboard equipment proposes a solution, which is assessed by the flight crew. When the solution is approved by the flight crew, the flown trajectory is updated and the aircraft broadcasts its new state and intent information. 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.**

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 A3 ConOps as well as of this OSED 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 not defined in this document (neither in A3 ConOps) and only a few of basic assumptions (namely, no conflicting situation immediately at the entry to the SSA and the existence of CTA at the exit of SSA) are considered in this context. To simplify the future extension of the concept by the definition of transition procedures, the SSA-part of flight is in the operational description (Section 4.2) delimited by two (broadly defined) stages, Setting-up Self Separation Stage and Self Separation Termination Stage, which covers these operations.

3. Operational Environment

3.1 Airspace characteristics

The considered airspace is regarded as **Self Separation Airspace** (SSA). As defined in the Autonomous Aircraft Advanced ConOps (iFly: D1.3), the SSA structure and characteristics are the following:

- Flight Crews of Autonomous aircraft are responsible for separation in accordance with predefined Autonomous Flight Rules (AFR; see Appendix 1).
- There is no flight level structure binding for AFR aircraft.
- User preferred routing is applied throughout.
- All aircrafts are broadcasting the information about the flight according the applicable airspace communication requirements.
- Airspace boundaries are dynamically allocated[1].

The proposed OSED is only considering the situations described in the Autonomous Aircraft Advanced (A^3) ConOps (iFly: D1.3), where only autonomous aircraft (aircraft under AFR) participate in the SSA. Airspace comprised of a mixture of aircraft flying under AFR and IFR is not considered.

The objective of the A3 ConOps developed in [D1.3] is to safely accommodate a three to six times increase in current en-route traffic levels. For this purpose two potential Separation Minima (SM) are considered in the context of SSA. While the Comfort Separation Zone is based on the current en-route Reduced Vertical Separation Minima (5NM horizontally, 1000ft vertically), the so-called Minimum Separation Zone considers a potential SM reduction discussed within the RESET project (3NM horizontally, 900ft vertically). Comfort Separation zone will be used during the initial OSA/OPA.

3.2 Communication

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 broadcasted** by autonomous aircraft (only ADS-B considered so far).
- **Information provided to/by a ground supporting system (SWIM)**. SWIM is expected to work in two models: pull model, when data are sent to user upon request, and push model, when some data are periodically sent.
- **Voice communication** will remain the backup means of communication in nonstandard or emergency situations.

[1] This is generally referred as Flexible Airspace Management (NextGen) or (Advanced) Flexible Use of Airspace (Eurocontrol, SESAR). The aim is to replace fixed airspace structures with volumes of airspace available in a dynamic manner. In this way any necessary airspace segregation is temporary, based on real-time usage within a specific time period.

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.
- **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).

ADS-B Initial Performance Assumptions:

- Broadcasted state information has got the form of State Vector and Identifier (which is part of Mode Status) and Air Referenced Velocity Report (DO-260A) (all SL).
- Air-Air data links State Vector Accuracy, Update Interval and Acquisition Range Requirements meet the **Equipage class A3** (DO-242A) (see Appendix 3).

SWIM (System Wide Information Management System) Operational Assumptions:

Currently, the SWIM structure and capacity is not defined, so the initial performance estimation is mostly left to 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

- o 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).

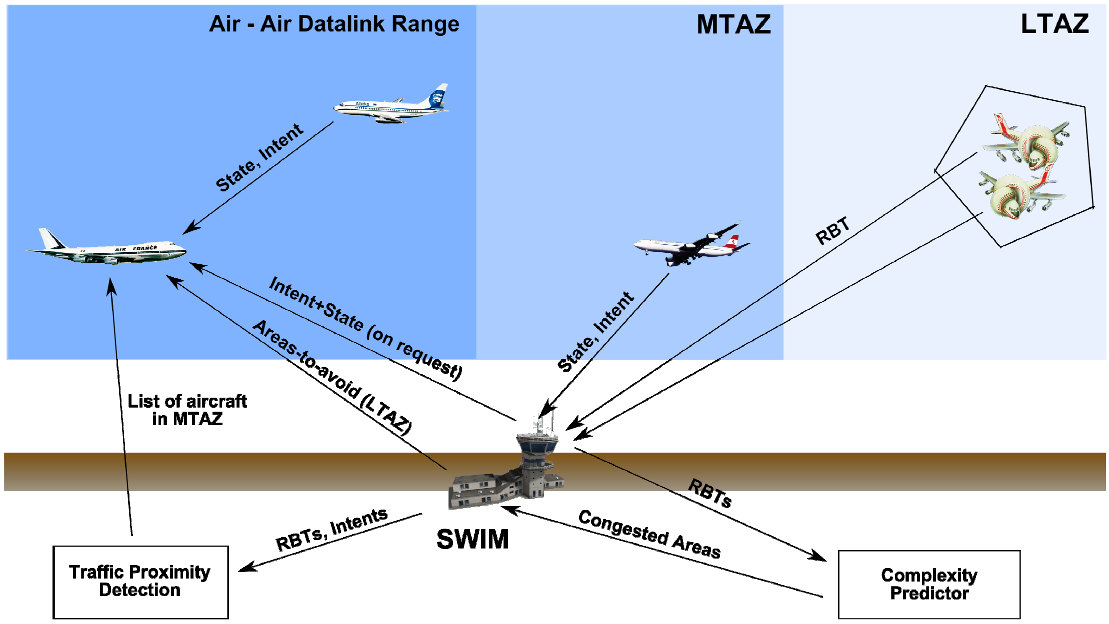

Figure 1: Information sharing process (from D1.3).

3.3 Roles and responsibilities

In the following chapter the participants involved in the SSEP operation and their roles and responsibilities are listed.

3.3.1 Autonomous aircraft

Information sharing is a key enabler of SSEP operations. In this context it is necessary that each aircraft operating in SSA conforms to the following:

- Autonomous aircraft shall **broadcast** the information about own flight according to the applicable Service Level and performance requirements (to be defined during OSA/OPA process)(all SLs).
- Autonomous aircraft shall immediately announce any **changes of its RBT to SWIM** (based on applicable performance requirements). (SL3 only)

3.3.2 Flight crew of Autonomous aircraft

The flight crew of an autonomous aircraft is fully responsible for separation in accordance with defined AFR rules. Advanced onboard supporting tools are indispensable to accomplish this goal. The optimal level of automation must be determined in usability studies. However, **all actions which are suggested by onboard support tools and which would directly influence the actually flown trajectory shall at**

least be approved by the flight crew. The description of related functional requirements forms a key part of this document.
A critical requirement is that the flight crew achieves and maintains a proper level of situation awareness, supported by a functionally adequate and well designed HMI, while operating under AFR.
It shall be assured that the flight crew is in the loop during all phases, to be aware of the system status and to be able to take-over when system fails.
The interaction of human-automation has been studied during iFly Work package 2.4 (iFly: D2.4). Based on a comprehensive literature study, deliverable 2.4 provides preliminary suggestions regarding automation levels with respect to single onboard decision support tools (see Appendix 4).
Considering these suggestions for the automation level, the information provided to the flight crew at any given time and time limits for human and system performance shall be assessed during further operation validation (not necessarily during OSA and OPA process).

3.3.3 Flight Operation Centers

Flight Operation Centers (FOC) covers Airline Operation Center and Airspace User Agent (all SLs). FOCs are responsible for the planning of flights of their own fleet as well as external fleets which pay for their services, with the goal of providing operational benefits to the airlines. The roles of FOCs are, in particular, *Strategic flow management* and *In-flight traffic monitoring*.

According to the A3 ConOps, FOCs are not SSEP essential. In other words, the role of FOCs is not critical for the safety and feasibility of SSEP operations in SSA and, consequently, they are not explicitly considered in the OSED operational description. Nevertheless, it is envisioned that FOCs will play a key role for the effectiveness of SSEP concept and for maximizing user benefits. In particular, their support for onboard flight planning by pre-processing of strategic information available from SWIM (traffic complexity, meteo data, etc) may increase considerably the efficiency of flight of their fleet as well as to decrease the probability of tactical maneuvering. In this context, FOCs and their role are key elements to be considered within a relevant business case studies.

3.3.4 Service providers

Service providers are responsible for maintaining the supporting operational services and associated quality as previously described. Under the following bullets there are listed future service provider and their associated services.

- **SWIM service provider** (SL3) shall ensure the SWIM-based support services as described in Section 3.2.
- **Advanced ground surveillance support** (SL3) will provide additional information which allows for an increase in flight performance, such as the traffic complexity prediction (generally information about recommended areas-to-avoid) and advanced meteo information.
- **Air Navigation Service Provider (ANSP)** (all SLs) controlling the adjacent managed airspace (e.g., departure/arrival TMA) are involved only in the transition procedures to/from SSA and in the potential negotiation of the related TMA entry constraints .
  The iFly project works under assumption that there are no **ANSP intervening during the self separation part of flight (even if self-separation fails)**. One of the main goals of the project is to assess up to which traffic density is this concept safe.
-

4. SSEP Operations Description

After a high-level overview provided in Chapter 2, this section contains a detailed analysis of SSEP operations. The description is elaborated from two different perspectives:

- Description of onboard processing of conflicts and trajectory changes.
- Decomposition of the SSEP operations into stages reflecting the status of own trajectory (RBT conflict-free, conflict detected but not being solved so far, trajectory is going to be changed, etc.).

4.1 Processing of Conflicts and Trajectory Changes

The key difference between self separation operations and the operation in current ATM lies in the possibility of the flight crew to modify (within SSA) the own trajectory without negotiation with ATC and/or other users. While in the current ATM the actions taken by involved aircraft are centrally coordinated by ATC, such a coordination mechanism is missing within SSA. In this context, the stability, and performance of a distributed ATM requires an implementation of new coordinating mechanisms which ensures the global stability of the system.

There are three basic types of events that may initiate flight/trajectory changes:

- Conflicts with other aircraft, where it is important to consider a coordination of the solution among conflicting aircraft.
- Conflicts with other types of hazards (weather, restricted areas, etc.) expressed in terms of **areas-to-avoid**.
- User preferences (pilot/FOC requests, new strategic information available, etc.) and conflicts with less severe hazards specified in terms of **areas-recommended-to-avoid**.

The following terms will be used thereinafter in this document:

- **Conflict** is any situation involving an aircraft and a hazard in which the applicable separation minima may be compromised. (ICAO Doc .9854 AN/458). In the context of this report, a conflict is more specifically defined as a predicted loss of separation (with another aircraft, an obstacle, restricted areas, hazardous weather, etc.).
- A **Loss of Separation (LoS)** is any situation in which the applicable separation minima are compromised.

Prior to giving a description of the conflict resolution process it is necessary to refine a description of the conflict itself. An essential definition for conflict processing is **the reference time of a conflict**. Within this document the *time of a Predicted Loss of Separation (PLOS)* is used for this purpose. This choice is motivated by a natural boundary between Separation Management aiming to prevent a Loss of Separation (LoS), and Collision Avoidance used in the case of a LoS to avoid a collision.

Based on the definition above, the urgency of a conflict can be described at any moment of conflict processing in terms of the time span between the actual time and the PLOS. This measure is referred to as **Time To predicted Loss of separation (TTL)**.

As already stated in Section 2, a definition of Collision Avoidance process is beyond the scope of this OSED. It is considered that for OSA/OPA purposes, Collision Avoidance will be modeled through a simple TCAS II based procedure[2]: In the case of a LoS, there is still a time period before a TCAS Resolution Advisory (RA) is issued. During this time period own aircraft will continue to solve the conflict according SSEP operations. If despite of this a TCAS RA is issued, the autonomous aircraft will always follow RA.

The following section focuses on the description of conflicts with other aircraft considering the two levels of coordination specified in AFR: priority rules for mid-term conflicts, and implicit coordination for short-term conflicts (detailed definition being provided). Subsequently, a description is extended to trajectory changes initiate by other types of conflicts or for performance purposes.

4.1.1 Conflicts with Other Aircraft

The conflict processing onboard of a self separating aircraft is driven by two sets of requirements:

- **Operational requirements and parameters** ensuring interoperability of actions taken by involved aircraft. These requirements are the key and are related to the coordination (including indirect coordination) of conflicting aircraft and to the information sharing. The definition of corresponding parameters should represent a complement to AFR.
- Performance requirements and parameters related to possible **airborne implementations (systems and procedures)** onboard an aircraft. The parameters are related to the onboard information processing (both automated and human-based), the forms of maneuvers, etc.

I. Operational Requirements

Interoperability of autonomous operations requires a common definition of several system parameters that are used by all self separating aircraft. These parameters are mainly related to the coordination of actions among conflicting aircraft and to the information sharing process.

i. CR Coordination

The conformance to AFR requires a definition of the system parameter unambiguously separating the maneuvers requiring an implicit coordination, from the maneuvers driven by priority rules. For this purpose **Short Term time Threshold (STT)** is defined as a TTL threshold. Due to the absence of any additional communication among conflicting aircraft, the start of a CR maneuver execution is the first point of onboard conflict processing which is detectable by surrounding aircraft. In this context, the operational requirements are refined here as follows:

- The CR maneuver which starts at TTL < STT shall fulfill the implicit coordination requirements with respect to conflicting aircraft. Such conflict is referred as a **Short Term Conflict**.
- The CR maneuver which starts at TTL > STT does not need to be coordinated, but the priority rules must be respected. Such conflict is referred as a **Mid Term Conflict**.

[2] In A3 concept, a possibility of a composite ASACAS (Airborne Separation Assurance and Collision Avoidance System) is discussed in this context.

ii. Information Sharing

Self separation operations are critically dependent on the availability of information about surrounding traffic. In this context, OSA/OPA requires a refined definition of SL2 and SL3, describing the expected amount of intent information broadcasted by autonomous aircraft (for both SP2 and SP3) and specifying the amount of information provided by SWIM (SP3).

For this purpose three additional operational characteristics are defined:

- **Mid Term Time Horizon (MTTH)** – defines the required amount of broadcasted intent information. The parameter specifies the minimum length (in time) of trajectory that will be possible to rebuild from the broadcasted intent information (an alternative solution is to consider the number of broadcasted Trajectory Change Points. This possibility could be considered during OPA).
- **Mid Term Awareness Zone (MTAZ)** – defines a dynamic area around each autonomous aircraft encompassing the traffic which could potentially cause an intent-based (detectable through broadcasted intent information) conflict with the aircraft. MTAZ thus delimits the level of support provided by SWIM in SL3 – SWIM-based services will support an autonomous aircraft by providing the information about the traffic in MTAZ.
- **Long Term Awareness Zone (LTAZ)** – defines a dynamic area around the RBT of each autonomous aircraft (within SSA) which is considered for potential trajectory changes. LTAZ thus delimits the level of support provided by SWIM in SL3 – SWIM-based services will support an autonomous aircraft by providing the strategic information about LTAZ (meteo information, areas-to-avoid, areas-recommended-to-avoid, etc).

II. Onboard Conflict Processing

The scope of the OSED is to focus on the operational aspect of self separating operations. The description of onboard conflict processing is thus provided only at high and general level. The parameters defined in this section aims to provide a generic description of an 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 goal of subsequent OSA/OPA process will be to answer if and which common minimum requirements shall be imposed on the potential airborne implementations.

A possible generic model of an 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 start) and at the same time the new intent is broadcasted to surrounding aircraft and to SWIM (SL3).

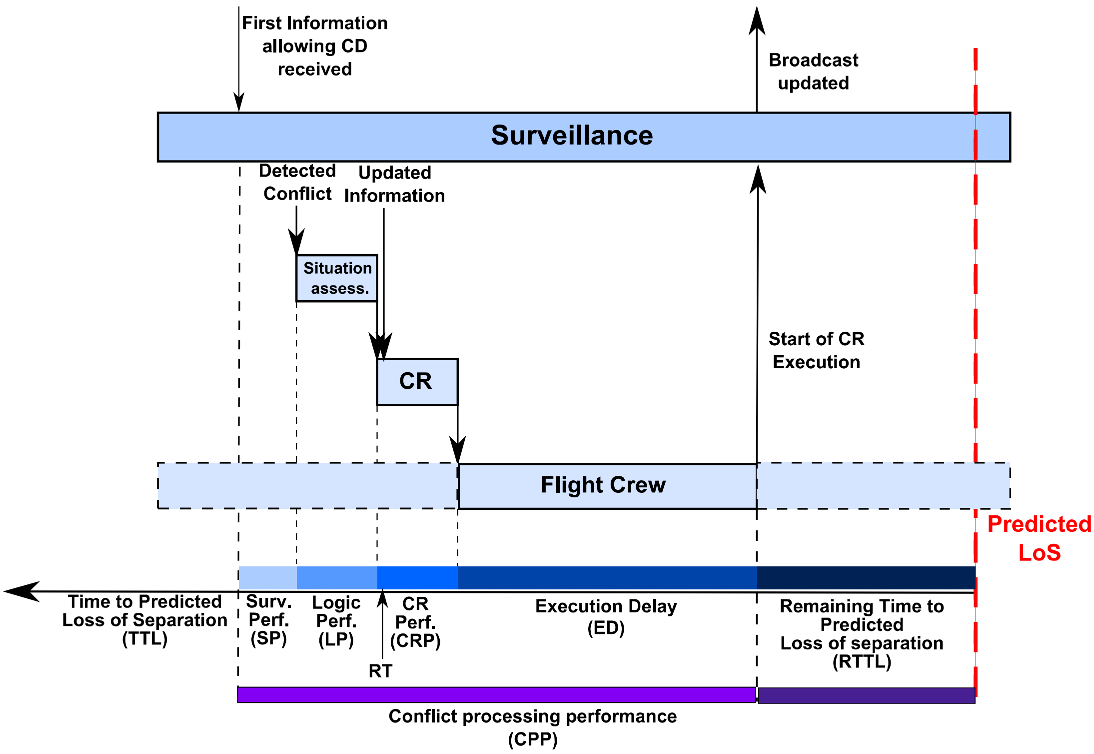

Figure 2: A generic model of onboard conflict processing.

The aim of this graph is to allow for a definition of performance parameters suitable for 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 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 considered during the OSA/OPA process.
- **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 description it may be useful to simplify the description of the airborne system (avionics and flight crew) behavior 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 predicted 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. 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).
- **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.

The choice of the form of a conflict solution is based on the conflict processing logic (discussed in the following section) which may slightly differ among implementations (OSA/OPA should consider a potential necessity of common requirements on the logic). Nevertheless, independently of its form, the solution shall always meet the operational requirements, 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.

While A3 allows some ambiguity in the definition of the logic, the following logic is proposed for OSA/OPA process:

1. For a conflict detected at TTL < STT, an open maneuver is selected. If also RTTL < TTL, implicit coordination is used.

2. For a conflict detected at TTL > STT, and RTTL (closed m.) > STT, a closed maneuver is selected (if own aircraft got lower priority).

3. For a conflict detected at TTL > STT, and RTTL (closed m.) < STT,

    a. If RTTL(open m.) < STT an open maneuver is selected (if own aircraft got lower priority) Implicit coordination is used.

    b. If RTTL(open m.) > STT an open maneuver is selected (if own aircraft has lower priority). Implicit coordination is not required in this case. There is an open issue as in this case (according AFR), the provided solution should be conflict-free up to MTTH. The possibility of relaxing this constraint should be investigated.

4. For all conflicts (e.g., areas-to-avoid) detected at TTL > MTTH, a closed maneuver is selected. The possibility for more relaxed conflict processing performance constraints should be considered.

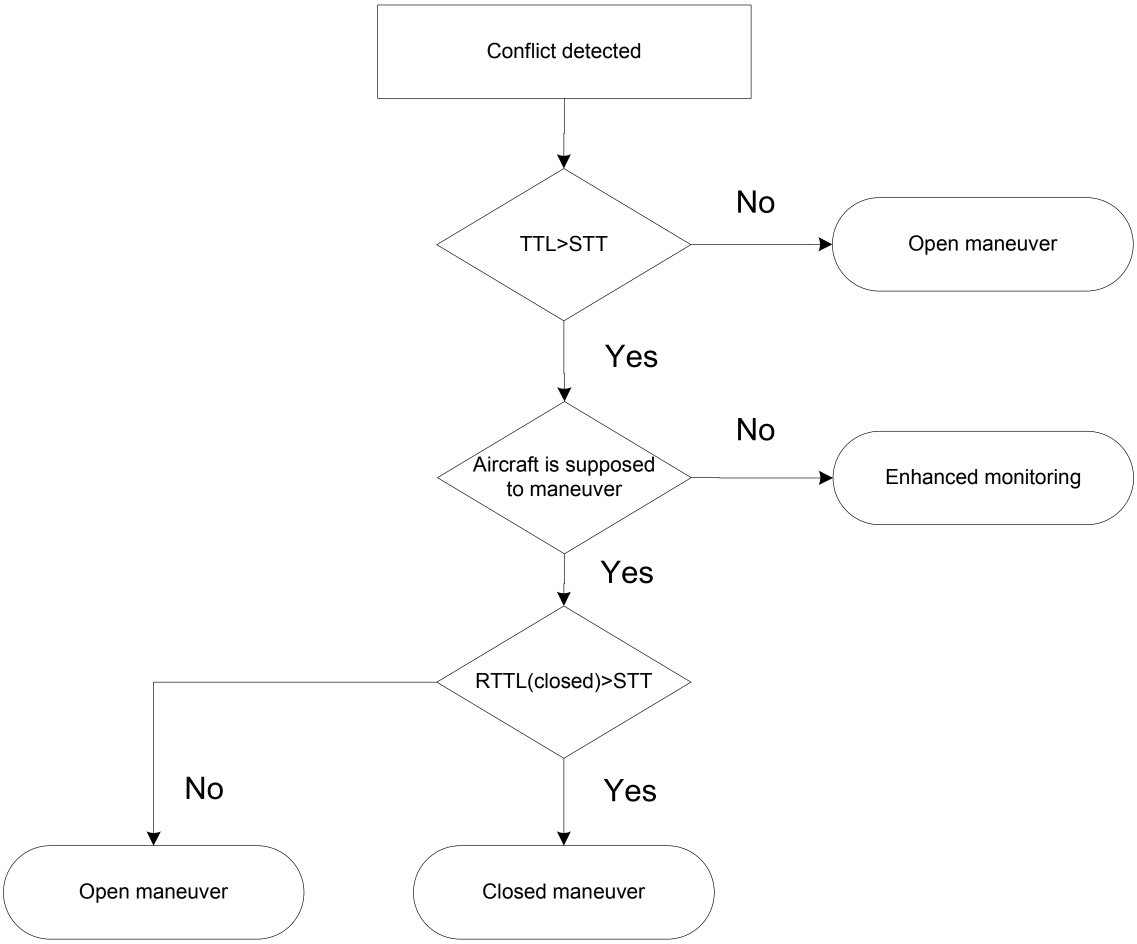

Figure 3: Conflict Processing Logic.

Note: **The case of a Mid-term multi-aircraft conflict is not completely solved through the current operational rules. This issue needs to be further investigated during OSA/OPA.**

4.1.1 Other Trajectory Changes

In addition to a conflict with surrounding aircraft, the own trajectory may be also changed in order to reflect other types of events: conflict with another type of hazard, performance reasons and as a response to flight crew request (which may be initiated by FOC, etc.). From the operational perspective, these changes are split as follows:

- Changes which are required, i.e. the trajectory shall be changed and the role of the flight crew is to decide **how** it will be changed.
- Changes which are recommended, i.e. by the flight crew, which decides **if and how** the trajectory will be changed.

While the trajectory changes motivated only by performance/optimization aspects are always classified as recommended, flight crew requests are by definition required changes. The classification of conflicts is discussed subsequently.

Based on the operational description, it is assumed that the hazards which do not represent a conflict with surrounding aircraft, are expressed in the form of areas. To reflect different levels of severity of hazards and to allow the classification (required vs. recommended) of related trajectory changes, two types of the areas are considered: **areas-to-avoid**, which shall be avoided (restricted areas, serious weather hazards); and **areas-recommended-to-avoid**, which represent strategic guidelines for the flight crew (long term prediction of congested areas, areas with high air traffic complexity, less severe weather hazards, etc.). Contrary to the conflicts with other aircraft which cannot be detected beyond MTTH (due to the amount of traffic information available onboard), the hazard areas may be known for the whole SSA part of the trajectory, i.e., these kind of conflicts may be also solved in a long time horizon.

As the trajectory changes described in this section are not caused by a conflict with surrounding aircraft, there is no requirement for coordination. However, the other requirements resulting from AFR are still valid:

- A solution of short term conflict shall not generate a new short-term conflict, etc.
- A solution of mid term conflict must be conflict-free at least up to the MTTH, etc.

For the stability and performance of the overall distributed ATM, it is important that an aircraft does not change excessively the part of its trajectory that is used for situation assessment onboard surrounding aircraft, i.e. its trajectory up to MTTH. Furthermore, it is anticipated that the most of the considered areas-to-avoid and areas-recommended-to-avoid will not evolve dramatically in time and therefore potential conflicts will be possible to be detected well in advance. For this reasons, the following **operational rules** are defined and should be validated during OSA/OPA:

- The trajectory changes classified as recommended shall not affect own trajectory up to the MTTH. The conflicts with areas-recommended-to-avoid detected at LLT < MTTH are ignored, except the case of an explicit flight crew request.
- The conflicts with areas-to-avoid detected at LLT > MTTH shall be solved without a modification of own trajectory up to STT (this requirement is not considered in A3).

4.2 Stages Decomposition of SSEP Part of Flight

In this section the SSEP operations of an autonomous aircraft are decomposed into complementary stages. The stages are defined in order to reflect the status of an autonomous aircraft in relation to the trajectory information shared with other airspace users (whether from SWIM or via broadcast).

The SSEP operations are delimited by the two transition stages at the boundary between the SSA part of flight and the controlled part of the flight. These stages initiate and terminate the self-separating operations and cover the process of the shift of responsibility from ground to flight crew and vice versa.

- SETTING-UP SELF-SEPARATION STAGE – Transition procedure related to the SSA entering and initiation of SSEP operations.
- SELF-SEPARATION TERMINATION STAGE – Transition procedure related to the SSA departure and termination of SSEP operations.

The **Airborne self separation operations** of an autonomous aircraft may evolve through the following complementary stages:

- REGULAR FLIGHT STAGE – Flight along the planned trajectory in absence of any detected threats/issues. The shared trajectory information is therefore stable.
- INITIATION STAGE – Flight along the planned trajectory while processing a detected conflict (obtaining proper situational awareness and selecting the proper resolution function). It means that there is an issue with the shared trajectory and the latter may be changed in the closed future.
- ENHANCED MONITORING STAGE – Identical with regular flight stage but with an enhanced monitoring of a detected conflict which does not require a trajectory modification. The trajectory is therefore stable but there is a known issue that may evolve in a conflict.
- NEW TRAJECTORY GENERATION STAGE **-** Flight along the planned trajectory while a new trajectory solving the detected conflict is built and assessed. It means that the trajectory is going to be changed, and a new trajectory will be available at the start of maneuvering.
- TACTICAL MANEUVERING STAGE – Flight along the planned trajectory while an open maneuver solving the detected urgent conflict is built and assessed. The trajectory is therefore going to be changed, but the update will be delayed with respect to the start of maneuvering.

The overall staged structure of the SSEP procedure is drawn in Figure 4. The solid arrows represent triggers, which initiate a stage switch. Dashed lines represent those cases where a new conflict is detected besides the one already being solved.

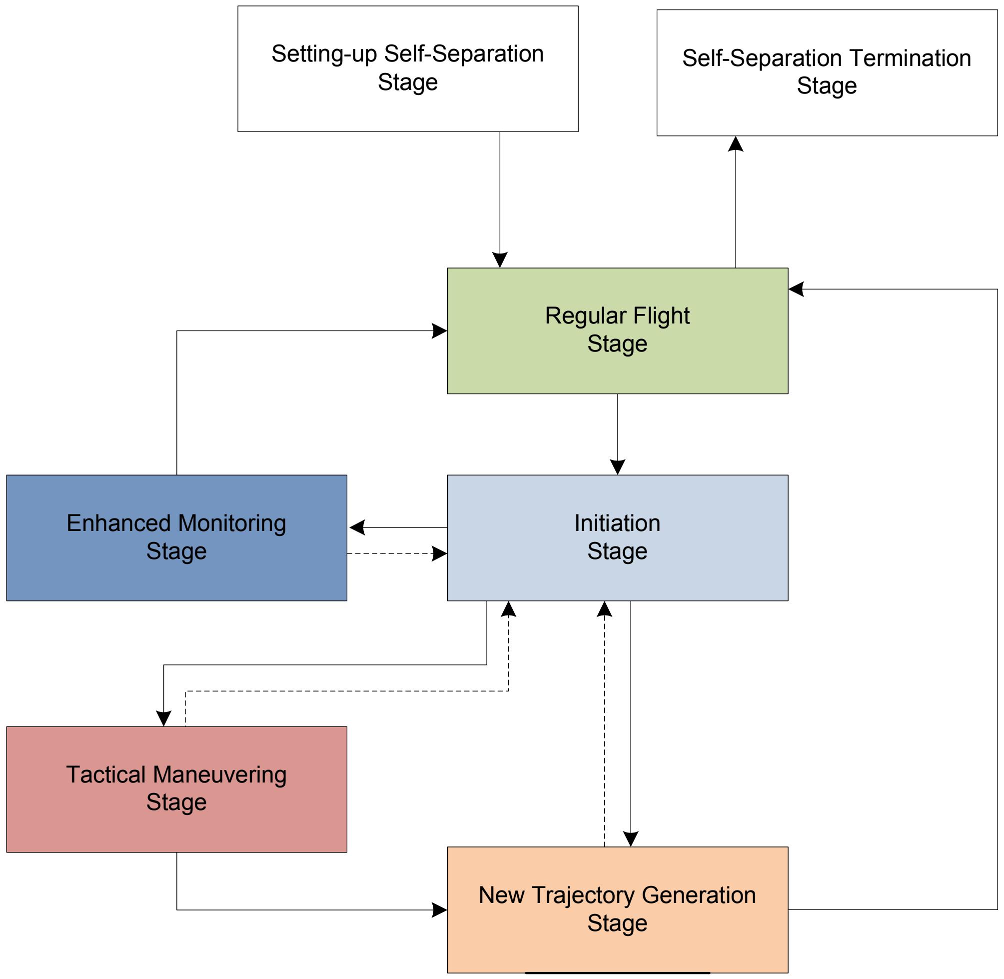

Figure 4: SSEP-stages diagram. Arrows represent triggers for new stage activation. Dashed lines represent possible stage switches, when in addition to the conflict being solved a new conflict with higher importance/priority is detected (this possibility should be further analyzed during OSA/OPA process).

4.2.1 Setting-up Self-Separation Stage and Self-Separation Termination Stage

These stages frame the A3 SSEP operations. *Setting-up Self-Separation Stage* covers the process of shifting the separation responsibility from the ANSP to the aircrew when aircraft exits TMA (MA) end enters SSA. *Self-Separation Termination Stage* covers the reversed process of shifting the separation responsibility from the aircrew to the ANSP, when the aircraft exits SSA and enters TMA (MA).

Since the A3 ConOps is limited in its scope to SSEP operations within SSA only, the detailed description of *Setting-up Self Separation* and *Self-Separation Termination Stages* is omitted in this document. Important in this regard is that the ANSP will have to make sure that the aircraft will not be in a conflicting situation when exiting ATC managed airspace and vice versa the aircraft cannot enter the arrival TMA when still in conflict.

4.2.2 Regular Flight Stage

In this stage the actual Reference Business Trajectory (RBT) meets all requirements of flight crew and involved stakeholders. The aircraft is navigated along this trajectory, which is considered to be optimal (no current opportunities for further optimization) and there are no conflicts detected. Ideally the whole flight could be performed being in this stage.

The following tasks must be ensured:

- Navigation/guidance of aircraft along the valid RBT.
- Broadcasting of the information about own state (all levels) and intent (Level 2 and 3).
- Monitoring of surrounding traffic and environment (including weather) and checking for potential hazards.
- Information about the surrounding traffic is presented to the flight crew in an appropriate form.

Operational requirements:

- Broadcasted 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).

A *Regular Flight Stage* is terminated if a **Trajectory Change Trigger Event** is detected (*Initiation Stage* follows) or when aircraft approaches the arrival TMA (*Self Separation Termination Stage*).

Initial set of Trajectory Change Trigger Events:

- Any kind of conflict with surrounding traffic.
- Any kind of other conflict detected (terrain, weather).
- Updated weather forecast (optimization opportunity).
- Flight crew request.

4.2.3 Initiation Stage

This stage is initiated by a Trajectory Change Trigger Event, when a modification of the current RBT may be required. Within this stage, the situation is assessed and an appropriate action is selected.

For these purposes the following tasks must be ensured:

- Selection of appropriate action suitable for solution of detected situation.
- Prioritization of trigger events if there are multiple of them at the same time.
- Maintaining of flight crew situation awareness by displaying correct and important information.

- Processing aircrew requests for a trajectory modification.

Operational requirement:

- Selected action shall conform to Autonomous Flight Rules.
- Any kind of conflict has priority over the trajectory optimization.
- Short-term conflicts have priority over mid-term conflicts.

Based on assessment of situation, the Initiation Stage is followed by:

- *Tactical Maneuvering Stage* for a short-term conflict.
- *New Trajectory Generation Stage* for other conflicts and events requiring a RBT change (mid-term conflict with lower priority of own aircraft, optimization, …).
- *Enhanced Monitoring Stage* for the events which do not require a RBT change but may represent a safety issue under specific conditions. In particular, a mid-term conflict with higher priority of own aircraft is considered in this case.
- Under specific conditions it may be possible to return to the *Regular flight stage*. This possibility is listed only for completeness, as the definition of such conditions does not exist yet. The possibility of this transition is also missing in Fig.4.

4.2.4 Tactical Maneuvering Stage

This stage is initiated for urgent events (typically short-term conflicts) when a fast action is required for maintaining safe separation.

Under specific conditions the *Tactical Maneuvering Stage* may be interrupted and the system may return to the *Initiation Stage*. The list of conditions which cause the interruption (e.g., in case of new incoming conflict of higher priority) has not been defined yet and should be examined during OSA/OPA process.

The following tasks must be ensured during this stage:

- Generation of an open maneuver(s) that solve the detected conflict.
- Displaying of the proposed solution to flight crew through a suitable HMI.
- Start of the execution of maneuver within the Execution Delay (see Figure 2) time.

Operational requirement:

- CR maneuver shall not generate a new short-term conflict.
- CR maneuver shall be conforming to AFR (implicit coordination if applicable, blunder protection, etc.)

- Tactical Maneuvering Stage is followed by the *New Trajectory Generation Stage,* which generates a new RBT (as a continuation of the open maneuver which is being executed).

4.2.5 New Trajectory Generation Stage

Within this stage a new trajectory, which solves the detected situation, is generated, presented to the flight crew (the proposed solution may be altered by them), loaded to the guidance (navigation) system and executed.

The following tasks must be ensured during this stage:

- Generation of a trajectory update that solves the detected conflict and is conflict-free for the mid-term time horizon.
- Optimization of RBT.
- Displaying of the proposed solution to flight crew through a suitable HMI, handling pilot's modifications.
- Uploading of the new trajectory to navigation/guidance system.
- Sending the information about new RBT to SWIM.

Operational requirement:

- New trajectory must be conflict-free at least up to the mid-term time horizon.
- New trajectory shall be conforming to AFR (blunder protection, etc.)

The New Trajectory Generation Stage ends with an update of the RBT in the navigation system (e.g., FMS) and the return to *Regular Flight Stage*. Under specific conditions a *New Trajectory Generation Stage* may be interrupted and the system returns to the *Initiation Stage*. The list of conditions which cause the interruption (e.g., in case of new incoming conflict of higher priority) has not been defined yet and should be examined during the OSA/OPA process.

4.2.6 Enhanced Monitoring Stage

The Enhanced Monitoring stage does not differ considerably from a Regular Flight Stage, with the exception that it includes the monitoring of a conflict which is a potential hazard. For instance, it may only be reflected by a modification of information displayed on the HMI (e.g., highlighted traffic), however, further requirements may result from OSA/OPA process. The typical example of this process is the monitoring of conflicts with lower priority aircraft.

No operational requirements for the moment.

The *Enhanced Monitoring Stage* is followed either by the *Regular Flight stage* (hazard disappear) or through the *Initiation Stage* (new trigger event generated).

5. Non-normal operations

The aim of this OSED is to describe in detail the operational services and provide a high-level functional system description for normal operations. Non-normal operations are not therefore discussed in this document and will be analyzed within the OSA process (WP9.2).

For reference, the emergency situations are handled in A3 ConOps using the following main rules:

- When an aircraft crew believes its aircraft is in an emergency situation, then that aircrew will declare an emergency through all available communication means.
- Emergency aircraft will obtain the highest priority level and will be required to exit SSA and reach Managed Airspace as soon as they are able.
- Separation responsibility from aircraft which have declared an emergency will fall upon nearby traffic (informed by SWIM and other communication means).

6. Functional System Requirements

Contrary to the operational description in Chapter 4 which is based on a notion of autonomous aircraft as a combination of the flight crew and onboard tools, this chapter is restricted to the onboard system tools and their high-level functional requirements. Functional description is based on the adapted generic Aircraft Surveillance Applications (ASA) architecture (DO-317, Figure 1-1).

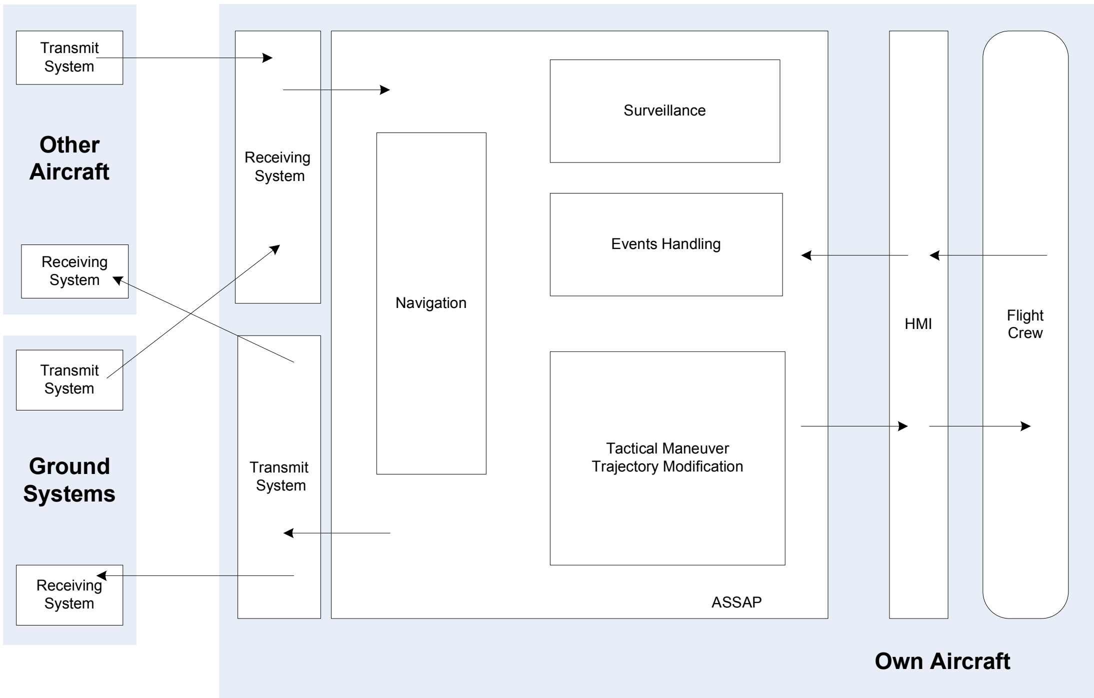

Figure 5: H High Level overview of airborne system architecture adapted from DO-317. The functional system requirements related primarily to Airborne Surveillance and Separation Assistance Processing (ASSAP) are discussed in this section.

Airborne tasks required for SSEP operations will be split between onboard tools and the flight crew. However, the tasks splitting itself may vary among different implementations and it may also depend on the situation context (e.g., flown FMS mode). A detailed tasks allocation therefore cannot be given without a validation of an onboard system design (implementation) and therefore it is not discussed in this chapter. A potential role of automation during SSEP operations was analyzed in iFly WP2.4, some suggestions from iFly D2.4 being listed in Appendix 4.

Key functionalities which are necessary for a safe execution of SSEP operations may be decomposed into several *Functional Blocks* (FB). Each of the blocks ensures specific group of tasks by providing needed functionalities. The proposed high-level functional blocks are the following:

- NAVIGATION
- SURVEILLANCE
- EVENTS HANDLING

- TRAJECTORY MODIFICATION
- TACTICAL MANEUVER

Stage-specific combinations of functional blocks are summarized in Table 1.

Table 1 SSEP phases and functional blocks: X **indicates that the functional block is active within the phase.**

Phases	Functional blocks				
	Navigation	Surveillance	Events Handling	Trajectory modification	Tactical maneuver
Regular flight stage	X	X			
Initiation stage	X	X	X		
Enhanced monitoring stage	X	X	X		
New trajectory generation stage	X	X	X	X	
Tactical maneuvering stage	X	X	X		X

The *Navigation* and *Surveillance* functional blocks run continuously during the SSEP operation.

6.1 Navigation Functional Block

This block includes the following functionalities:

- Navigate aircraft along valid RBT (including manual control).
- Broadcast updated state and intent data as well as information about their accuracy and reliability.

Initial assumption/performance estimates:

- For initial performance and safety assessment it is considered that the quality of broadcasted information correspond to the standard value of RNP required during the en-route phase of flight.
- Broadcasted state information has got the form of State Vector, Mode Status and Air Referenced Velocity Report (DO-260A) (all SL)

- Air-Air data links SV Accuracy, Update Interval and Acquisition Range Requirements meet the Equipage class A3 (DO-242A) (all SL)

Performance requirements:

- The broadcasted intent allows a prediction of the aircraft planned trajectory up to MTTH (SL2 and SL3).
- Whenever the intent information of an aircraft is changed, a new intent should be broadcasted **immediately** (SL2 and SL3).
- The necessity to broadcast information that the intent is going to be changed (**temporal intent tag)**, will be investigated during OSA and OPA (SL2 and SL3).

6.2 Surveillance Functional Block

This block includes the following functionalities:

- Collecting and maintaining surveillance information on surrounding traffic.
- Detection of conflicts with surrounding traffic:
  - Based on the available intent information – up to the Mid Term Time Horizon (MLAT) of own flight.
  - Based on the available state information – up to the Short Term Time Horizon (SLAT) of own flight.
- Detection of other hazards (restricted areas, weather, ground proximity, …).
- Checking for opportunities to optimize own flight.
- Enhanced monitoring functionalities.
- Maintaining flight crew Situation Awareness through a HMI.

Operational Requirements:

- If the information about relevant traffic is not updated according to the performance requirements:
  - The information must be marked as obsolete or invalid (both for state and intent data).
  - If applicable (SL3), this information must be queried from the corresponding aircraft or from SWIM.
- SWIM provides a complete list of aircraft relevant to own flight up to Mid Term Time Horizon – traffic list (SL3).
- (SL3 only) In the case of missing information about an aircraft on the traffic list, the information must be queried from SWIM.
- Conflict detection will run continuously during the SSEP operation and all detected conflicts will be reported.
- **There is no change in communications as a result of detected conflicts.**

Operational Requirements:

- Conflict detection is a continuous process which runs at a given frequency (TBD) with the best information available.

- SP (see Figure 2) – should be maximally TBD seconds/minutes

Initial assumptions/performance estimates:

- MLAT = 10 minutes, SLAT = 3 minutes
- Air-Air datalink range is 90NM (120 NM desired – Equipage class A3 (DO-242A))

6.3 Events Handling Functional Block

This block includes the following functionalities:

- Conflict processing
  - Conflict prioritization
  - Conflict classification (Mid vs. Short Term)
  - Assessment of **Priority rules** (see Appendix 2) for Mid Term conflicts
  - Choice of a suitable Conflict Resolution process (Open/Closed maneuver) in accordance with AFR (Appendix 1)
- Assessment of opportunities for trajectory optimization.
- Providing the flight crew with relevant information through a suitable HMI.

Operational requirements:

- Situation assessment runs continuously, during the time when conflict information is available.

Performance requirements:

- LP – should take maximally predefined time (TBD)

Initial assumptions/performance estimates:

- When a new conflict appears during a CR process, the CR process should not be interrupted except for well defined conditions. However the new information should be included in the process. Exception conditions may include the interruption of the solution for a Mid Term conflict in case a new Short Term conflict is detected. This issue should be analyzed in detail during OSA/OPA process.

6.4 Trajectory Modification Functional Block

This block includes the following functionalities:

- Conflict resolution (closed maneuver solution),
- Open maneuver (conflict-free) continuation,
- Trajectory optimization,
- Presentation of proposed solution to flight crew and handling of flight crew preferences and selection through a suitable HMI.
- Initiation of the accepted solution (e.g., enter new intent into FMS)
- Immediate broadcast of the FMS calculated intent.
- Sending of new RBT or intent to SWIM (SL3 only).

Operational requirements:

- The algorithm does not rely on any actions from the conflicting aircraft.
- The proposed conflict solutions follow AFR, in particular, they are conflict-free up to or beyond the MTTH, blunder protection is considered, etc.
- Optimization process (in absence of any conflict) modifies the RBT only beyond the MTTH.

Functional requirements:

- 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.

Initial assumptions/performance estimates:

- The algorithm is always able to find a solution.
- CPP - should take no longer than a maximally predefined time (TBD), the first estimation (to be verified in OSA/OPA) is 2 minutes.

6.5 Tactical maneuver Functional Block

This block includes the following functionalities:

- Conflict resolution algorithm providing an open maneuver solution.
- Presentation of proposed solution to flight crew and handling of flight crew preferences and selection.
- Initiation of the selected open maneuver execution, and
- Broadcasting of updated intent (RBT) information.

Operational requirements:

- The algorithm does not rely on any action from the conflicting aircraft
- The proposed conflict solutions follow AFR (implicit coordination if applicable, blunder protection, etc.).
- Conflict resolution makes full use of all information available at time RT (Reference Time, see Figure 2). 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.

Functional requirements:

- Algorithm is able to solve conflicts with multiple aircraft.
- 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.

Initial assumptions/performance estimates:

- The algorithm is always able to find a solution within a maximally predefined time (TBD)
- CPP – should take maximally 30 seconds.

7. Link with Action Plan 23 Deliverables

It may also be useful to link the above mentioned stages/functional blocks with the elements of airborne self-separation application described in deliverables D3 and D4 of Action plan 23 (AP23: D3,D4). The **elements of airborne self separation** proposed at (AP23: D3, D4) are

- *Transferring separation responsibility* – this element of airborne self separation is equivalent to processes running within *Setting-up Self-Separation Stage* and *Self-Separation Termination Stage* of SSEP procedure.

- *Conflict management* - this element of airborne self separation is equivalent to *Surveillance and Events Handling functional blocks*.

- *Maneuver without conflict* – this element of airborne self separation is equivalent to *Trajectory modification & Tactical maneuver functional block.*

8. Scenarios

The following examples introduce scenarios focused on several types of conflicts and combinations of incoming conflict and optimization requirements. All described scenarios deal with the situation from own aircraft perspective.

Scenario 1: A conflict with another aircraft has been detected and solved by means of a closed maneuver. There are two different courses of this scenario depending on the priority of own aircraft.

This scenario covers the situation when own aircraft is flying its RBT and a mid-term conflict is detected, i.e., the RTTL for closed solution is more than STT. Further action taken by the ownship aircraft depends on the priority level of the ownship compared to the priority level of the other aircraft involved in the conflict.

If **own aircraft has got higher priority** then it will continue to fly its (unchanged) RBT. As the ownship aircraft is not expected to solve the conflict by modifying its trajectory, all actions are left upon the other aircraft involved in the conflict. The only action ownship takes is the enhanced monitoring of the conflicting aircraft.

At the moment when the other aircraft starts to broadcast and fly a new trajectory, which solves the conflict and no other conflicts are detected, ownship continues to fly its unchanged RBT without any further requirements for enhanced monitoring.

When TTL>STT and the other aircraft still has not broadcasted a modified intent which would solve the conflict, own aircraft with higher priority shall detect a short term conflict and start to solve it according to AFR. The conflict is no longer to be solved by means of a closed maneuver/enhanced monitoring, but with an open maneuver.

When **own aircraft has got lower priority**, the responsibility for resolving the conflict lies fully on own aircraft. The system should suggest several solutions which will be assessed by the flight crew. The flight crew may select one solution and approve it or may require modifications or even suggest its own solution. As soon as the flight crew accepts one of the solutions and executes the maneuver, the new intent is broadcasted. According to the AFR, this new proposed trajectory should solve the mid-term conflict and be conflict-free up to MTTH or beyond.

If the flight crew of own aircraft with lower priority rejects the solution, a new cycle or re-calculations is started when the RTTL(closed maneuver) is larger than STT. When RTTL(closed m.) < STT, than the conflict should be solved by means of an open maneuver. This situation should be reported to appropriate authorities.

Comment: *Own aircraft does not exchange directly any additional information concerning the conflict with other aircraft or the ground systems, so ownship does not have any indication that the other aircraft has detected the conflict and/or is processing the solution until it starts to execute the new trajectory . For this reason the possibility of broadcasting a temporary intent mark when a process of conflict resolution is ongoing onboard should be investigated during the OSA/OPA process.*

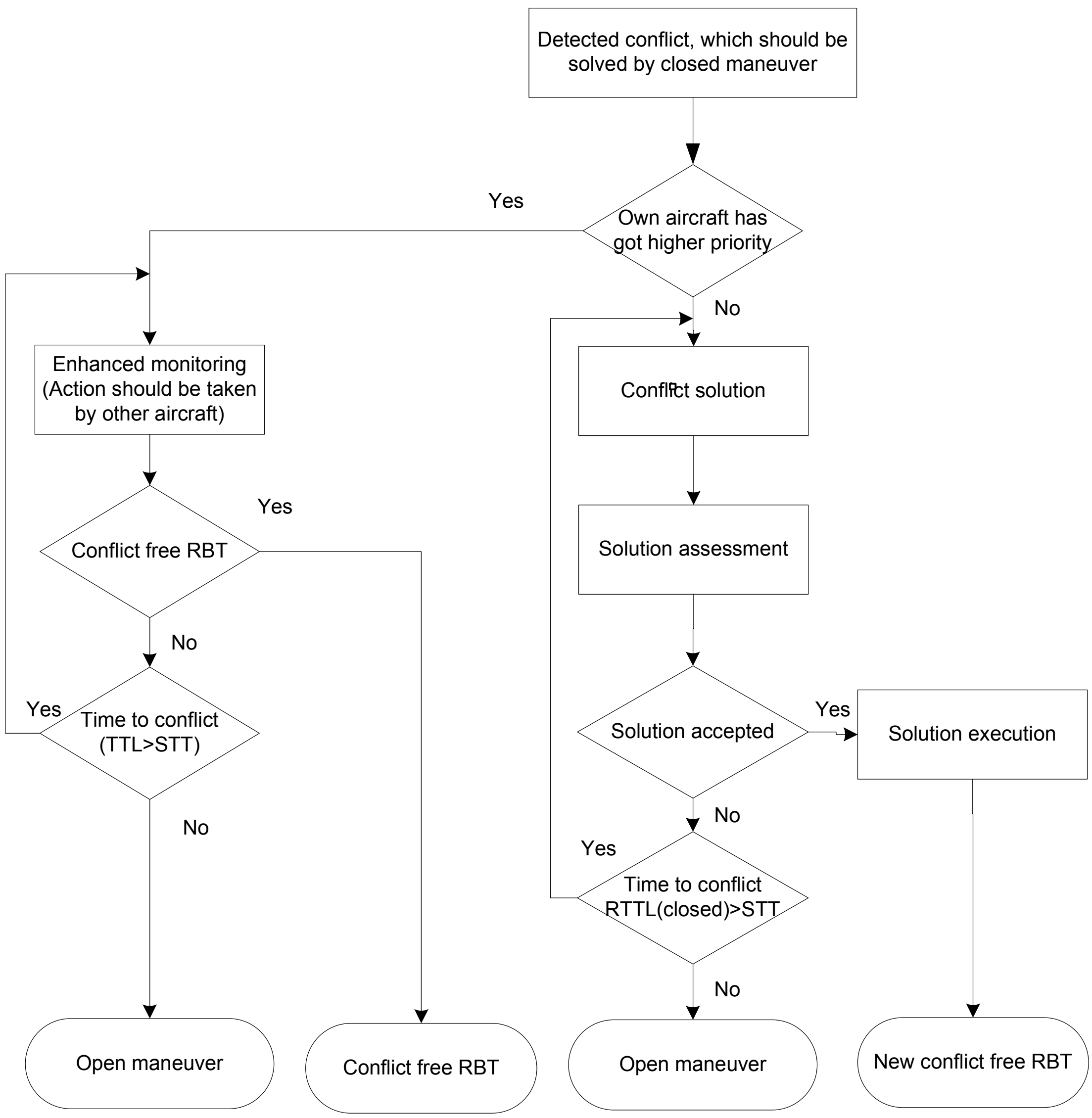

Figure 6: Scenario 1: Conflict with another aircraft has been detected and solved by closed maneuver.

Scenario 2: Conflict with another aircraft has been detected and solved with an open maneuver. Subsequently, the RBT is updated accordingly.

This scenario covers the situation when own aircraft is flying its RBT and a short-term conflict, which should be solved with an open maneuver, has been detected. All aircraft involved in such conflict are obligated to maneuver. The maneuvers, possibly proposed by the onboard systems, must be generated according to the implicit coordination principles which ensure the complementariness of trajectories flown by conflicting aircraft. There is no direct additional information exchange between the involved aircraft with the exception of broadcasted state (possibly intent) information.

Any short term conflict should be solved as soon as possible. The onboard systems should propose only a maneuver or a sequence of simple maneuvers which solve the short-term conflict and conform to AFR (do not create a new short term conflict, blunder protection considered, etc.). As the TTL for such conflict is already short, the time left for human processing of the situation is limited. The flight crew may therefore propose only minor modifications to the presented solutions (strictly speaking this is not a requirement, the operational requirement being that the flight crew is responsible to take action in time). Both involved aircraft are required to actively solve the conflict. The generated maneuver shall be complete and independent of the other aircraft, i.e., own aircraft maneuvering shall solve the conflict even if the other aircraft does not solve the conflict.

During the time period, when an open maneuver is assessed, the corresponding RTTL is continuously recomputed. At the moment when RTTL for an open maneuver passes PLOS, RTTL(open) < PLOS, a separation management failure should be reported to appropriate authorities. However, the search for a maneuver solving the situation and acceptable by flight crew is still continuing until a solution is accepted by the flight crew or a TCAS RA is issued. If a RA is issued, the autonomous aircraft shall always follow RA.

As soon as the aircraft starts to maneuver, the search for the continuation of open maneuver will be initialized. Continuation of the open maneuver has to assure that the RBT is updated in a way that meets the AFR requirements.

The proposed solution(s) are processed by the flight crew, who chooses and accepts one of them or rejects them requiring modifications and therefore a re-calculation (taking into account time constraints).

Figure 7: Scenario 2: Conflict with another aircraft has been detected and solved with open maneuver.

Scenario 3: An aircraft received updated meteo data: a weather hazard area has been identified.

Since a detected hazard area may be classified as an area-to-avoid or an area-recommended-to-avoid, there are two possible ways how to deal with them.

If the detected weather hazard area is classified as an-area-to avoid, it has to be treated in the same way as a conflict. Depending on the RTTL, closed maneuver (for a mid-term conflict) or open maneuver should be used.

If the detected weather hazard area is classified as an-area-recommended-to avoid, it is further treated as a trajectory optimization task. It means that it will be handled only if the resulting trajectory changes do not affect own trajectory up to MTTH (SL2 and SL3). Otherwise, the corresponding trajectory modification must be requested by the flight crew.

Appendix 1: Autonomous Flight Rules

Autonomous Flight Rules (AFR), as stated in (iFly: D1.3), is a set of rules obligatory for autonomous aircraft (operating in SSA and performing self-separation).

- Autonomous aircraft are responsible for maintaining separation with all other aircraft.
- Autonomous aircraft are required to maintain separation from designated areas and no-fly zones.
- Autonomous aircraft are required to adhere to flow management constrains. Renegotiation will have to take place if these constrains cannot be met.
- Lower priority autonomous aircraft involved in a medium term Intent based conflict ruled by priority are required to manoeuvre to solve it sufficiently in advance, so that the conflict does not continue until the conflict resolution becomes a short term cooperative conflict.
- Autonomous aircraft shall not manoeuvre in a way that creates a short term (3 to 5 minutes) conflict.
- The trajectory of autonomous aircraft shall at no time place the aircraft in a 2 minutes state vector conflict (blunder protection).
- Autonomous aircraft shall not enter Manager Airspace without the approval of the controlling entity of that airspace.

Appendix 2: Priority rules

The principles of Priority rules stated bellow have been extracted from A3 ConOps (iFly: D1.3).

Medium term conflict resolution does not require the coordination between conflicting aircraft. In absence of coordination, priority rules will be used.

- Priority rules are applied only to Medium Term Conflict Resolution.
- Priority rules determine the priority level of each aircraft, that means determine which aircraft has got the right way and which aircraft has to manoeuvre.
- Priority rules will be identical for all aircraft.

Priority level considerations are the following

- Priority level will be broadcasted so it can be used by other aircraft
- Priority level will be determined based on
  - CTA requirements
  - Manoeuvrability
  - Mission statement
- Aircraft with lower priority level have to manouevres to prevent the conflict from becoming a short term conflict.
- 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.

CTA requirements (when aircraft get closer to the TMA arriving point (Metering Fix))

- Priority level will increase, when the Arrival Manager (AMAN) will/can issue an updated CTA with a reduced window size
- Aircraft have a higher priority when they get a tighter constraint.
- The priority level is no indication of position in the arrival sequence but is only used for MediumTerm conflict resolution.
- The priority assigned to aircraft will be the highest under normal operations, if an aircraft has a fixed CTA or is actively spacing. However, the highest priority level do not relief the aircraft from the self-separation resposibilities required in SSA.

Normal Operations Priority Levels – CTA-related	
Priority level	Aircraft status
X	Normal priority level according to TBD priority rules
X+1	Smaller CTA time window than the other aircraft
X+2	Fixed CTA assigned or actively spacing aircraft

The aircraft manoeuvrability will be considered in the priority level determination, e.g.

- Speed envelope
- Turning radius
- Climb rate

The aircraft mission will be reflected in its priority level.

- Non-normal and emergency aircraft will broadcast higher priority levels than normal operating aircraft.
- The following table summarizes some of the categories considered for priority determination:

	Category	Circumstances for Selection
EMERGENCY	Emergency	When an aircraft is in an emergency condition
NON-NORMAL	Non-own surveillance capable	Unable to broadcast its state and/or intent, its position only detected through primary radar
	Non-self separation capable	Aircraft can perform all its normal tasks, except self separation
NORMAL	Ambulance flight	When a flight is operating as an air ambulance and the patient is in a life threatening condition, or requires stable flight operations.
	Military aircraft in a national defence mission	Applies to those military aircraft which are performing surveillance broadcasting (does not apply to fighters in an interception mission, spy aircraft or other which do not broadcast their state and intent)
	Military ordnance transport	When a military aircraft is carrying sensitive ordnance (weapons, explosives, or other harmful materials) in a transport mission
	Special Transport	Civil aircraft carrying dangerous or sensitive goods
	Scene of Search	When an aircraft is operating at the scene of a search area or is operating as a scene of search co-ordinator. If an aircraft is en-route to or from a scene of search, it should be treated as a normal aircraft
	Prioritized VIP aircraft	High level government officials (not Head-of-states) which have been given a higher level of priority
	Normal Aircraft	When non of the above is applicable

Appendix 3: ADS-B Performance

Accuracy, Update interval and Acquisition Range

This appendix recapitulates the characteristics of Equipage class A3 as presented in DO-242A, table 3-4(a).

Operational domain: Terminal, En Route and Oceanic/Remote Non-Radar
Applicable Range: 40NM<R≤90 NM
Required 95th percentile SV Acquisition Range: 90NM*, 120NM desired
Required SV Nominal update Interval (95th percentile): ≤12 s
Required 99th SV Received Update period (Coast interval): ≤24 s

Example Permitted Total SV Errors Required To Support Application (1 sigma, 1D)

- Standard deviation of horizontal position vector: σ=200m
- Standard deviation of horizontal velocity vector: σ = 5m/s
- Standard deviation of vertical position error: σ = 32ft
- Standard deviation of vertical velocity error: σ = 1fps

Max. errors due to ADS-B (1 sigma, 1D) e.g. the allowable contribution to total state vector error from ADS-B:

- Standard deviation of horizontal position vector: σ=20m
- Standard deviation of horizontal velocity vector: σ = 5m/s
- Standard deviation of vertical position error: σ = 0.25ft
- Standard deviation of vertical velocity error: σ = 1 fps

* The 90 NM range requirements applies in the forward direction (that is the direction of the own aircraft's heading). The required range aft is 40NM. The required range 45 degrees to port and starboard of the own aircraft's heading is 64NM. The required range 90 NM to port and starboard of the own aircraft's heading is 45 NM. (120 NM desired range applies in the forward direction. The desired range aft is 42 NM. The desired range 45 degrees to port and starboard of the own aircraft's heading is 85 NM.).

Appendix 4: Suggested Automation Levels for an example SSEP implementation (from iFly D2.4)

OODA categories* and tasks, which fall under**	**Tasks (handled by the SSEP operation) associated with OODA categories**	**SSEP Functional Blocks***	**Proposed level of automation (iFly: D2.4, p. 31)** for an example SSEP implementation described in (iFly: D1.3, p.67)**
OBSERVE – gathering, monitoring and filtering data	Collecting and maintaining surveillance information	Surveillance	Automation level 5 or 4 respectively (OBSERVE category)
ORIENT – deriving a list of options through analysis, trend prediction, interpretation and integration	Detection of conflicts, detection of other hazard, checking for opportunities of own flight optimization	Surveillance	
DECIDE – decision-making based on ranking available options	Conflict processing , assessment, situation prioritization and choice of suitable CR process	Situation assessment	Automation level 4 up 6
	Conflict resolution process	Tactical maneuver & Trajectory Modification	Automation level 6 or 7 (Action automation does not exceed level 3). Sheridan's level of Automation for decision 3 or 4
ACT – execution or the authority to act on the chosen decision	Initiation of conflict solution execution and immediate broadcasting of approved solution (possibly sending RBT to SWIM)	Tactical maneuver & Trajectory Modification	Automation level 1-3

*The Functional block *Navigation* excluded, due to the fact, that the functionalities covered by *Navigation* are not SSEP specific.

** For NASAs' Level of Autonomy Assessment Scale see iFly: D 2.4, p. 30, for Sheridan's levels of Automation for decision and action selection see iFly: D 2.4, p. 24.

*** Boyds' (1996) "Observe, Orient, Decide, and Act" loop.

Appendix 5: List of References

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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. 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. 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

Appendix 6: Abbreviations

ACAS Airborne Collision Avoidance System
ADS-B Automatic Dependant Surveillance - Broadcast
AFR Autonomous Flight Rules
ANSP Air navigation Service Provider
ASSAP Airborne Surveillance and Separation Assurance Processing
ATM Air Traffic Management
CD Conflict Detection
CR Conflict Resolution
CTA Controlled Time of Arrival
ETA Estimated Time of Arrival
FB Functional Block
FOC Flight Operations Centre
HMI Human Machine Interface
LoS Loss of Separation
MA Managed Airspace
OPA Operational Performance Assessment
OSA Operational Safety Assessment
OSED Operational Services and Environment Description
PAZ Protected Zone
RAA Restricted Airspace Areas
RBT Reference Business Trajectory
SL Service Level
SSA Self Separating Airspace
SSEP Airborne Self-Separation
SWIM System Wide Information Management System
TBD To Be Defined
TIS-B Traffic Information Service - Broadcast
TMA Terminal Area
WHA Weather Hazards Areas

Appendix 7: 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

RT	Reference Time (Onboard conflict processing)
MTAZ	Mid Term Awareness Zone (Operational requirements: Information sharing)