Tactical Separation System for Small Air Transport Vehicles: design advancements in the COAST Project

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Abstract. Small Air Transport (SAT) is emerging as the most suitable transportation means in order to allow efficient travel, in particular for commuters, on a regional range based on the use of small airports. In this framework, the project COAST (Cost Optimized Avionic SysTem), funded by the Clean Sky JU and started in the year 2016, aims to deliver key technology enablers for the affordable cockpit and avionics, including dedicated technology for Tactical Separation decision support to the pilot. This paper first reports the high-level description of the COAST proposed Tactical Separation System (TSS) and, then, describes the design advancements of the system in the framework of the COAST project. TSS is an ADS-B-based self-separation system aimed to extend traffic situational awareness and to provide the pilot with suggested manoeuvres to maintain the required separation minima. It will constitute an enabling technology for implementation of the separation responsibility delegation to the flight segment (self-separation) in the future SESAR environment, representing a step-forward in the framework of the development of Airborne Separation Assurance Systems (ASAS) for Small Aircraft. The TSS receives consolidated traffic picture (position and velocity of all tracks) from the ADS-B receiver and its own position and velocity from the GNSS receiver. Additional surveillance information, if available, can be also sent in input to the TSS, such as TCAS status, if available. Based on this overall information in input, the TSS performs its main assigned functions, i.e. Conflict Detection and Conflict Resolution. In the paper, after a description of the implemented design process, the overall TSS architecture and interfaces and its concept of operations are outlined. Based on that, an overview of each functionality implemented in the TSS is briefly reported, namely: Coarse Filtering, Conflict Detection, Severity Assignment, Conflict Resolution and overall TSS Logic. In addition, the basic features of the dedicated TSS Human-Machine Interface are also outlined. In the paper, finally, the achievements reached up to date in the COAST project for the design of this technology and related HMI are reported and the next steps are indicated.

1. Introduction
In the last decades the concept of Small Air Transport (SAT) gained an ever increasing importance across Europe. The concept refers to the use of fixed wing aircraft with 5 to 19 seats (or similar cargo vehicles), belonging to the EASA CS-23 category, in order to enable the transportation of people (or goods) over a regional range based on the use of small airports. Several benefits, in comparison with the use of larger commercial vehicles on the same routes, are associated to the introduction of the SAT category in the Air Transport System (ATS), such as reduced fuel consumption, reduced turnaround times, and increased economic viability [1]. Considerations as the ones above outlined have motivated the push for the research activities in the SAT domain, starting from the assessment of the general concept and feasibility, in line with the needs expressed by the ACARE Flightpath 2050 [2], targeting a goal of 4 hours door-to-door journey for the 90% of travellers in Europe.
In particular, in the EU the EPATS project emphasized the need for developing proper innovations, based on research and development activities, in order to fill the gap towards the implementation of the SAT concept of operations by using specifically designed or upgraded aircraft, especially to enable the SAT aircraft single pilot operations. It has been emphasized that some enabling technologies for the SAT concept implementation can be identified, such as: self-separation, collision avoidance, traffic awareness, VTOL, STOL, GNSS, Performance Based Navigation (PBN), ADS-B surveillance, automatic emergency landing system, and others. Many of these technologies are already studied and applied in the aeronautical field, even if not necessarily in the SAT framework, and cross-fertilization from the commercial vehicles and from the RPAS (Remotely Piloted Air Systems) domains can be exploited for the SAT technologies development. These considerations also emerged, then, from the findings of subsequent EU projects addressing the domain of Personal Air Transport, such as the EU funded project PPlane (The Personal Plane Project) [3].

In the recent years, therefore, the SAT topic has been included in the Clean Sky 2 Joint Undertaking in the European Union’s Horizon 2020 Research and Innovation Programme and the project COAST (Cost Optimized Avionics SysTem) has been funded. It is integrated into overall SAT projects ecosystem where parallel projects address topics such as affordable health monitoring, electrical power generation and distribution, landing gear, de-icing, fly-by-wire architecture and where COAST is the only project addressing affordable SESAR operations for SAT vehicles. The project, started in the year 2016, aimed to tackle the SAT challenge and to deliver key technology enablers for the affordable cockpit and avionics, while also enabling the single pilot operations for small aircraft. The COAST consortium included companies assuring wide range of competences. With specific reference to CIRA, automatic landing systems are addressed in the RPAS framework since long time ([4]-[6]), as well as Self-Separation ([7]-[10]) and Collision Avoidance Systems ([11]-[13]), ADS-B applications ([14]-[15]) are a constantly growing research field and also automatic trajectory generation for Unmanned Aerial Vehicles (UAVs) navigation ([16]-[19]) is a common topic that can be useful in the SAT domain.

In the project COAST, therefore, research and developments activities are carried out addressing some enabling technologies for the implementation of the SAT vehicles single pilot operations [20] and, among these technologies, the Tactical Separation System (TSS) is considered. The TSS is an ADS-B-based advanced self-separation system aimed to extend traffic situational awareness and to support the pilot decision making by automatically calculating and suggesting proper manoeuvre aimed to maintain the required separation minima, should a loss of separation be foreseen over the considered time horizon [21].

TSS belongs to the category of Airborne Separation Assurance Systems (ASAS) [22] and is devoted to perform conflict detection and resolution at tactical level. In the framework of the research activities addressing conflict detection and resolution strategies, the Italian Aerospace Research Center (CIRA) devoted significant effort in the last decade, leading to the development of both Collision Avoidance ([11]-[15]) and Self-Separation ([9]-[10]) systems as well as to the development of an integrated system implementing and harmonizing both the functionalities ([7],[23]). These systems reached the Technology Readiness Level (TRL) 6 by means of proper successful flight test campaigns that have been carried out in different Italian and international projects led by CIRA ([7],[13]).

Based on this relevant background, gained through applications mainly on RPAS vehicles, CIRA is developing in the COAST project a specific Tactical Separation System for the implementation onboard of the SAT vehicles [21]. This system is able to support the pilot in real-time in order to ease his/her tasks in presence of congested traffic scenarios. The proposed system is able to act in real-time during the flight in order to: detect possible conflict situations involving own vehicle and surrounding traffic, compute a safe manoeuvre to maintain separation with other traffic and, finally, propose the manoeuvre to the pilot. This allows reducing the pilot’s decision-making process related workload in performing the self-separation task, while at the same time enhancing the flight safety level.

In the paper, a description of the design process implemented in COAST for the TSS technology is reported in section 2. Then, in section 3 it is reported of the overall TSS architecture with the related interfaces and the TSS concept of operations is outlined. Based on that, each functionality implemented in the TSS is briefly outlined is section 4, including the outline of the dedicated TSS...
HMI. In section 5, finally, the achievements reached up to date in the COAST project for the design of the TSS technology and related Human-Machine Interface (HMI) are reported and the next steps are indicated.

2. Design process
The TSS is developed in COAST according to an incremental design and implementation process, which is commonly used for all the flight management related technologies that are addressed in the project [24]. The development process started in the first quarter of the year 2017 and will be finalized through the integration and validation into the Compact Computing Platform [25] by the first quarter of 2021. The design and development process encompasses five stages, as described in the following.

- **Phase 1:** first phase of TSS system design, including preliminary design of the algorithms devoted to the TSS functionalities, TSS design requirements refinement from the overall system requirements, Input/Output (I/O) requirements revision and update with respect to the first system requirements level, integration and demonstration requirements revision and update with respect to the first system requirements level. This phase has been completed in the second quarter of the year 2018.

- **Phase 2:** first phase of TSS prototype and lab validation, including preliminary software (SW) implementation in Matlab/Simulink® environment of the algorithms designed in the phase 1, preliminary validation through fast time simulation in simplified simulation environment in Matlab/Simulink (on purpose designed in the framework of this development phase), tuning of the algorithms parameters, preliminary design and SW implementation of the dedicated TSS HMI to be hosted in the COAST Personal Electronic Device (PED) provided to the pilot. This phase has been completed in the first quarter of the year 2019.

- **Phase 3:** second phase of TSS system design (design update), including tuning of the TSS algorithms in order to improve them based on the results of the first phase of prototyping and validation (phase 2), final SW architecture and final SW I/O interfaces definition, design update of the TSS HMI, final refinement of all the affected TSS requirements. This phase has been completed in the fourth quarter of the year 2019.

- **Phase 4:** second phase of TSS prototype and lab validation, including final SW implementation in Matlab/Simulink environment of the algorithms updated in the phase 3, final validation of this SW through fast time simulation in detailed simulation environment in Matlab/Simulink, TSS SW code generation in C++ (from the final TSS model in Matlab/Simulink by using Mathworks Simulink Coder® and Matlab Coder®), integration of the TSS code with the TSS HMI code in the same SDK environment and related validation. This phase has been completed in the third quarter of the year 2020.

- **Phase 5:** integration and validation of the TSS SW code in the CCP, where the TSS and related HMI SW code that have been provided as output of phase 4 are integrated and validated on the CCP (Compact Computing Platform). This phase is currently just started and ongoing.

3. Architecture, interfaces and concept of operations
The TSS constitutes an enabling technology for implementation of the separation responsibility delegation to the flight segment (Self-Separation) in the future SESAR environment [26] and its implementation represents a step-forward in the framework of the development of Airborne Separation Assurance Systems (ASAS) [22].

The major TSS functions are the ones of Conflict Detection, Conflict Prioritization, and Conflict Resolution, properly supported by dedicated overall TSS Logic. The conceptual scheme of the TSS is depicted in the following Figure 1. As represented in Figure 1, the TSS receives consolidated traffic picture (position and velocity of all tracks) from the ADS-B receiver and its own position and velocity from the GNSS receiver, all consolidated by the dedicated Surveillance Processing application, compliant with applicable RTCA standard DO-317 [27]. The Conflict Detection module checks each track’s projected trajectory with respect to its own projected trajectory, in order to assess if potential violations of separation specified volumes exist. Based on this check, all the detected tracks are classified and the most dangerous identified by the Severity Assignment module. The information
concerning the most dangerous track representing a loss of separation risk is then sent to the Conflict Resolution algorithm, which is activated by the TSS Logic module in order to elaborate suitable manoeuver to be executed to restore the safe separation minima.

This classification of the detected tracks and the suggested separation manoeuver is sent to the multifunction display (MFD), or to a proper portable device (tablet), to support the pilot’s decision-making and, concurrently, an alert is provided using aural feedback to the pilot. In the Figure 1 it is also represented a future improvement of the TSS, improvement that indeed is out of the scope of the COAST project, involving the communication of the TSS status in broadcast to all surrounding vehicles, by adding proper information to the ADS-B Out message. The suggested manoeuver to restore the separation is subject to a predefined strategy: the TSS provides purely horizontal or purely vertical or purely speed magnitude manoeuver or their combination up to a full 4D manoeuver.

For what concerns the TSS concept of operations, the system is designed to be a decision making support system for the single pilot in managing the separation with respect to the surrounding traffic. The TSS, therefore, is not connected with the aircraft autopilot and has no authority on the aircraft guidance, authority that always remains under the pilot’s responsibility. The TSS supports the pilot’s situational awareness by continuously performing (at frequency cycle of 1 Hz) the conflict detection and prioritization tasks as well as automatically elaborating suitable separation manoeuver should a risk of loss of separation emerge from the conflict detection phase. All these functionalities will be better detailed in the following. Nevertheless, it is worth to emphasize here that the TSS is continuously running and performing his tasks and, should a conflict condition be detected, it alerts the pilot by providing visual alert on the HMI as well as providing aural alert. In such a condition, the TSS automatically elaborates a separation assurance manoeuver, which is proposed to the pilot by means of proper graphical representation on the dedicated HMI. The pilot is able to evaluate the manoeuver and, if it is considered appropriate, the manoeuver can be frozen on the HMI to allow the pilot to implement it (directly or by inputting the suggested references into the autopilot). Should the manoeuver become no longer applicable due to relevant changes in the conflict geometry, the TSS will propose a new manoeuver to the pilot. Once the conflict condition is solved (i.e. once the clear of conflict condition is met), the TSS returns to the normal running mode, continuously checking for possible conflicts. In case of TCAS (ACAS) activation, the TSS (ASAS) is designed to receive TCAS II alert signal and, in such a case, to stop providing suggestions to the pilot, because the activation of the TCAS, which is an emergency system, implies that the tactical action of the TSS was not effective in solving the conflict, which over time is therefore muted into a potential collision risk. It is obvious, on the other hand, that the TSS action at tactical level is designed in order to solve the conflict situations before they represent collision risks at emergency level. Therefore, the TSS (ASAS) tactical
action is aimed to prevent the insurgence of emergency conditions that would trigger the TCAS (ACAS) activation. The TSS is designed in order to propose separation manoeuvres that are compliant with the Rules of the Air, so allowing its application in the common commercial airspace and to inherently assure TSS-TSS self-compatibility. More details about TSS requirements and concept of operations are reported in the reference paper [21].

4. Functionalities description
The TSS has been designed in Matlab/Simulink® environment, in compliance with the architecture represented in Figure 1, as reported in the following Figure 2. The main TSS functionalities can be identified as in the following: Coarse Filtering, Conflict Detection, Traffic Prioritization (indicated as “Severity Assignment” in Figure 1), TSS Logic, Conflict Resolution. In addition, in the figures is also indicated the Surveillance Processing application that feeds the TSS with properly processed traffic data, in accordance with the RTCA DO-317B standard [27].

Figure 2. TSS implementation in Simulink® environment.

A description of each functionality has been already reported in the reference paper [21] and in the following only the most relevant aspects are outlined, in order to emphasise the information flow towards the provision of the final TSS outcomes to the pilot through the HMI.

The Coarse Filter module provides a pre-selection of the traffic, selecting the surrounding aircraft to be processed by the TSS, based on the distance and on the time-to-go (TTG). Once received traffic information about surrounding aircraft resulting from the Coarse Filter module, the Conflict Detection module checks for potential loss of separation between ownship and each considered aircraft. The Traffic Prioritization module receives the information elaborated by the TSS Conflict Detection and the ones provided by ACAS application on-board (if any) and derives from them the severity level associated to each traffic vehicle involved. Finally, it performs a prioritization of all the surrounding traffic based on the severity level computed. The TSS Logic module implements properly designed logic in order to determine which action TSS has to perform in terms of resolution manoeuvre, based on all the information elaborated and collected by the whole TSS environment. Moreover, once all the information referred to the priority conflicting aircraft and related conflict resolution manoeuvre evolution are collected, the module evaluates if properly formulated Clear of Conflict condition is satisfied. The Conflict
Resolution module is activated once at least one conflicting aircraft has been detected by the Conflict Detection module and the TSS Logic evaluated that a separation manoeuvre has to be suggested to the pilot via the HMI. The resolution manoeuvre is elaborated according to properly designed algorithms and it can consist in: track angle change, or altitude change, or speed change, or in a combination of these, if needed, up to a complete variation of the speed vector of the ownship. The Conflict Resolution module elaborates a separation maneuver that is compliant with the Rules of the Air (RoA). In this way, it is assured TSS compatibility with the RoAs for integration with surrounding traffic and it is also assured at the same time self-compatibility (TSS-TSS). An example of purely horizontal separation manoeuvre (track change) elaborated by the TSS is reported in the following Figure 3.

![Figure 3](image3.png)

**Figure 3.** Exemplary TSS elaborated maneuver for separation assurance (purely horizontal, track change maneuver).

The TSS HMI provides the pilot, finally, with graphical representation of the surrounding traffic information elaborated by the TSS, including the classification of the traffic, the indication of the higher priority conflict and the representation of the suggested traffic separation manoeuvre, in terms of both graphical and numerical indications. It provides the pilot with visual and audio alerts and allows him/her to freeze the visualisation of the proposed manoeuvre, once evaluated as acceptable (the manoeuvre is continuously evaluated by the TSS and, if conflict conditions changes lead to the need of a new manoeuvre, it is automatically updated and proposed once again to the pilot). An example of purely horizontal separation manoeuvre (track change) elaborated by the TSS and represented to the pilot through the HMI (developed in the Software Development Kit provided by Honeywell) is reported in the following Figure 4.

![Figure 4](image4.png)

**Figure 4.** Exemplary HMI representation of a TSS elaborated maneuver for separation assurance.
5. Conclusions
The Tactical Separation System (TSS) represents a self-separation enabling technology to support single pilot operations for the SAT vehicles. TSS provides the pilot with increased situational awareness and with proper decision-making support, in compliance with the expected pilot responsibilities in the future SESAR environment. The innovations introduced by the Tactical Separation System are: extension of situational awareness and provision of Tactical Separation Management including resolution manoeuvres; Traffic Avoidance (ASAS) functionality, assuring compatibility with ACAS, in compliance with expected SESAR Phase 2 and Phase 3; self-compatibility (TSS-TSS) and real-time update of the suggested manoeuvre in case of sudden change in conflict geometry; compliance of the manoeuvres with the Rules of the Air, while also minimizing deviations from the original trajectory and reducing, if possible, the fuel consumption. Current maturity level is TRL 5, with work in progress for the integration of the SW in the hosting CCP (Compact Computing Platform) by first quarter of 2021. TSS technology is expected to reach the TRL 6 (in-flight demo on EVEKTO EV55 aircraft), performing two flight test trials by the year 2023.

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