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Flight management enabling technologies for single pilot operations in Small Air Transport vehicles in the COAST project

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Abstract. Small Air Transport (SAT) is emerging as suitable transportation means in order to allow efficient travel over a regional range, in particular for commuters, based on the use of small airports and fixed wing aircraft with 5 to 19 seats, belonging to the EASA CS-23 category. The affordability of the SAT industry needs to be supported by the availability of new technological solutions allowing reducing the related operational costs while at the same time maintaining the required flight safety levels. In this framework, Clean Sky 2 Joint Undertaking funded the project COAST (Cost Optimized Avionics SysTem), which started in 2016 with the aim of tackling this challenge and delivering key technology enablers for the affordable cockpit and avionics, while also enabling the single pilot operations for small aircraft. The project activities cover several technologies and, among them, some selected ones, specifically addressing flight management, are considered in this paper, whose aim is the one of providing an outline of the design and implementation process status reached up to date, emphasizing the obtained results and the work to be done in the future activities expected to be performed in the project. The selected technologies here considered are the ones of tactical traffic separation and enhanced situational awareness, meteorological enhanced awareness, and pilot's incapacitation emergency management. The paper, therefore, focuses on a selected cluster, from the overall framework of the COAST project, of SAT single pilot operations enabling technologies: Tactical Separation System (TSS), Flight Reconfiguration System (FRS), and Advanced Weather Awareness System (AWAS). In the paper, a description is first reported of the overall COAST project objectives, motivations and approach to the SAT vehicles cockpit design. Then, the implemented design process is outlined and the description of each of the above-indicated selected technologies is presented (the additional technologies considered in the COAST project are out of the scope of this paper). Based on that, for each of the considered systems (TSS, FRS, AWAS) the status of the design and implementation process is described and the next steps expected to be implemented in the project are outlined.

1. Introduction

In the last decades, the concept of Small Air Transport (SAT) gained an ever increasing importance across Europe as well as in the United States. 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, 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. The interest for the SAT concept has been clearly expressed in the European Union supported research activities in the project EPATS (European Personal Air Transport System) [1], envisaging the emerging need for a new air transportation paradigm, enabling the movement of small groups of people for regional range trips by using small aircraft. In particular, the project emphasized the need to fill the communication gap, which exists on interregional national and European destinations with underdeveloped transport network, located in a distance longer than 300 km, where implementation of others modes of fast transport (high-speed rail, traditional airlines) is irrational due to too low flow density travel and where road transport is too disadvantageous in individual, social as well as ecological dimension [1]. The same project, then, outlined 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. In particular, in the EPATS project, among the other findings, it has been emphasized that [1]: considering the expected SESAR ATM environment [3], for the single pilot operations it is needed the availability of advanced self-separation and advanced collision avoidance on-board equipment, making use of ADS-B (Automatic Dependent Surveillance – Broadcast) and GNSS (Global Navigation Satellite System) data; automatic emergency landing system needs to be installed on-board, in order to support single pilot operations. These considerations have been emerged, then, also 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) [4].
Based on the above-described framework, 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. The project, started in the year 2016, aims 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 [5].
In this paper, in section 2 a description is reported of the overall COAST project objectives, motivations and approach to the SAT vehicles cockpit design. Then, the implemented design process is outlined in section 3 and the description of each of some selected technologies is presented in section 4, with specific reference to the flight management technologies that are addressed in this paper among all the ones that are considered in COAST.

2. COAST project motivations and objectives

Based on the applicable literature analysis, on the considerations expressed in the ACARE Flightpath 2050 vision as well as on the findings of the EPATS project, the COAST consortium worked on the identification of the most relevant enabling technologies for the design of affordable avionic system for the SAT vehicles cockpit. Indeed, a quite big set of technologies, procedures and capabilities can be useful to support the SAT paradigm implementation, including: on-board systems for self-separation, on-board systems for collision avoidance, on-board systems for traffic awareness, VTOL, STOL, GNSS, PBN (Performance Based Navigation), ADS-B, 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 the related competences are well represented in the COAST consortium. A cross-fertilization from the commercial vehicles and from the RPAS (Remotely Piloted Air Systems) domains can be exploited for the SAT technologies development, as these domains are very well supported by the consortium members. For instance, automatic landing systems are addressed by R&D activities in the RPAS framework since long time ([6]-[8]), as well as Self-Separation ([9]-[11]) and Collision Avoidance Systems ([12]-[14]), ADS-B applications ([15]-[16]) are a constantly growing research filed and also automatic trajectory generation for Unmanned Aerial Vehicles (UAVs) navigation ([17]-[19]) is a common topic that can be useful in the SAT domain. Nevertheless, a selection of the most relevant technologies to be addressed in the COAST project has been performed, in order to make possible the technological development according to the allocated timeframe and budget. In particular, the COAST project addresses the development of the following technologies:

- Affordable Surveillance System (SURV), which is an affordable surveillance system for the SAT segment addressing operational needs of the future low altitude operations including detection of non-cooperative threats.
- Tactical Separation System (TSS), which is an ADS-B-based advanced self-separation system to extend traffic situational awareness. The system provides the pilot with suggested manoeuvers aimed to maintain the required separation minima.
- Flight Reconfiguration System (FRS), which is an emergency flight path management system in case of pilot's incapacitation, able to cooperate with related avionic systems, such as navigation systems, flight controls, airport database, data link, and additional sensors.
- Advanced Weather Awareness System (AWAS), which provides complete awareness of weather situation with (both observed and forecast) information assisting the pilot in avoiding entry into atmospherically dangerous areas.
- Scalable GNSS Receiver (GNSS), which provides improved accuracy, integrity, and reliability by introducing the Dual-Frequency and Multiple Constellation (DFMC) GNSS receiver maintaining affordable cost.
- Compact Computing Platform (CCP), which is a scalable, reusable, and reliable platform for advanced cockpit functions, affordable for the CS-23, featuring compact HW design, innovated SW architecture and simple customization for different aircraft platforms [20].
- High-Integrity Electronics (HIE), enabling smart actuators and sensors, health monitoring and prognostics resulting in the reduced operational costs and reducing the aircraft integration complexity.
- Integrated Mission Management System (IMMS), which is an additional technology that has been introduced within the scope of the COAST project in the year 2020 and is devoted to full mission automation through Trajectory Planning and Tracking Guidance integrating Tactical Separation and Weather Awareness and Avoidance [21].

In the following of this paper, more details are provided about some selected technologies, under study in the COAST project, that are specifically designed to support the situational awareness and the decision making of the pilot, in order to enable SAT vehicles single pilot operations. These technologies are: the Tactical Separation System (TSS), the Advanced Weather Awareness System (AWAS) and the Flight Reconfiguration System (FRS).

3. Design process

The overall COAST proposed concept of the avionics and cockpit architecture has been described in [5]. The design and development process applied in COAST for all the addressed technologies implements an incremental approach, encompassing five stages, as described in the following.

- Phase 1: first phase of technology system design, including preliminary design of the algorithms, requirements refinement from the overall system requirements, 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 technology prototype and lab validation, including preliminary SW implementation of the algorithms designed in the phase 1, preliminary validation through fast time simulation in simplified simulation environment, tuning of the algorithms parameters, preliminary design and software (SW) implementation of the dedicated Human Machine Interfaces (HMIs) to be hosted in the 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 technology system design (design update), including tuning of the 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 HMIs, final refinement of all the affected requirements. This phase has been completed in the fourth quarter of the year 2019.
- Phase 4: second phase of technology prototype and lab validation, including final SW implementation of the algorithms updated in the phase 3, final validation of this SW through fast time simulation in detailed simulation environment, SW code generation in C++, integration of the main code with the HMI code and related validation. This phase has been completed in the third quarter of the year 2020 for TSS and AWAS and is going to be completed by the end of 2020 for FRS.
- Phase 5: integration and validation of the SW code in the hosting platform (CCP or dedicated platform), where each technology and related HMI SW codes that have been provided as output of phase 4 are integrated and validated on the CCP [20] or on dedicated platform. This phase is currently just started and ongoing.

4. Flight management technologies description

In this section, a description is reported of some selected technologies, under study in the COAST project, that are specifically dedicated to support the situational awareness and the decision making of the pilot, in order to enable SAT vehicles single pilot operations. As already anticipated, these technologies are: the Tactical Separation System (TSS), the Advanced Weather Awareness System (AWAS) and the Flight Reconfiguration System (FRS).

4.1. Tactical Separation System (TSS)

The Tactical Separation System (TSS) is an ADS-B based Advanced Traffic Situational Awareness and Self-Separation system, constituting an enabling technology for the implementation of the separation responsibility delegation to the flight segment (Self-Separation) in the future SESAR environment [3]. TSS receives traffic data (position and velocity) by the ADS-B IN device and receives ownship navigation data by the on-board GNSS, all consolidated by dedicated Surveillance Processing application in accordance with the RTCA DO-317B standard [22].

TSS provides the pilot, through dedicated HMI on portable device, with: relevant information about the surrounding traffic over a tactical time horizon, including the classification of the surrounding traffic in terms of possible loss of separation and/or collision risk; suggested manoeuver aimed to restore the required separation minima, should conflict situation (i.e. predicted loss of separation with respect to surrounding traffic) emerge during the flight. Tactical separation provided by TSS (which is an ASAS, Airborne Separation Assurance System ([23]-[24])) complements the standard traffic picture, provided e.g. by Traffic Situation Awareness with Alerts (TSAA) or ACAS (Airborne Collision Avoidance System), because TSS operates longer ranges to prevent collision situations and traffic alerts. This results in minimum interference of the CS-23 traffic with respect to other surrounding traffic.

The major functions implemented in the TSS are the ones of Conflict Detection, Conflict Prioritization, and Conflict Resolution, properly supported by dedicated overall TSS Logic. The TSS implementation in Simulink® environment is reported (only at the higher level of the SW modules) in the following Figure 1, where also a brief outline of the specific functionalities is reported.

TSS provided outputs are all the information about the classification of the detected tracks and the suggested manoeuver (if any) proposed to the pilot as support to his/her decision making.

TSS achieved up to date TRL 5. More details about the TSS are reported in [25] and [26].

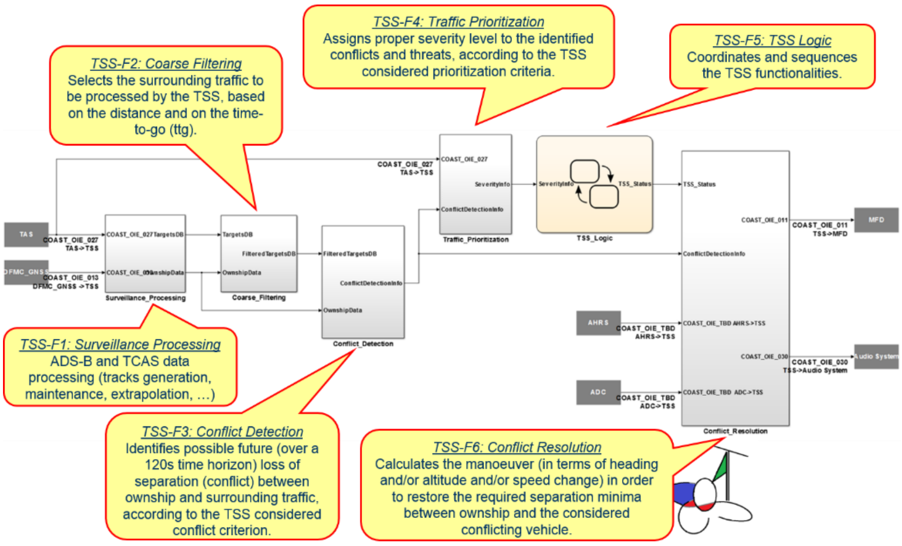

Figure 1. TSS implementation (higher level of the SW modules) in Simulink® environment [26].

4.2. Advanced Weather Awareness System (AWAS)

The Advanced Weather Awareness System (AWAS) presents weather conditions to the pilot to prevent the insurgence of emergencies due to flight in bad weather, providing observed and forecast detailed geographic information concerning weather hazards for different meteorological situations. The system allows elaborating more meteorological variables to display multiple hazards in a unique interface. The data are frequently updated and available along the flight path of the aircraft. The system is composed by two main applications: AWAS on-board segment, which accesses the SatCom channel and visualizes the weather data provided by the ground segment; AWAS on-ground segment, which provides to the on-board segment synthetic information based on the weather data ground repository. The AWAS information are visualized on the dedicated HMI hosted on a dedicated PED. The AWAS uses the GNSS position of the aircraft, hence it provides more targeted and more accurate weather information pertinent to the real trajectory, thus reducing data volume.

The AWAS on-ground application is the core of the entire system; the weather data ground repository is powered by MATISSE (Meteorological AviaTIon Supporting SystEm) platform developed by CIRA [27]. The AWAS system interfaces with the SatCom system to receive weather information from the AWAS on-ground. Schematic representation of the overall AWAS high-level architecture is reported in Figure 2.

As output the AWAS provides elaborated information in terms of both observed and forecast data, through proper graphical representation on the dedicated HMI, where the pilot has the possibility to enable only observed or forecast layer as well as both.

AWAS achieved up to date TRL 5. More details about the AWAS are reported in [28] and [29].

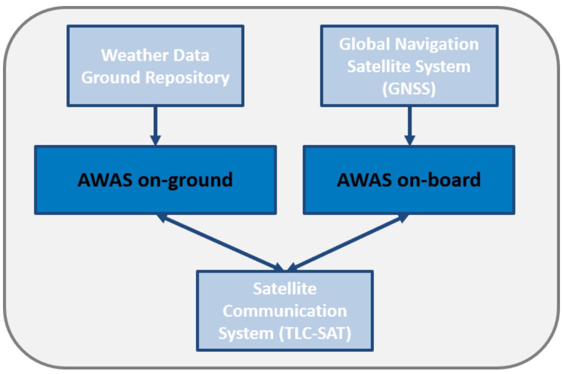

Figure 2. AWAS high-level architecture [29].

4.3. Flight Reconfiguration System (FRS)

The Flight Reconfiguration System (FRS) is aimed at managing emergency events that may occur on-board during the flight and in particular pilot incapacity. The FRS can be activated manually by emergency button or automatically by another subsystem such as pilot-health monitoring (out of the scope of the COAST project). Once activated, the FRS transitions into emergency mode, the transponder sets 7700 code, the FRS takes over the control of the aircraft via the autopilot and stabilizes the level flight. The aircraft enters into a holding pattern, continues straight-levelled flight in constant speed, or initiates descent in case of pressure problems, and, meanwhile, FRS computes the Emergency Flight Plan. Once the Emergency Flight Plan is available, it is communicated to the ATC and the aircraft is guided to the selected airport. Landing can follow in two different scenarios depending on the level of aircraft equipage: automatic landing and low-speed controlled flight into terrain. In case of automatic landing, which can be implemented if the aircraft is equipped with advanced autopilot capable of approach and landing and the appropriately equipped airport is in range, the aircraft is guided to the destination point by the FRS and, after reaching the Final Approach Fix (FAF), automatic landing is performed. In case of low-speed controlled flight into terrain, the FRS guides the aircraft to the selected airport and aligns with the landing strip. Before landing, it stabilizes the heading, sets glide slope, and maintains low speed to complete a controlled crash into terrain at minimum speed to give the best chance for the crew and passengers to survive.
Mandatory equipment that are needed on-board to support the FRS implementation are: an autopilot, which is capable to control in automatic regime (maintain and change) attitude, heading, altitude, and velocity, and a high-integrity GNSS. Further equipment are desirable, such as a radar altimeter, which would significantly improve safety due to a good timing of flare.
FRS is standalone hardware module connected with on-board systems: GNSS receiver (allowing to define current geographic position, flight direction and velocity) and autopilot (driven with FRS commands in order to execute route designed by FRS to deal with critical situation).
FRS software implements algorithm performing automatic flight diversion management. Multiple possible flight paths are calculated, considering different airports, and, using multiple criteria optimization, decision is made automatically which path should be taken when FRS will be activated. New flight path is calculated based on databases (including airport database, aircraft performance database and terrain/obstacles database) and signals from on-board systems. Schematic representation of the overall logic of the path optimization algorithm implemented in the FRS is reported in the following Figure 3. FRS is expected to achieve TRL 5 by the end of the year 2020.

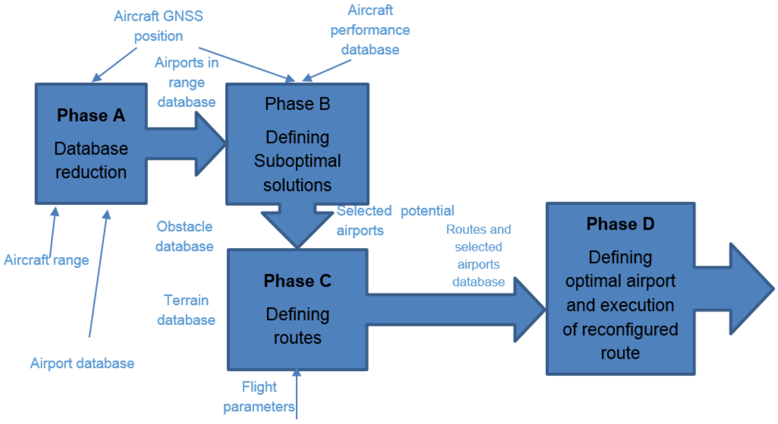

Figure 3. FRS path optimization algorithm logical representation.

5. Conclusions

In order to support the growth of the SAT business domain, the availability of new technological solutions allowing reducing the related operative costs represents a challenge of capital importance. COAST aims to deliver key technology enablers for the affordable cockpit and avionics, while also enabling the single pilot operations for small aircraft. Some technologies are considered in COAST as outstanding with respect to the project aims: Tactical Separation System (TSS), Flight Reconfiguration System (FRS), Advanced Weather Awareness System (AWAS), Integrated Mission Management System (IMMS), Affordable Surveillance System (SURV), Scalable GNSS Receiver (GNSS), Compact Computing Platform (CCP), High-Integrity Electronics (HIE). This paper reported the status of the project activities with respect to TSS (TRL 5 achieved), AWAS (TRL 5 achieved) and FRS (TRL5 to be achieved by the end of 2020). All the COAST technologies are expected to reach the TRL 6 (in-flight demo on EVEKTOR EV 55 aircraft) by the end of the COAST project (2023).

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