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Synergy in Future Avionics: An Overview of Multiple Technologies for Small Air Traffic Segment in the COAST project

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Abstract. The paper describes research and development activities under Clean Sky 2 Cost optimized Avionic System (COAST) program. The main goal of this development was to deliver technology enablers at TRL 5 for affordable cockpit and avionics. The target segment for the technology enablers is aircraft with 1 to 19 passengers and small cargo aircraft belonging to CS-23 category. The main aim is to provide overall summer during the whole COAST program development per individual technology. Sections are divided per each technology with their results and overall contribution to the program. The Clean Sky 2 COAST program covered the development of following technologies: Cockpit Architecture SAT avionic system architecture, Flight Management Tactical Separation System (TSS), Advanced Weather Awareness System (AWAS), Flight Reconfiguration System (FRS), Navigation and Surveillance Dual Frequency Multi-Constellation GNSS Receiver (GNSS), Low-cost Integrated Navigation System (NAV), Affordable Integrated Surveillance System (SURV), Platform technologies Compact Computing Platform (CCP), High Integrity Electronics for health monitoring (HIE), Integrated Mission Management System Integrated Mission Management System (IMMS). These technologies were part of several flight test campaigns which took place in the Czech Republic with Evektor company using EV-55 aircraft.

1. Introduction

Small Air Transport (SAT) is nowadays of increasing fundamental importance as an air transportation segment, exploiting fixed wing aircraft with 5 to 19 seats (EASA CS-23) to move people on a regional range, leveraging the existing network of regional airports. The benefits that can be achieved by using CS-23 vehicles in comparison with bigger ones, such as CS-25, have been well emphasized in literature since decades, as for instance done by the project EPATS [1]. Such benefits include reduced fuel consumption, reduced turnaround times, increased economic viability, possibility to use existing network of small airports so not requiring large infrastructural investments. In addition, the usage of SAT is able to support the ACARE Flightpath 2050 [2] goal of 4 hours door-to-door journey for the 90% of travelers in Europe, because travelling through large vehicle and airports requires usually on average 1.5 hour from parking lot to aircraft boarding, while at regional airports this can be just 30 minutes. In addition, by maximizing the exploitation of regional airports would help in reducing the big airports capacity bottlenecks and positively reduce the regional airports unused spare capacity [3]. The activities carried out by NASA in the US also are on the same page, as indicated in the results of the projects AGATE [4] and SATS [5]-[6]. In order to make viable, also economically, the exploitation on a wider scale of SAT vehicles, nevertheless, the implementation of Single Pilot Operations (SPOs) is needed for such business domain, which in turn requires dedicated technological automation improvements on-board, such as 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, and the availability of automatic pilot incapacitation management systems on-board, in order to manage also not-nominal operational conditions in a safe way [7]-[8]. For instance, in [9] it is clearly emphasized that additional advanced automation tools are required to recover from pilot incapacitation in general, a data-link outage or break-up, as well as a coincidence of both events together. Similarly, in [10] it is emphasized the need for self-separation enablers onboard to support the implementation of the SPOs without involving additional workload for the (single) pilot, which is also of capital importance to allow assuming the possible delegation of the separation responsibility to flight segment, in specific cases, under the future SESAR ATM operational environment [11]. 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, tackles the SAT challenge and delivered key technology enablers for the affordable cockpit and avionics, while also enabling the single pilot operations for small aircraft. This project represents a research and development journey aimed at reshaping the cockpit and avionics systems of smaller aircraft, making them more affordable and technologically advanced. By reaching a technological readiness level (TRL) 5 and 6, COAST sets out to cater to aircraft with 1 to 19 passengers and small cargo planes falling under the CS-23 category. At its core, the COAST program aimed to incubate innovative technologies, having in mind that, as above emphasized, the capabilities of automation need to improve drastically before the second human in the flight deck can be replaced, so the COAST program aimed to reduce operational costs and pilot's workload thanks to innovative increased automation, which is foreseen as a path to single pilot operations. This paper encapsulates the program's multifaceted nature, providing a comprehensive overview of the whole program.

2. COAST Technology enablers

The following sections describes each technology enablers divided per categories: Flight Management, Navigation & Surveillance, Platform Technologies, and Integrated Mission Management System.

2.1. Flight Management

The following chapter describes Flight Management enablers such as Tactical Separation System (TSS), the Advanced Weather Awareness System (AWAS), and the Flight Reconfiguration System (FRS). These innovations have the potential to redefine flight management, enhancing safety, efficiency, and adaptability in the aviation sector.

2.1.1. Tactical Separation System (TSS)

In this chapter, we delve into the Tactical Separation System (TSS), a cutting-edge technology at the heart of aviation safety. TSS stands as an ADS-B (Automatic Dependent Surveillance-Broadcast) based system, offering advanced traffic situational awareness and self-separation capabilities. Through a dedicated Human-Machine Interface (HMI), TSS equips pilots with a comprehensive tactical view of surrounding air traffic, including classifications and potential separation issues. In the event of a conflict situation, TSS not only identifies impending separation risks but also recommends specific manoeuvres to maintain a safe distance from nearby aircraft. TSS is designed to provide pilots with crucial information and guidance to ensure safe and efficient flight operations. TSS furnishes pilots with real-time information about the surrounding traffic over a tactical time horizon. This includes the classification of nearby aircraft in terms of potential loss of separation and collision risks. In the event of a conflict situation, where a predicted loss of separation with surrounding traffic is imminent, TSS provides pilots with suggested maneuvers. These maneuvers are aimed at restoring the required separation distance, enhancing safety during the flight. [12].

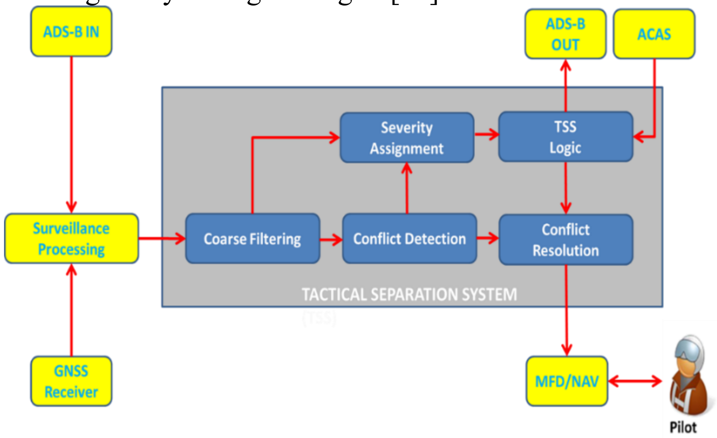

Figure 1 TSS Architecture.

2.1.2. Advanced Weather Awareness System (AWAS)

AWAS stands as a technological milestone aimed at enhancing pilot weather awareness during flights. What distinguishes AWAS is its ability to manage the entire weather data process, from data collection to onboard data visualization. Its primary objectives encompass furnishing real-time weather information for monitoring and forecasting hazardous conditions, all while providing an advanced and user-friendly visualization interface. AWAS not only represents a significant stride in aviation technology but also harmonizes with the evolving expectations of the SESAR environment, establishing itself as a cornerstone technology within the COAST project. The On-board Application serves as the core, processing meteorological data to offer real-time insights and forecasts. AWAS provides a graphical Human-Machine Interface offers an intuitive, user-friendly way for pilots to interact with weather data. There is a ground element, built on the MATISSE platform, consolidates weather information from various sources, including satellites and numerical forecasts. Integrated Satcom ensures periodic availability of weather data on-board. AWAS presents weather information on the Multi-Functional Display (MFD) in the cockpit or via a dedicated portable device, equipping pilots with essential knowledge to make informed decisions and navigate safely through varying weather conditions. [13].

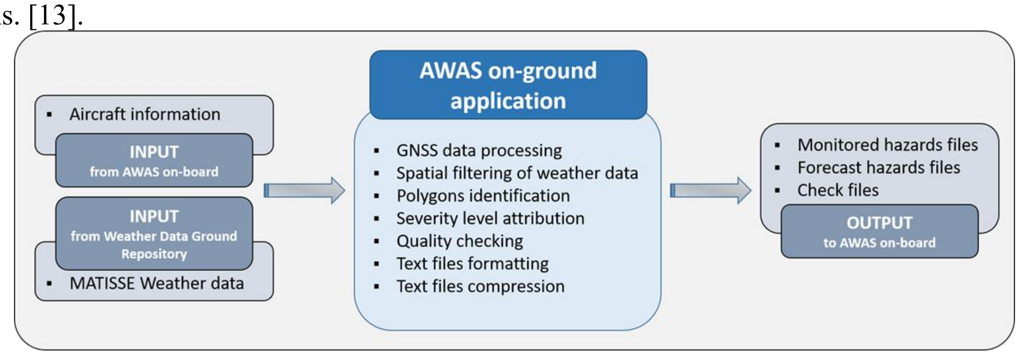

Figure 2 AWAS on-ground application architecture.

2.1.3. Flight Reconfiguration System (FRS)

This chapter describes the Flight Reconfiguration System (FRS), a critical technology designed to manage in-flight emergencies, especially cases of pilot incapacity. FRS can be activated either manually via an emergency button or automatically through subsystems like pilot-health monitoring (beyond the COAST project's scope). When engaged, FRS shifts into emergency mode by setting the transponder to code 7700 and taking control of the aircraft via the autopilot. It stabilizes the aircraft, potentially entering a holding pattern, maintaining level flight, or initiating descent if pressure issues arise. Simultaneously, FRS computes an Emergency Flight Plan and communicates it to air traffic control (ATC) for guidance to a selected airport. Landing options depend on the aircraft's capabilities. If equipped with advanced autopilot and the destination airport supports it, automatic landing is an option. Otherwise, FRS guides the aircraft to align with the landing strip, stabilizes its heading, sets glide slope, and maintains low speed to facilitate a controlled descent into terrain, optimizing the chances of survival for crew and passengers. Key equipment includes an autopilot capable of automated control and a high-integrity GNSS. Radar altimeters enhance safety during critical phases of flight. FRS comprises standalone hardware connected to onboard systems, including a GNSS receiver and the autopilot. Its software employs sophisticated algorithms to calculate multiple flight paths, considering various airports and criteria, aiding in decision-making during FRS activation [14].

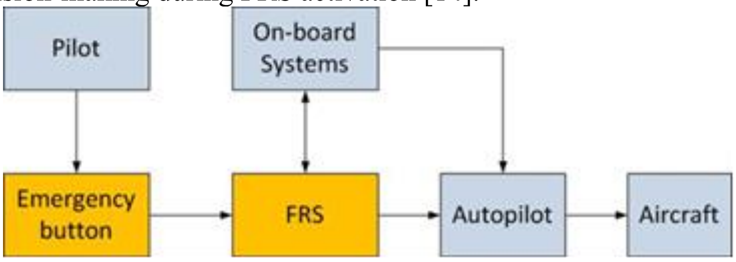

Figure 3. FRS scheme of aircraft control in emergency [7]

2.2. Navigation & Surveillance
This section describes the following technology enablers: Dual Frequency Multi-Constellation GNSS Receiver (GNSS), Low-cost Integrated Navigation System (NAV), Affordable Integrated Surveillance System (SURV).

2.2.1. Dual Frequency Multi-Constellation GNSS Receiver (GNSS)
This chapter delves into the innovative technology of the Dual Frequency Multi-Constellation GNSS Receiver (GNSS), a pivotal component within the Clean Sky 2 COAST program. This cutting-edge technology is designed to enhance accuracy, integrity, and reliability while maintaining affordability—a significant leap in both hardware and software paradigms. The GNSS receiver achieves its remarkable capabilities by operating in dual-frequency mode, harnessing signals from internationally protected aeronautical radio navigation services (ARNS) bands, specifically L1 and L5. Additionally, it seamlessly processes signals from various satellite constellations, including but not limited to Galileo, BeiDou, and GLONASS [15].

2.2.2. Low-cost Integrated Navigation System (NAV)
This chapter presents the brief overview and insights garnered from the Clean Sky 2 COAST project, focusing on the development of a prototype navigation system tailored for the general aviation sector, particularly small aircraft transportation. The NAV technology encompasses both the significant software enhancements and the hardware components integral to the prototype's creation. One of the paramount achievements highlighted in this chapter is the introduction of a hybrid navigation solution. This innovation incorporates several notable features, including a cost-effective inertial measurement unit, integration with SBAS augmented GPS, and extended assistance through radar altimeter and terrain elevation mapping. The performance of this hybrid navigation solution is quantified through a presentation of accuracy levels across key navigation parameters during actual flight conditions. This technology enabler emphasizes the feasibility of delivering high-precision hybrid navigation solutions by harnessing existing onboard aircraft sensors while leveraging the affordability of inertial sensors. [16]. This technology has been demonstrated during 2022 and 2023 and reached the TRL6 in the and of program phase.

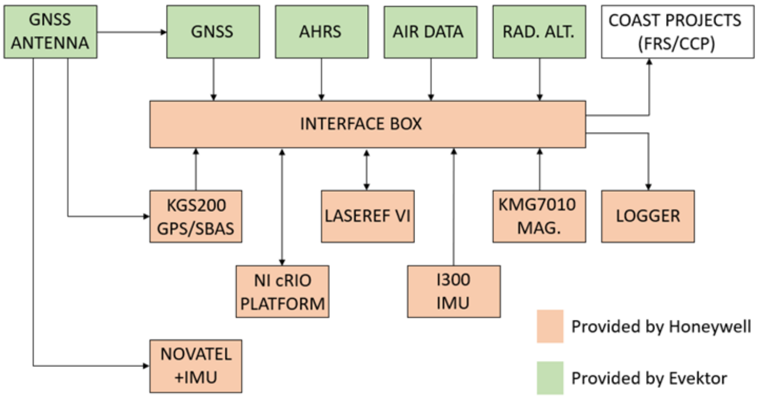

Figure 4 NAV Hardware diagram installed on aircraft.

2.2.3. *Affordable Integrated Surveillance System (SURV)*

Integration of new airspace users, especially those operating at lower altitudes, is a gradual but vital process. Numerous initiatives are underway to develop smart, automated, interoperable, and sustainable traffic management solutions. Safety, however, remains the foremost concern. Even before the advent of these new airspace users, there was a pressing need for an affordable surveillance system capable of ensuring complete protection against traffic, terrain, and obstacles within the Small Air Transport (SAT) segment. Now, with drones and soon Urban Air Mobility (UAM) aircraft becoming integral parts of the SAT operational environment, the importance of addressing this need has only intensified. This SURV enabler shows a promising and cost-effective SAT solution that not only enhances situational awareness but also offers collision avoidance capabilities. A significant aspect of this solution is its reliance on radar technology, which, historically, has faced limitations due to its high cost and installation complexities. However, advancements in radar concepts leveraging state-of-the-art technology are making this approach increasingly feasible, with anticipated adoption across various aircraft categories. The chapter has highlighted the successful flight testing of the initial SURV (Surveillance) system in June 2021 and outlined plans for the final testing of the complete system integrated with radar in 2022. Moreover, one of the main takeaways from the radar concept definition and trade-off considerations is the recognition of the need for legislative action to secure a portion of the frequency spectrum for surveillance radars. This proactive approach is essential to ensure the effective deployment of radar-based surveillance solutions in the evolving aviation landscape, promoting both safety and efficiency in low-altitude airspace operations [17]. This technology completed its development with TRL5.

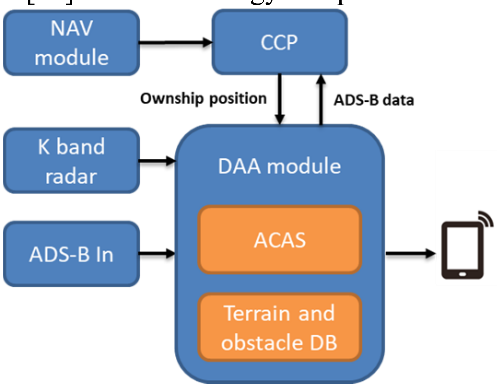

Figure 5 High level SURV architecture.

2.3. *Platform Technologies*

In this chapter, we turn our attention to the following aviation innovation—Platform Technologies, with a specific focus on High-Integrity Electronics (HIE) and the Compact Computing Platform (CCP).

2.3.1. *High-Integrity Electronics (HIE)*
This chapter describes High-Integrity Electronics (HIE), a pioneering technology with a profound impact on aviation. HIE is at the forefront of efforts to enable smart actuators and sensors, ushering in an era of health monitoring and prognostics that promises to reduce operational costs and simplify aircraft integration. Key technology elements underpinning HIE's transformative capabilities include an ultra-compact design, wireless connectivity, and small-footprint local processing. These elements represent the pillars upon which the future of aviation is being built, providing a foundation for enhanced efficiency, reduced complexity, and increased operational intelligence. As we delve deeper into this chapter, we will uncover the intricacies of HIE technology, exploring its potential to revolutionize aircraft systems and redefine the aviation landscape. From compact design to wireless connectivity, we will witness how HIE is poised to shape the future of aviation, bringing about a new era of smarter, more efficient aircraft operations [15].

2.3.2. *Compact Computing Platform (CCP)*
In this chapter, we focus on the Compact Computing Platform (CCP) enabler, a critical milestone within the Clean Sky 2 Cost Optimized Avionic System (COAST) program. CCP is a technological powerhouse that integrates key elements critical to its operation. CCP features two types of interfaces: safety-critical and open-world. Safety-critical interfaces adhere to avionics communication standards, while open-world interfaces leverage widely accepted standards. Both support multiple simultaneous communication sessions, all safeguarded by a firewall to protect aircraft instruments. CCP serves as a host for user applications like Tactical Separation System (TSS) and Advanced Weather Awareness System (AWAS), driven by a Software Development Kit (SDK). A web browser on a Portable Electronic Device (PED) visualizes application content and collects user inputs. CCP's development comprises two key areas: Platform Engineering, which focuses on essential hardware and software blocks, and Innovative Elements, dedicated to advanced features that provide technological differentiation and a competitive edge [18].

2.4. *Integrated Mission Management System*
This chapter describes the final IMMS technology enabler which combines following enablers described in the previous chapters: Flight Reconfiguration System (FRS), Tactical Separation System (TSS), and Advanced Weather Awareness System (AWAS). These technologies, while formidable in their own right, stand as independent enablers for single pilot operations, operating in relative isolation. The main aim was to combine these enablers and develop the synergy system. Integrated Mission Management System (IMMS), which ambitiously seeks to unify the functionalities of Trajectory Planning, Flight Reconfiguration, Tactical Separation, and Weather Awareness into a singular, cohesive system [19]. The IMMS has been successfully demonstrated during the last flight test campaign in 2023 reaching the TRL 5.

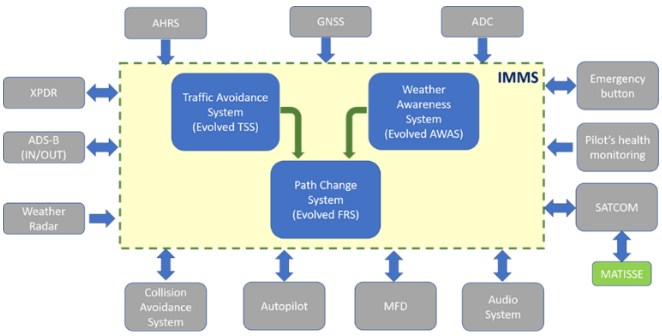

Figure 6 IMMS Architecture description.

3. Flight Demonstrations
In total there were completed three flight demonstrations conducted as part of the Clean Sky 2 COAST program, performed during the years 2021, 2022, and 2023. These demonstrations were carried

out utilizing the EV 55 aircraft, near to Kunovice city in Czech Republic. The primary intention behind these demonstrations was to showcase the core functionality of the technologies under development, with a deliberate focus on omitting fault conditions, power failure recovery, sensor loss, and other specialized scenarios. Each technology within the COAST program had specific objectives and scenarios defined for these flight demonstrations, contributing to a comprehensive assessment of their capabilities. Prior to each flight test, a meticulous series of phases were undertaken, including training, project briefings, laboratory integration, installation, and comprehensive reviews. These preparatory phases were critical in ensuring the success of the flight tests and in achieving the program's overarching goals.

4. Conclusions

In conclusion, the Clean Sky 2 Cost Optimized Avionic System (COAST) program is on the verge of completing its mission this year with resounding success. In the project, some technologies have been considered as outstanding for the implementation of Single Pilot Operations in SAT vehicles. These technologies are aimed to provide the pilot with increased situational awareness and with proper decision-making support, also in compliance with the expected pilot responsibilities in the future SESAR environment. Based on such considerations, the technologies have been specifically presented in the paper even if in a very summary way and include: the Dual Frequency Multi-Constellation GNSS Receiver (GNSS), the Low-cost Integrated Navigation System (NAV), the Affordable Integrated Surveillance System (SURV), High-Integrity Electronics (HIE), the Compact Computing Platform (CCP), the Integrated Mission Management System (IMMS), which includes dedicated Tactical Separation System (TSS), Flight Reconfiguration System (FRS), and Advanced Weather Awareness System (AWAS). Each of these technologies has been presented in the paper, by outlining the concepts underlying the design that is ongoing in the COAST project and by emphasizing the innovation potential related to the future introduction of these technologies in the SAT domain. The overall presentation and discussion of the COAST proposed technologies reported in the paper shows that the COAST approach to the SAT technologies design is coherent with the aim of providing the SAT vehicle pilot, especially in case of single pilot operations, with enhanced cockpit functionalities, which are affordable in terms of implementation costs for the target CS-23 segment. These enhanced functionalities are able to provide enhanced situational awareness (SURV, TSS, AWAS), automatic support to the decision making in managing the self-separation (TSS), information support in managing the flight with respect to emerging critical weather conditions (AWAS), automatic management of emergency conditions (FRS) and, finally, overall mission management automatic support (IMMS). All technologies described above were designed, implemented as prototypes and validated both in laboratory and then, through 3 phases on flight demonstration using EVEKTOR EV55 and EVEKTOR VUT 100 over the Kunovice airport, as per detailed analyses reported in the references, reaching TRL of 5 and 6, exceeding the project goals.

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