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# A concept for an Integrated Mission Management System for Small Air Transport vehicles in the COAST project

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**Abstract.** Small Air Transport (SAT) is emerging as suitable transportation means 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. In this framework, Clean Sky 2 Joint Undertaking, in the European Union's Horizon 2020 research and innovation program, funded the project COAST (Cost Optimized Avionics SysTem), which started in 2016 with the aim of delivering key technology enablers for the affordable cockpit and avionics, while also enabling single-pilot operations for aircraft in the SAT domain. In the project, some relevant flight management technologies to support single-pilot operations are considered, namely the ones of tactical traffic separation and enhanced situational awareness, meteorological enhanced awareness, and pilot's incapacitation emergency management. These technologies have been subject to a dedicated design and implementation process, based on an individual approach where each of them has been considered as independent and dedicated single-pilot operations enabling technology. Nevertheless, during the project execution, it emerged the opportunity to consider proper integration and enhancement of such technologies to design a unique Integrated Mission Management System (IMMS). Such IMMS technology has been considered as a potential solution to support the more effective and safe management of situations of pilot's incapacitation during the flight, under single-pilot operations, and as a relevant step forward towards more autonomous aircraft. Based on these considerations, Clean Sky supported and funded proper extension of the COAST project scope, to include the design of the additional Integrated Mission Management System. This paper, therefore, aims to outline the main concepts implemented by the baseline individual technologies (Flight Reconfiguration System, Tactical Separation System, and Advanced Weather Awareness System) already considered in the COAST project and representing the basic building blocks towards IMMS and, after that, aims to introduce the IMMS motivations and opportunities. Furthermore, the paper describes the main functionalities expected to be implemented by the Integrated Mission Management System and, finally, the expected design and implementation process.

## 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



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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, and so the need for developing proper innovations to enable the SAT aircraft single pilot operations. In addition, considering the expected SESAR ATM environment [3], for the single pilot operations it is needed the availability on-board of advanced decision making support systems and of more automation in general. These considerations 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 the original scope of the project some relevant flight management technologies to support the single pilot operations were included, namely the ones specifically designed to support the situational awareness and the decision making of the pilot, in order to enable SAT vehicles single pilot operations [6]. These technologies are: the Tactical Separation System (TSS), the Advanced Weather Awareness System (AWAS) and the Flight Reconfiguration System (FRS). During the project execution, nevertheless, it emerged the need and opportunity to perform a step forward, from the consideration of individual technologies supporting the single pilot operations, such as the ones above-indicated, to the introduction of a more comprehensive integrated technology, benefitting from the inclusion of the individual ones and extension of functionalities, aimed to represent an enabling technology for more autonomous operations. Such technology is the Integrated Mission Management System (IMMS).

In this paper, in section 2 a description is reported of the baseline individual technologies developed in the COAST project to enable single pilot operations. Then, in section 3, the motivations and opportunities are described that led to the inclusion of the Integrated Mission Management System (IMMS) within the scope of the COAST project. Based on that, in section 4 the IMMS proposed concept is introduced and the planned design and implementation process is then outlined in section 5.

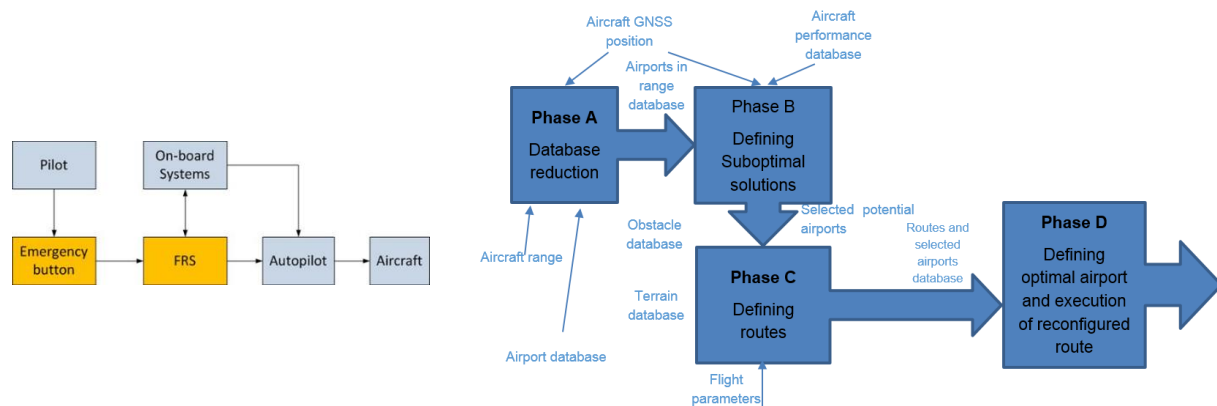
## **2. Flight management individual technologies in the COAST project**

In this section, a description is reported of the individual COAST technologies that are the baseline and represent the building blocks towards the design of the IMMS.

### *2.1. 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). The FRS integration within the aircraft avionics is conceptually represented in the following Figure 1.



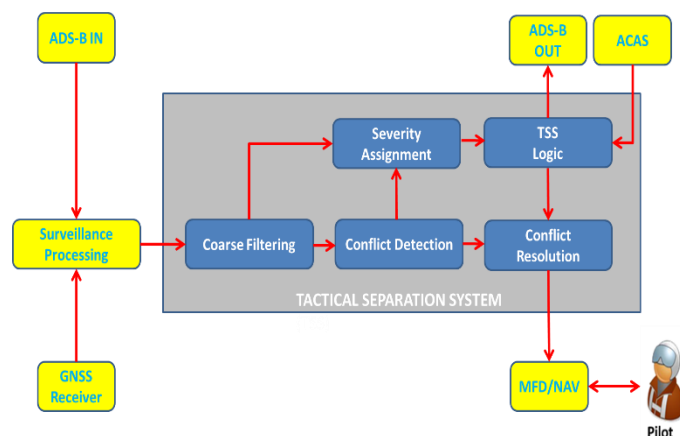
**Figure 1.** FRS integration within the aircraft avionics [5].

**Figure 2.** FRS path optimization algorithm logical representation [6].

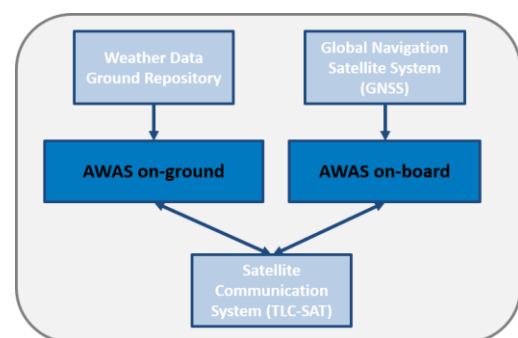
From a flight management perspective under single pilot operations, FRS purpose is to plan the route and execute it in case of emergency flight. The design uses multiple signals from onboard systems (including GNSS receiver) and internal databases (including information on available airports and terrain hazards) which are used as input signals for designing routes planning and decision-making algorithms. The algorithm constantly searches for airports in range, picks the most suitable ones, and design routes to them in a manner avoiding terrain hazards. From multiple possible alternative routes build to multiple possible destinations, the most suitable one is picked with a designed algorithm which is based on Multiple-Criteria-Decision-Making methods. Schematic representation of the overall logic of the path optimization algorithm implemented in the FRS is reported in the previous Figure 2. Such a plan is then converted into autopilot commands and feed to an autopilot for guiding aircraft to emergency destination. Activation of the system is done using the emergency button which is activated on demand, for instance in the case of the pilot incapacitation. As already reported above, in such a case flight control mode is reconfigured and the autopilot starts to be guided by FRS, which also changes the transponder code for informing other airspace users on an emergency on board for making a clear and air traffic-free environment for flight execution. The typical time horizon considered by FRS is at a maximum of 30 minutes of flight to the destination airport, so airports that are of such time range availability are suitable as an emergency solution. Algorithms adopted to be feed by weather data and air traffic data are planned to be designed for IMMS as an extension of existing algorithms of the FRS. Such algorithms are to be used during strategic planning and tactical phase made by IMMS, making FRS enabler for this technology development. FRS is designed by Politechnika Rzeszowska (Rzeszow University of Technology) and Łukasiewicz Institute of Aviation and is expected to achieve TRL 5 by the end of the year 2020. More details about the FRS are reported in [7].

## 2.2. 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 [8]. 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 manoeuvre 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. The TSS high-level conceptual architecture is reported in the following Figure 3 [9]. TSS provided outputs are all the information about the classification of the detected tracks and the suggested manoeuvre (if any) proposed to the pilot as support to his/her decision making. From a flight management perspective under single pilot operations, the TSS is a technology designed for suggesting to a pilot maneuvers on a tactical level for avoiding air traffic hazards. Following TSS commands would result in providing such spatial and time separation that there is no situation in the air where TCAS would activate. This increases the safety of flight because all maneuvers in flight for the avoidance of air traffic are elaborated and performed in a medium term time horizon, not allowing to turn into an immediate threat of midair collision. It is worth mentioning that the TSS does not automatically execute the calculated maneuver, as such a change would lead to a change in the flight plan. Execution of maneuvers must be cleared by the human pilot and, if needed, properly acknowledged to the ATC (unless the modification does not lead to change in the assigned trajectory with proper margins under free-flight concept [10] or under delegation of the separation responsibility to the flight segment based on the new separation modes expected in future SESAR environment [3]). TSS is a fundamental system which can support IMMS by providing traffic information to be used to optimize the path generation phase during the flight and to support the evaluation and execution of separation assurance maneuvers during the flight. TSS is designed by CIRA and achieved up to date TRL 5. More details about the TSS are reported in [9] and [11].



**Figure 3.** TSS high-level conceptual architecture.



**Figure 4.** AWAS high-level architecture.

## 2.3. 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 and AWAS on-ground



segment. Schematic representation of the overall AWAS high-level architecture is reported in the previous Figure 4 [12]. 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 [13]. The AWAS system interfaces with the SatCom system to receive weather information from the AWAS on-ground and provides the pilot with elaborated information in terms of both observed and forecast data. From a flight management perspective under single pilot operations, the provision of weather information is crucial for flight planning (e.g. decision not to fly on stormy weather is made by the pilot or to avoid cumulonimbus cloud). There are systems available for giving limited information on the weather (e.g. weather radar), but the information given is limited (not all phenomena are shown) and is not easily obtained by other aircraft systems. The funding idea for AWAS is that information onboard regarding weather phenomena will always be limited by the equipment of aircraft but it is fundamental to optimize flight execution and improve flight safety. Therefore AWAS is able to send directly to an aircraft, with the use of the Satellite link and according to properly developed protocols to minimize packet size and data transfer, weather information that are displayed to the pilot. Update of this data is made in a reasonable manner (15 minutes time slots), which corresponds to a possible change in weather and showing phenomena occurring not too late, but also not too often. Since all the data are sent to aircraft from the ground station there is no limitation in extending the functionality of unforeseen phenomena or new conditions which would be a limiter when meteorological equipment would be installed onboard. Therefore, AWAS is enabler technology for strategic and tactical planning within IMMS as it enables the system to get weather data necessary within convenient time slots. AWAS is designed by CIRA and achieved up to date TRL 5. More details about the AWAS are reported in [12] and [14].

### 3. IMMS motivations and opportunities

Based on what outlined in the previous section 2, the FRS, TSS and AWAS technologies are being designed, implemented and demonstrated as independent systems, therefore not benefitting from the possible interaction and information exchange among them ([5]-[6]). The FRS technology, not being supported by TSS, assumes that the de-confliction of ownship with respect to the surrounding traffic is performed by ATC, through instructions given to the traffic to clear the airspace near the destination airport to allow the transit of the ownship controlled by the FRS, with relevant negative impact on the airport throughput and related efficiency and cost effectiveness. Furthermore, the FRS technology, not currently supported by the AWAS, does not consider the weather hazards when performing the path planning task. The TSS does not exchange information with the FRS and AWAS and, not receiving info by the AWAS, the TSS cannot consider, in the conflict resolution manoeuvre elaboration, possible weather hazards, therefore not considering weather avoidance constraints. In addition, TSS does not perform generic traffic clustering, because these would be not used by any application, not being it connected with the FRS. The AWAS does not provide info neither to FRS nor to TSS, but only to the pilot through the dedicated HMI. This prevents the implementation of weather avoidance by TSS, for separation purposes, and by FRS, for trajectory planning in case of pilot incapacitation. Therefore, in order to further increase the market impact of the innovative CS-23 cockpit technologies designed in COAST and to support a step-forward towards higher automation on-board, inherently reducing the CS-23 aircraft operational costs, it has been recognized the opportunity of extending the scope of the COAST project to include the design, implementation, integration and validation of an Integrated Mission Management System (IMMS), including additional flight demos where also IMMS prototype will be used during the flights.

The IMMS is aimed implementing into a unique system the functionalities of Trajectory Planning, Flight Reconfiguration, Tactical Separation and Weather Awareness. It is conceived to be applicable as both support system in nominal flight conditions (also supporting softly skilled pilots, by providing them with instructions to reach the destination airport) and as emergency system assuming management and guidance of the aircraft in case of pilot incapacitation.

#### 4. IMMS concept and functionalities

Nowadays commercially available Flight Management Systems (FMS) are able to perform automatic route execution, often using the user-defined waypoints, and some of these systems can use extended instrumentation to perform the automatic landing, while being also able to support the pilot in taking decisions, such as for instance FMS calculating fuel consumption [15]. Although these systems are very convenient from the pilot point of view, there is still a need for human pilot presence onboard, due to lack of aggregation of input signals, such as air traffic, obstacles, not taking into account weather situation, and need of communication with Air Traffic Control (ATC). These factors constitute the biggest issue when considering human pilot fatigue regarding flight path planning and execution. That is why single pilot operations are available only for small air transportation, and their use is also limited (excluded commuter class aircraft). Further improvement of control systems must lead not only to finer route execution but also to automatic route definition [16]. Even for CS-25 category aircraft, nowadays flight plan is declared preflight with the best knowledge of foreseen airspace situation and weather situation. This leads to many companies fighting for time-slots of flight and even flight levels. All these factors contribute to the cost generation of a single flight. Every route extension, on the other hand, leads to an increase in overall CO<sub>2</sub> emission. One way of finding a compromise between the shortest path start to destination and air routes which extend route is to use so-called Free Route Airspace (FRA). In this type of airspace, where no predefined air routes are used, airspace users must define such routes before the flight and then execute it [17]. Still, the pilot must declare a flight plan for most of the airspace types and inform ATC about the planned route. This part can be improved by means of automatic control systems fed with a new type of data and with innovative methods of decision making.

Based on such observations and emphasized limitations affecting current procedures and technologies and taking into account the considerations expressed in section 3 about the opportunity to benefit in COAST from the presence of the individual flight management technologies outlined in previous section 2, in the COAST project emerged the idea of working on an integrated functionality able to overcome the above mentioned limitations: the Integrated Mission Management System (IMMS).

Before defining all the systems needed for extending route planning and execution functions for the IMMS, it is worth considering the decision points for route definition and execution done by a human pilot. The first decision made by the pilot before the flight is where to fly from a given origin. The second one (when the destination is known) is how to get there. The third one is making the decision if it is possible to get there (e.g. due to the limited range of aircraft or weather conditions on a given day). This decision is followed by declaring a flight plan to Air Traffic Control (ATC) before starting a flight.

Once in flight, the need of altering route is in most cases induced by the following unforeseen conditions: technical issues (e.g. greater than expected fuel consumption), human-factor related situation onboard (e.g. sickness of one of the passengers, security reasons, etc.), weather hazards (e.g. storm which started after take-off), air traffic at tactical level (e.g. aircraft on a possible loss of separation course), the situation at the destination airport (e.g. missed slot for landing). These groups of factors can be considered medium time horizon factors influencing route.

There are also factors that must be considered as instantaneous threats and will influence the path immediately. Such groups include sudden: technical problems (e.g. engine cutout), human-factor and security issues (e.g. terrorist threats), weather hazards (e.g. microburst), air traffic at emergency level (e.g. TCAS warning).

Based on these considerations, it emerges that the Integrated Mission Management System must have the possibility of deciding on a given point should it define a new route or follow the defined one. The proposed method for the developed system is to divide decision phases based on the time horizon of flight. The first one would be a long time horizon: this time horizon should be considered as more than a half-hour of flight (assumed for future consideration) or flight from origin to destination whichever takes longer. Such a time horizon should be correlated with strategic planning. The second phase is a medium time horizon: it is assumed here that this set is given by the lower limit of 2 minutes from the threat, and upper limit of 15 minutes to threat. Such a time horizon should be correlated with tactical planning. The third phase is a short time horizon: it is assumed here that this should be considered less

than 1 minute from a threat. Such a time horizon should be correlated with sudden maneuvers to deal with threat in emergency conditions.

The integration of FRS with TSS and AWAS into a unique IMMS, managed by proper Mission Automation Logic, leads to possibility of extensive support to the single pilot by means of automatic trajectory (re-)planning at strategic level during the flight, should it be required due to needed path changes, while taking into account traffic congestions as well as weather hazards (observed and forecasted) already in the path (re-)planning phase. In addition, at tactical level, the integration of these technologies into IMMS allows automatic elaboration during the flight of traffic avoidance maneuvers, should loss of separation risk emerge, while taking into account requirements in terms of avoidance of weather hazardous zones as well as of traffic congested zones. These overall functionalities of the IMMS can be exploited not only as automatic system supporting the single pilot operations but also as automatic system assuming the guidance of the aircraft, in case of pilot's incapacitation, while assuring at the same time strategic route (re-)planning, optimized with respect to weather hazardous airspaces and congested airspaces to be avoided, and tactical self-separation, managing possible loss of separation conditions emerging during the flight towards the emergency destination airport. The IMMS, therefore, constitutes not only a more comprehensive enabler for SAT vehicles single pilot operations but also a step forward towards more autonomous SAT aircraft.

## 5. Design process

Challenges for the development of the IMMS are of multiple categories. The first one is a group of technical ones. This includes agreeing on the standard of hazard description between technologies, properly equipping aircraft for testing, ensuring sufficient calculation power to design route, and run algorithms in real life. The second group is on algorithm design and development including such problems as the decision making process, route planning process, route execution, and most importantly communication with the pilot on-board. Moreover, the extension of some functionalities of the existing individual baseline systems is needed, e.g. clustering of air-traffic done by the TSS to provide convenient data for strategic planning.

IMMS design activities within the COAST project started in July 2020 and by the end of 2020 all system requirements are expected to be defined. In the year 2021 it is planned the IMMS System Design and Review phase, followed in 2022 by IMMS testing in laboratory conditions until reaching TRL 5. A real-life demonstration is planned for 2023, using EVEKTOR EV55 test aircraft, finally reaching TRL 6.

Such a tight schedule would not be available if not aided by proper tools including the possibility of simulation of flight dynamics and systems in the Software-In-The-Loop environment followed by Hardware-In-The-Loop environment. A laboratory stand developed at the Rzeszów University of Technology is one of the elements which are to be used for this purpose. Base functionalities include the possibility of conducting simulated flight with sophisticated flight models, which may be influenced by simulated weather conditions. Moreover, it is possible to extend simulation with additional aircraft being potential threats to original simulated aircraft for which IMMS is to be used.

## 6. Conclusions

Possibility of future single pilot operations is strongly dependent on technical advancements and equipment of aircraft. Technologies developed within the COAST project have been shown which will contribute to future Integrated Mission Management System as well as a baseline for such system design. Further works on the topic will include the definition of requirements for the system, system design, and extended testing using Software-In-The-Loop simulation, Hardware-In-The-Loop simulation, and flight tests. One of the additional benefits of the project is the extended collaboration between parties from different European countries, which not only extends research collaboration but also gives the possibility to get what is the best know-how available to develop such a system.

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