Latest developments in AWAS: the Advanced Weather Awareness System in the COAST Project

M Montesarchio¹, A L Zollo¹, M Ferrucci¹ and E Bucchignani¹

¹CIRA, Italian Aerospace Research Centre, Via Maiorise snc, 81043 Capua (CE), Italy

Abstract. In the framework of the COAST (Cost Optimized Avionics SysTem) project funded by Clean Sky 2 Joint Undertaking in the European Union’s Horizon 2020 Research and Innovation Programme, several key technologies are under development, aimed to enable single pilot operations of Small Air Transport (SAT) vehicles. One of these technologies is AWAS (Advanced Weather Awareness System), which aims to provide and visualize on board of the aircraft updated weather information regarding areas affected by weather hazards, in order to increase the weather awareness of the pilot. The system is composed by three main components: AWAS on-ground, devoted to generate and provide on board data regarding weather hazards observed and forecast along the flight route; AWAS on-board, aimed to send on-ground information concerning aircraft position and current time and to elaborate data provided by AWAS on-ground; AWAS Human Machine Interface (HMI), that visualize data on-board over a Portable Electronic Device (PED). AWAS on-ground and AWAS on-board segments are connected each other via a low-cost satellite communication system. The meteorological information is extracted from MATISSE (Meteorological AviaTIon Supporting System), a prototype software developed by the Meteorology Laboratory of CIRA. This paper describes the main functionalities and components of the system under development, highlighting the advancements achieved with respect to the one presented in 2020, and the work performed to allow the on-board integration of AWAS system. Furthermore, the paper reports the main results obtained during the dedicated flight test campaign successfully completed in summer 2021, validating the technology when integrated into the aircraft.

1. Introduction

In the last decades, the research activities in the domain of Small Air Transport (SAT) are increasing since it is becoming the most suitable transportation means for travel over a regional range. In this perspective, the Clean Sky 2 Joint Undertaking in the European Union’s Horizon 2020 Research and Innovation Programme funded the COAST (Cost Optimized Avionics SysTem) project with the aim to develop key technologies for the design of affordable avionic system for the SAT vehicles cockpit, also enabling single pilot operations. The project, described in [1], covers several technologies, some of them addressing flight management, such as the Advanced Weather Awareness System, aimed to increase pilot’s weather awareness.

More in details, the objectives of AWAS are to provide and visualize on-board consolidated and updated synthetic information concerning weather hazards occurring during the flight. Indeed, it is well known that monitoring and forecasting of adverse meteorological conditions are crucial for safety and optimization of all flight phases, especially for small aircrafts that are not equipped with adequate meteorological instrumentation.

The technology handles the whole process, from data collection and elaboration to visualization by means of an intuitive interface; the weather data are processed in order to limit the data throughput and, hence, allow the usage of a cheap connection system for the transmission on board of the aircraft.
The system development, started in 2017, has been completed in 2021 up to reach TRL5 after going through the following stages: initially, the algorithms design of a preliminary version of the software has been performed, together with its implementation and validation; afterwards, changes and updates to the prototype have been carried out and its final version has been validated; finally, the code has been integrated into the on-board Compact Computing Platform (CCP) [2], the platform for advanced cockpit functions under development in COAST. During summer 2021, the dedicated flight test campaign has been successfully performed to verify the correct behaviour and effectiveness of the technology when integrated on-board of the aircraft.

The main AWAS features have been already presented in [3] and [4]; this paper describes the latest advancements carried out in the system development. Specifically, Section 2 provides a general description of the system components, in Section 3 the validation activity carried out to allow the integration on board of the aircraft is illustrated, whereas Section 4 describes the results of the first flight campaign performed in the COAST project. In Section 5, the main conclusions are reported.

2. AWAS components
The AWAS high-level architecture and data flow are depicted in Figure 1. As shown, AWAS prototype consists of three main blocks: AWAS on-ground and AWAS on-board applications, which allow generation and elaboration of weather hazards information, and AWAS Human Machine Interface (HMI), devoted to the visualization on board of the aircraft. The input weather data are extracted from the Weather Data Ground Repository, whereas a Global Navigation Satellite System (GNSS) is used to determine the aircraft position. The exchange of data between on-ground and on-board segments occurs through a Satellite Communication System (TLC-SAT).

In the following subsections, the most important features of the main system components are summarized, while additional details are reported in [4].

![Figure 1. AWAS high-level architecture and data flow.](image-url)

2.1. Weather Data Ground Repository
Weather hazard data are extracted from MATISSE (Meteorological AviaTIon Supporting SystEm) [5], a prototype software developed by the Laboratory of Meteorology of CIRA in TECVOLII (Technologies for autonomous flight) project founded by MIUR (Italian Ministry of Education, University and Research). MATISSE collects, elaborates and integrates into a unique geodatabase data coming from several sources, such as satellite data provided by Meteosat Second Generation platform, outputs of Numerical Weather Prediction models (e.g. ECMWF IFS [6] and COSMO-LM [7]), data from meteorological archives, ground based data (e.g. CIRA weather stations), data provided by websites.

Furthermore, the Laboratory of Meteorology developed several products, integrated in MATISSE, devoted to detect areas potentially affected by meteorological hazards, e.g. cumulonimbus [8], heavy
precipitation, strong winds, icing [9], lightning [10] and clear air turbulence [11]. They are mainly based on satellite data and ECMWF IFS model, for monitoring and forecasting respectively.

2.2. AWAS on-ground

AWAS on-ground is a software developed in MATLAB and running at CIRA. It elaborates data stored into the MATISSE geodatabase and generates, for each weather hazard, one compressed text file with information concerning polygons enclosing dangerous areas (coordinates and severity level), both for monitored and forecast conditions. Furthermore, two additional text files are generated reporting supplementary information about the provided weather data (check files).

AWAS on-ground application starts as soon as input regarding current date and aircraft position is received from AWAS on-board through an FTP on-ground repository; this information is used to extract weather data only over an area surrounding the aircraft, limiting the amount of data to be sent on board.

2.3. AWAS on-board

AWAS on-board is a software developed in C++, running on the CCP on-board. It is composed by 3 main applications and 1 loader, as shown in Figure 2. The first application, AWASFtpApp, integrates an ARINC (Aeronautical Radio, Incorporated) interface to get information about current time and ownship position and manages the exchange of information between on-ground and on-board segments by means of an FTP Client application. Furthermore, it performs the unzip of weather hazard text files received from AWAS on-ground and a check on the data availability, storing them into local filesystem (FS). Then, the AWASLoader gets files from the filesystem and distributes them to the other two applications, AWASWeatherApp and AWASForecastApp, which generate JSON files containing observations and forecasts respectively, and send them to the HMI to allow the visualization on board.

Through the FTP on-ground repository, AWAS on-board periodically sends input to AWAS on-ground concerning current date and aircraft position, in order to request updated weather data.

The code has been developed in order to be executed using Linux Operating System, adopting suitable libraries to support all the system functionalities and to allow the integration of the code into the CCP on board of the aircraft.

![Figure 2. AWAS on-board architecture.](image)

2.4. AWAS HMI

AWAS HMI is devoted to display the weather hazards information on the PED on-board of the aircraft. It consists of a Javascript code implemented in the Honeywell Software Development Kit (SDK) environment and has been specifically designed for COAST project.
A base map and a data area are available, in order to depict dangerous areas through graphical layers (using different styles and colours, depending on kind and severity level of the hazard) and to show additional data by means of two tables on the dashboard. Specifically, two layers have been developed, one for observations and one for forecasts, which can be activated by the pilot individually or together. The visualization is periodically updated on the base of the latest data received by AWAS on-ground and elaborated by AWAS on-board.

3. AWAS validation for the on-board integration

Once completed the system design of AWAS prototype, the phase of laboratory validation has been carried out and the CIRA computing systems have been used as fast-time SW simulation environment to perform tests aimed to validate all its main functionalities. The exchange of information between AWAS on-ground and AWAS on-board applications has been carried out by means of the FTP on-ground repository, but without the usage of a satellite link, since it was not yet available at that phase of the project.

First of all, the capability of AWAS on-ground to automatically produce output has been assessed, by verifying that AWAS on-ground application starts as soon as the input from AWAS on-board is received and it generates proper hazard zipped text files corresponding to the right aircraft position and reference time. The produced text files have been checked also in terms of information concerning the weather hazards detected along the flight route, verifying that, for each hazard, the polygons identified enclose all the areas affected by the specific hazard and the text files have a format compliant with the established one.

Then, the capability of AWAS on-board to produce output data to allow the weather information generation and their visualization on board has also been assessed. Specifically, a comparison has been carried out between the output of AWAS on-board application (JSON files) and textual files produced by AWAS on-ground. More in details, it has been verified the matching between the information reported in the two different sets of data, checking the information regarding the availability of input weather data, the number of polygons and, for each polygon, the number of vertices. The same procedure is carried out for both monitoring and forecasting meteorological conditions. Indeed, based on the type of weather data considered, the data pre-processing and the execution time for the output generation are different.

Finally, the generation of AWAS HMI output has been assessed. Specifically, it has been verified the HMI capability to reproduce, in the SDK environment, the information concerning polygons enclosing areas affected by weather hazards, by using different labels, colours and styles. Furthermore, the proper visualization of two tables in the dashboard has been checked, for monitoring and forecasting data respectively, reporting the additional information indicated in the check files produced by AWAS on-ground. Figure 3 shows an example of test performed to assess the correctness of data reported in the tables, displaying a comparison with check text files from which the information is extracted. The picture illustrates an example of the final version of AWAS representation in SDK environment, overlapping both monitored and forecast weather hazards to the moving map adopted into the interface.
Figure 3. Example of final AWAS HMI representation, displaying monitored and forecast weather hazards on the moving map and the two tables reporting additional information. The content of tables is compared to the corresponding check text files provided by AWAS on-ground.

Furthermore, additional tests have been carried out in order to assess the dimension of AWAS on-ground output data and its execution time, verifying that they meet the requirements of the COAST project in terms of data throughput and update. Moreover, for operational applications, it is fundamental to check the capability of the software not to crash in case of possible problems. Therefore, the prototype has been tested under non-nominal operating conditions, i.e.:

- when errors in the information exchange between on-ground and on-board segments occur, e.g. in case that some AWAS on-ground files are empty or not received on board,
- in case of connection problems,
- when the FTP on-ground repository is offline.

In all cases, it has been proven that AWAS on-ground and AWAS on-board do not crash and the correct functioning of the applications is restored as soon as the nominal conditions return.

It is worth noting that the prototype has been run testing several dates, with the aim to consider different scenarios, e.g. days characterized by few or no hazards, and days with several hazards, with a consequent larger amount of resources required, in terms of computational time and amount of data to transfer. Furthermore, a long-time test has been carried out in order to demonstrate that AWAS SW, when solicited for a longer period, produced output coherently, adapting weather data to the updated aircraft position and considering the latest available weather input data.

The positive results of all the performed tests have enabled AWAS to reach the TRL5 maturity level and the proper functioning of the prototype with respect to the AWAS technology requirements has been assured.
4. AWAS flight demonstration
The first flight test campaign, coordinated by the project leader Honeywell, has been carried out from 28th June to 1st July 2021 around the Kunovice International Airport (Czech Republic), by using the EVEKTOR EV-55 aircraft. Several flights have been performed in order to demonstrate the COAST technologies, including the AWAS system. The aim of the flight demonstration was to verify the correct functioning of the technology when integrated into the Compact Computing Platform on board of the aircraft. Specifically, the following functionalities were tested:

- the capability of AWAS on-board to request updated weather data, providing GNSS information on-ground;
- the data transfer through the FTP on-ground repository by means of satellite link;
- the processing of monitored and forecast weather data by AWAS on-ground application and provision of corresponding information on-board;
- the elaboration of weather data by AWAS on-board application;
- the visualization on board through the dedicated HMI.

The functioning of AWAS has been verified during the various flights performed. In particular, the visualization on the PED on-board of the aircraft has been checked and the execution of AWAS on-ground has been constantly monitored, in order to verify its functioning and to obtain any additional information necessary for the flight data analysis.

During the flights, weather data with reference to the actual position of the aircraft have been provided by accessing in real time to the MATISSE geodatabase, referring to preselected dates during which several hazards were detected around Kunovice International Airport, allowing to test the visualization of different dangerous areas on the HMI.

In order to assess if the prototype worked properly, a post flight data analysis has been performed, comparing data stored on-board into the FDR (Flight Data Recorder) with data stored on-ground into the CIRA computing system and images of PED recording. Specifically, the assessment of output files generation by the two AWAS applications, the comparison between information reported in TXT and JSON files (produced by on-ground and on-board segments respectively) and the analysis of data visualized on board have been carried out. Such a comparison has been performed for all available sets of data: during the whole flight campaign, several requests have been generated by AWAS on-board and sent to AWAS on-ground, and weather hazard files have been correctly generated and provided on-board to allow their elaboration and visualization on HMI. Only some exceptions due to connection problems occurred during the flights.

Figure 4 reports an example of data generated during one of the performed flights; it compares data generated by AWAS on-ground and their corresponding visualization in the HMI, with reference to a date and an aircraft position required by AWAS on-board. More in details, Figure 4 (a) and Figure 4 (b) show data produced by AWAS on-ground application in MATLAB environment, for observations and forecasts respectively: check text files (with information concerning which weather hazards have been detected, forecast range in case of forecasts and availability of input weather data into MATISSE geodatabase) and images displaying the different weather hazards individuated over a geographical area centred on aircraft position. Figure 4 (c) displays the visualization obtained over the PED by means of the AWAS HMI, showing observed and forecast polygons overlapped on each other and two tables on the dashboard reporting the additional weather information included in the check text files. Additionally, also TXT and JSON files generated by AWAS on-ground and AWAS on-board respectively have been analysed: the comparison highlights that, for each hazard, number of polygons, number of vertices, severity level and information regarding availability of weather data and forecast range (in case of forecasts) properly match between the two different sets of files. The post flight data analysis revealed the successful functioning of AWAS prototype: it worked as expected and correctly showed weather hazards information to the pilot.
Figure 4. Example of data generated during flight demonstration: check files and images obtained through AWAS on-ground application for observations (a) and forecasts (b); visualization obtained through AWAS HMI (c).

5. Conclusions
In the present work, the latest achievements obtained in the development of the Advanced Weather Awareness System in the framework of the COAST project have been described. AWAS is aimed to provide information regarding observed and forecast weather hazards to pilots of SAT vehicles. The data are elaborated and processed on-ground in order to allow the provision of only synthetic information on-board of the aircraft, allowing the usage of cheap connection systems for the data transmission. In the last project phases, the validation of the technology and its integration in the hosting Compact Computing Platform have been completed. The system reached the TRL5 maturity level and it has been tested during the dedicated flight test campaign carried out in June 2021 by using EVEKTOR EV-55 aircraft, highlighting the correct processing of the weather hazards data and their visualization in the HMI.

AWAS technology will be evolved towards its integration in the IMMS (Integrated Mission Management System [12]-[13]) technology, devoted to automatically optimize the trajectory while considering air-traffic, weather conditions, terrain and obstacles, including extension of the functionalities as well as improvement of the on-board data elaboration efficiency once integrated in the IMMS. The IMMS system will integrate the enhanced versions of three different COAST technologies: AWAS, TSS (Tactical Separation System [14]-[15], managing tactical traffic separation) and FRS (Flight Reconfiguration System [16]-[17], managing pilot’s incapacitation emergency). In the next years, a second flight test campaign is planned in order to test both individual COAST technologies and the integrated IMMS system.

Acknowledgments
COAST (Cost Optimized Avionics SysTem) project has received funding from the Clean Sky 2 Joint Undertaking, under the European Union’s Horizon 2020 research and innovation programme (Grant Agreement No. 945535). The authors acknowledge the CIRA project TECVOL II (Technologies for autonomous flight) founded by MIUR (Italian Ministry of Education, University and Research).

6. References
[1] Di Vito V, Beran J, Kabrt T, Grzybowski P, Rogalski T, Maslowski P and Montesarchio M 2021 Flight management enabling technologies for single pilot operations in Small Air Transport vehicles in the COAST project. *IOP Conf. Ser.: Mater. Sci. Eng.* **1024** 012089.
[2] Zaykov P, Beran J and Axman P 2021 Compact Computing Platform for Future General Aviation in the COAST Project. *IOP Conf. Ser.: Mater. Sci. Eng.* 1024 012088.

[3] Zollo A L, Montesarchio M, Buccignani E, Mercogliano P and Beran J 2017 An Advanced Weather Awareness System for small aircraft. *7th EASN International Conference on Innovation in European Aeronautics Research*, 26-29 September 2017, Warsaw, Poland.

[4] Montesarchio M, Zollo A L, Ferrucci M and Buccignani E 2021 Advanced Weather Awareness System for Small Air Transport vehicles: design advancements in the COAST project. *IOP Conf. Ser.: Mater. Sci. Eng.* 1024 012086.

[5] Rillo V, Zollo A L and Mercogliano P 2015 MATISSE: an ArcGIS tool for monitoring and nowcasting meteorological hazards. *Adv. Sci. Res.*, 12, 163-9.

[6] Hortal M 2002 The development and testing of a new two-time-level semi-Lagrangian scheme (SETTLS) in the ECMWF forecast model. *Q. J. R. Meteorol. Soc.*, 128, 1671–87.

[7] Steppeler J, Doms G, Schättler U, Bitzer H W, Gassmann A, Damrath U and Gregoric G 2003 Meso-gamma scale forecasts using the nonhydrostatic model LM. *Meteorol. Atmos. Phys.*, 82, 75-96.

[8] Rillo V, Zollo A L, Mercogliano P and Galdi C 2015 Detection and forecast of convective clouds using MSG data for aviation support. *Proc. 2015 IEEE Metrology for Aerospace (MetroAeroSpace)*, 4-5 June 2015, Benevento, Italy, pp 301-5.

[9] Zollo A L, Biron D, Melfi D, Mercogliano P and Zauli F. 2017 Aviation meteorology: an icing detection product based on EUMETSAT data. *Proc. 2017 EUMETSAT Meteorological Satellite Conference*, 2-6 October 2017, Rome, Italy.

[10] Raffa M, Mercogliano P and Galdi C 2016 Georeferencing raster maps using vector data: A meteorological application. *Proc. 2016 IEEE Metrology for Aerospace (MetroAeroSpace)*, 22-23 June 2016, Florence, Italy, pp 102-7.

[11] Manzi M P, Zollo A L, Mercogliano P and Galdi C 2015 Aviation weather awareness: development of algorithms for the detection of weather hazard through the use of EUMETSAT products. *Proc. 2015 IEEE Metrology for Aerospace (MetroAeroSpace)*, 4-5 June 2015, Benevento, Italy, pp 466-71.

[12] Di Vito V, Grzybowski P, Rogalski T and Maslowski P 2021 A concept for an Integrated Mission Management System for Small Air Transport vehicles in the COAST project. *IOP Conf. Ser.: Mater. Sci. Eng.* 1024 012087.

[13] Di Vito V, Grzybowski P, Rogalski T and Maslowski P 2021 Design Advancements for an Integrated Mission Management System for Small Air Transport vehicles in the COAST project. Submitted to *EASN 2021 Conference Proceedings*, *IOP Conference Series: Materials Science and Engineering*.

[14] Di Vito V, Torrano G, Cerasuolo G and Ferrucci M 2021 Tactical Separation System for Small Air Transport Vehicles: design advancements in the COAST Project. *IOP Conf. Ser.: Mater. Sci. Eng.* 1024 012085.

[15] Di Vito V, Torrano G, Cerasuolo G and Ferrucci M 2021 Enabling SAT single pilot operations: Tactical Separation System design advancements in the COAST Project. Submitted to *EASN 2021 Conference Proceedings*, *IOP Conference Series: Materials Science and Engineering*.

[16] Grzybowski P and Szpakowska-Peas E 2020 Flight reconfiguration system – an emergency system of the future, *Aircraft Engineering and Aerospace Technology*, DOI 10.1108/AEAT-03-2020-0052

[17] Grzybowski P, Rogalski T and Filipowicz M 2021 Experimental verification of the emergency destination definition in Flight Reconfiguration System in the COAST project. Submitted to *EASN 2021 Conference Proceedings*, *IOP Conference Series: Materials Science and Engineering*.