Advanced Weather Awareness System for Small Air Transport vehicles: design advancements in the COAST project

M Montesarchio\textsuperscript{1,2}, A L Zollo\textsuperscript{1,2}, M Ferrucci\textsuperscript{1} and E Bucchignani\textsuperscript{1,2}

\textsuperscript{1}CIRA, Italian Aerospace Research Centre, Via Maiorise snc, 81043 Capua (CE), Italy
\textsuperscript{2}Fondazione Centro Euro-Mediterraneo sui Cambiamenti Climatici, REGional Models and Geo-Hydrological Impacts (REMHI), Viale Thomas Alva Edison snc, 81100 Caserta (CE), Italy

Abstract. It is well known that, in the aviation sector, flights are strongly influenced by weather conditions, especially considering small aircrafts. This kind of vehicles, ideal for transportation on regional base, are having an increasing importance in the last decades. In the framework of the COAST (Cost Optimized Avionics SysTem) project, funded by Clean Sky 2, several key technologies are under development for the affordable cockpit and avionics in the area of small aircrafts. One of these technologies is AWAS (Advanced Weather Awareness System), devoted to increase the weather awareness of the pilots, providing on board information concerning monitoring and forecasting of weather hazards having not negligible potential impact on the aircrafts. AWAS technology is composed by two applications, namely AWAS on-ground and AWAS on-board, connected each other via a satellite link. The AWAS on-ground is the core of the entire system, devoted to provide on-board synthetic information concerning the weather hazards detected or forecast over an area defined according to the aircraft position. The weather information is extracted from the geodatabase of MATISSE (Meteorological AviaTIon Supporting SystEm), a prototype software developed by the Meteorology Laboratory of CIRA, in which weather data coming from different sources are stored. The AWAS on-board application, instead, is devoted to provide on-ground the required input information (such as the aircraft position). Moreover, it decodes the data received by the on-ground application and allows the visualization of weather information in the cockpit by means of a Human Machine Interface specifically designed for the project. In this work, the main features of the AWAS system are presented, along with the future activities to be carried out in the COAST project.

1. Introduction
In recent times, Small Air Transport (SAT) vehicles are becoming the most suitable means of transportation, especially considering travel over a regional range. They include fixed wing aircraft with 5 to 19 seats, or similar cargo vehicles, belonging to the European Aviation Safety Agency (EASA) CS-23 category. In order to promote the growth of the SAT business domain, it is essential to ensure the availability of technologies allowing to reduce operative costs. The COAST (Cost Optimized Avionics SysTem) project, funded by the Clean Sky 2 Joint Undertaking in the European Union’s Horizon 2020 Research and Innovation Programme, takes on this challenge: to develop several key affordable technologies enabling single pilot operations for small aircrafts. An overview of the whole project and of the technologies under development addressing flight management is provided in [1]-[2]. In particular, one of the considered technologies is Advanced Weather Awareness System (AWAS), devoted to increase the weather awareness of pilots on board, which is an essential issue during the flight phases.
Indeed, flight’s safety and optimization are strongly influenced by weather conditions that can be encountered along the route [3]. Hence, it is crucial to have on board updated information concerning weather phenomena that can negatively affect air operations, i.e. aviation hazards, including intense weather events (e.g., tornadoes) and adverse weather conditions (e.g. icing, heavy rain, lightning and strong winds). Unfortunately, small aircrafts are not equipped with adequate meteorological instrumentation. Therefore, in order to increase weather awareness of pilots, weather information from the ground are needed. Furthermore, generally small aircrafts use cheap connection systems for communications, so it is essential to reduce the information amount to be transferred on board. In this framework, different systems are available on the market, such as XMWX [4], AWARE [5], AWDSS [6] and SESAR 4DWeatherCube (SESAR Solutions Catalogue 2017), nevertheless, with respect to AWAS, they are addressed to different market segments and regions, only operational on ground or only providing information about observed weather conditions. The AWAS ambition is to provide consolidated and updated detected and forecast weather information on board during the flight and to show them to the pilots by means of an intuitive interface managed by a dedicated on-board application. In this view, AWAS integrates different data sources, elaborating available input data in order to provide on board synthetic information concerning geographical areas to be avoided, also allowing the usage of a cheap connection system for the transmission. Moreover, a dedicated Human Machine Interface (HMI) is under development, to allow an intuitive on-board visualization of the weather hazards. A preliminary description of the Advanced Weather Awareness System has been already provided in an introductory paper [7]. Here, the advancements achieved are presented. Specifically, Section 2 provides a general overview of the system architecture, Section 3 and Section 4 describe the platform used to manage weather data and the two main AWAS applications respectively; finally, Section 5 illustrates the HMI.

2. System design and architecture

The development of the system started in 2017 and has been subdivided in 5 phases: initially, the requirements definition and the preliminary design of the algorithms have been performed (first phase of system design); then, a preliminary version of the software has been implemented and validated (first phase of prototype and laboratory validation). Based on the validation results, the system design has been updated and a new version of the code has been implemented and validated (second phase of system design and of prototype and laboratory validation). Currently, the integration and validation of the code into the on-board Compact Computing Platform (CCP) [8] are in progress, being a platform for advanced cockpit functions under development in COAST. The high-level architecture of AWAS is depicted in Figure 1.
It is mainly composed by two different applications:

- **AWAS on-ground**, running on CIRA computing systems, devoted to the generation and on-board provision, based on the aircraft position, of synthetic information concerning weather hazards occurring during the flight;
- **AWAS on-board**, running on the on-board CCP, having the dual purpose to manage and visualize the weather information provided by the ground segment and to send input concerning the aircraft position to AWAS on-ground.

Another main system component is represented by the weather data ground repository, from which the AWAS on-ground application extracts input data (observations and forecasts) for the generation of weather hazards information.

AWAS on-ground and AWAS on-board applications are connected each other via a low-cost satellite communication system (Satellite Communication System, TLC-SAT): the link is bidirectional, allowing AWAS on-board to send aircraft information to the on-ground segment for the elaboration of the meteorological data and, at the same time, to receive on the aircraft the weather hazard information.

The aircraft data sent to the on-ground segment are extracted from the Global Navigation Satellite System (GNSS): it is another technology under development in COAST, based on the Dual-Frequency and Multiple Constellation GNSS receiver. Its usage allows the weather data generation only over a specific area around the aircraft, with a significant reduction of the information to be sent on-board.

The on-board weather hazards data visualization is performed over a Portable Electronic Device (PED) into the cockpit, without need of input from the pilot, since the system automatically updates weather information.

A more detailed description of the ground repository of weather data and of the two AWAS applications, namely AWAS on-ground and AWAS on-board, is provided in the following sections.

### 3. Weather data ground repository

The weather hazards information is integrated in MATISSE (Meteorological AviaTIon Supporting SystEm) [9], a prototype software developed by the Meteorology Laboratory of CIRA in the frame of TECVOLII (Technologies for autonomous flight) project founded by MIUR (Italian Ministry of Education, University and Research).

MATISSE collects and elaborates weather data coming from different sources. According to the specific case, raw data or products based on them are processed in order to be integrated into a unique PostgreSQL database with PostGIS extension. The high-level architecture of the ground repository is depicted in Figure 2.

![Figure 2. Weather data ground repository.](image)

More in details, the following meteorological data are managed in MATISSE:

- **Satellite data** provided by Meteosat Second Generation (MSG) platform. Different EUMETSAT products are extracted over Europe, such as Atmospheric Motion Vectors (AMV), Divergence (DIV), Lifted Index (LI) and Optimal Cloud Analysis (OCA).
• Data coming from meteorological archives, such as European Center Medium Weather Forecast (ECMWF) MARS Archive (Meteorological Archival and Retrieval System).
• Ground based data, including also weather stations installed at CIRA.
• Data provided by websites.
• Output of Numerical Weather Prediction (NWP) models, such as forecasts from the IFS (Integrated Forecasting System) [10] of ECMWF or from COSMO-LM model [11].

Satellite data, ECMWF data and COSMO-LM model output are available for scientific purposes thanks to CIRA agreement with Italian Air Force Meteorological Service (ITAF-Met).

Some of the above described data have been used to develop products for monitoring and forecasting of weather hazards. Specifically, concerning monitoring, products for the detection of areas potentially affected by cumulonimbus [12], heavy precipitation, strong winds, icing [13], lightning [14] and clear air turbulence [15] have been developed. They are mainly based on satellite data, with the exception of the lightning one based on maps available in the Blitzortung website (www.blitzortung.org). Concerning forecasting, instead, data from NWPs have been adopted as input for algorithms aimed to identify areas potentially affected by cumulonimbus, heavy precipitation, strong winds and clear air turbulence.

Currently, the output of ECMWF-IFS model is used; if necessary, it could be considered also the output of COSMO-LM, which is run at CIRA over south Italy at very high resolution including urban parameterization. Further products are also available in MATISSE, such as those addressing nowcasting of precipitation [16] and fog nowcasting on specific airports [17].

The data are stored into a geodatabase accessed by the AWAS on-ground application to generate the required synthetic information concerning monitored and forecast weather hazards occurring on the flight route.

4. AWAS applications
This section describes the two main AWAS applications under development in the COAST project: AWAS on-ground and AWAS on-board.

4.1. AWAS on-ground
AWAS on-ground, core of the entire system, is a software application developed in MATLAB environment, running on CIRA computing systems. It is devoted to the elaboration of weather data available in MATISSE, in order to generate textual files reporting information about weather hazards to be sent on-board. The main steps performed by the application are reported in Figure 3, along with its input and output data.

![Figure 3. AWAS on-ground application.](image)

The application starts when it receives from the AWAS on-board application, by means of an FTP on-ground repository, a text file specifying aircraft position, flight ID and current time. The information reported in the text file is elaborated and used to extract, by means of specific queries, the required weather hazards information from the MATISSE geodatabase, both in terms of monitoring and forecasting. The request of weather data is performed over a limited geographical area centred on the aircraft position, allowing to reduce the amount of weather information to be provided, and considering the time indicated in the text file provided by the on-board segment.
Once the extraction of the different meteorological products from MATISSE is completed, for each weather hazard the polygons enclosing the dangerous areas are identified; to this aim, several operations are performed and image processing techniques are applied, in order to generate polygons with a limited number of vertices and to optimize the number of identified areas (for example avoiding the polygons overlapping). In this way, it is possible to reduce the data to send on board, preserving anyway the completeness and quality of information, and allowing the on-board generation of final maps of simpler interpretation for the pilot. On the base of fixed thresholds (specific for each weather hazard), a severity level is associated to each polygon, namely moderate or severe.

Then, for each monitored and forecast hazard, a single text file is generated reporting, for each polygon, only the coordinates of the vertices and the severity level; in this way, the maximum files dimension is in the order of few tens of KB, allowing the usage of a cheap connection system for the on-board transmission of data. Nevertheless, it has to be considered that the final amount of data is strongly dependent on the weather conditions occurring over the specific area of interest.

Two additional check text files are finally produced, for monitoring and forecasting respectively, specifying additional information concerning which weather hazard has been detected and the availability of the required weather products into MATISSE geodatabase.

In order to further minimize the size of data to send on board, the text files produced by the AWAS on-ground application are compressed, allowing a faster on-board transmission of the information.

The final files are then stored into an FTP on-ground repository and used as input by the AWAS on-board application to perform the weather data visualization on the PED.

### 4.2. AWAS on-board

AWAS on-board is a software application developed in C++ environment, running on the Compact Computing Platform on board of the aircraft. The whole process is shown in Figure 4.

![Figure 4. AWAS on-board application.](image)

The first task of the application consists in managing the exchange of information between on-ground and on-board segments by means of the FTP on-ground repository, accessed on-board via satellite link. Specifically, the application provides to the on-ground segment data concerning aircraft position and current time, necessary to extract the meteorological conditions of interest (as described in Section 4.1).

This information, obtained from the Global Navigation Satellite System (GNSS), is reported, in addition to the flight ID, in a text file provided on-ground by means of the FTP repository.

Hence, once received monitored and forecast data by the AWAS on-ground segment, the C++ software deals with the decompression of the zipped text files. Data are then decoded and a check of data integrity and consistency is carried out, comparing the content of files concerning the availability of weather data with the files reporting the hazard level and the coordinates of polygons’ vertices enclosing the dangerous areas. The weather information is elaborated and arranged in order to allow the visualization on-board by means of a Human Machine Interface (HMI), which is described in details in the following
section. Two different set of data are generated in JSON format, for monitored and forecast hazards respectively, allowing the pilot to activate one or both of them on demand, and to visualize the information of interest overlapped to the baseline moving map over the PED. It is noteworthy that AWAS on-board periodically sends input to AWAS on-ground in order to request updated weather data to be shown on the cockpit.

5. AWAS HMI
The Human Machine Interface of AWAS system has been developed inside the Software Development Kit (SDK) environment provided by Honeywell (project partner); it handles the on-board visualization of the weather hazards information, periodically updated on the basis of the last data received by AWAS on-ground. To this aim, it has been developed a JavaScript code for the representation of areas where adverse weather conditions are observed or forecast, using as input the two different JSON files with all the needed information produced by AWAS on-board.

A specific colour has been chosen for each hazard and severity level, considering the moving map used in the SDK environment, adopting a label to identify the hazard. Furthermore, in order to distinguish between monitoring and forecasting data, a different kind of representation has been implemented: the first ones are displayed by means of solid lines, whereas the second ones with dashed lines. It is worth noting that all the adopted choices are aimed at ensuring a clear interpretation and characterization of the meteorological conditions.

As previously mentioned, the system allows the pilot to visualize monitored and forecast data separately or overlapped each other, by activating on demand the specific layer of interest. Moreover, two tables are represented on the dashboard reporting the additional weather information included in the check text files produced by the AWAS on-ground application. An example of AWAS on-board visualization in SDK environment is displayed in Figure 5, showing all data concerning monitoring (Figure 5 (a)) and forecasting (Figure 5 (b)) respectively. It is noteworthy that in the same interface, along with weather data, information about the Tactical Separation System (TSS), are also shown, being another COAST technology devoted to manage tactical traffic separation and enhanced situational awareness [18]-[19].

![Figure 5. Example of AWAS HMI representation for monitored (a) and forecast (b) weather hazards.](image)

6. Conclusions
In this work, the functionalities of the Advanced Weather Awareness System, under development in the framework of the COAST project, have been described. It is an innovative system aimed to increase the weather awareness of pilots of Small Air Transport vehicles; it manages the whole process from the data collection and the on-ground elaboration of synthetic information concerning observed and forecast weather hazards to the on-board visualization.
Two main applications have been developed to handle the system functionalities: the first one, running on-ground, is devoted to the generation of textual files with information about geographical areas to be avoided, based on weather data integrated in the CIRA MATISSE platform; the second one, running on-board, decodes this information and performs the visualization on a Portable Electronic Device by means of an intuitive interface. In order to use an affordable satellite connection system for the exchange of information between on-ground and on-board applications, weather data are properly processed in order to reduce the total amount to be transferred. To this aim, a synthetic formatting of the file has been adopted and the weather information is extracted only over a limited area surrounding the aircraft, based on the position provided on-ground by the on-board segment.

Currently, the AWAS technology is at TRL5 maturity level and the integration of the software in the Compact Computing Platform is in progress, expected to be completed at the beginning of 2021. Finally, AWAS technology is expected to reach the TRL6 level; it will be tested in two flight test campaigns planned in the COAST project.

In our opinion, the system is significant since it targets weather threat detection and is able to provide inputs for flight reconfiguration. In this regard, a new technology is under development in the COAST project, which will integrate AWAS, TSS and FRS (Flight Reconfiguration System [1]-[2]) technologies: the Integrated Mission Management System [20], devoted to allow a full mission automation through trajectory planning and tracking guidance integrating tactical separation and weather awareness.

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