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## Cognitive Decision-Making Support for Avionics Analytics

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**Final Technical Report**

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# REPORT DOCUMENTATION PAGE

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| <b>15. SUBJECT TERMS</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                         |                                             |     |                                                               |                                                                                 |
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**SmartAirSpace**

**Cognitive Decision Support for Avionics Analytics**

# **Performance Report**

## **Performance Evaluation (Part I)**

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FA9550-19-1-7038

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## **Summary**

This report presents the research carried out within the third year of the project entitled “Cognitive Decision Support for Avionics Analytics” supported by the Air Force Office of Scientific Research under award number FA9550-19-1-7038. Overall, it reports the progress on Work Package (WP) 4 tasks which has been unfortunately affected by delays due to the pandemic restrictions and paperwork required by the UK Civil Aviation Agency (CAA). The report entails outputs and outcomes from WP4 which mainly involves technical and legal preparation to fly the project’s drones as part of activities for the outdoor trials on the framework prototype developed in WP3 and reported in APR 2. The application software of the Decision Support System (DSS) includes the Avionics Analytics Ontology (AAO) developed in WP2 and reported in APR 1. The work presented also includes technical details of further programming work on the software application of the framework prototype of the AAO-based DSS for ATM (AODSATM) proposed by the project. A discussion on the way travelled so far in the project and the way forward for it is also presented.

## Dissemination

The research in the third year of the project has made possible the publication of three papers: two conference papers and a journal paper as follows.

- C. C. Insaurralde et al., “Ontology-Based Situation Awareness for Air and Space Traffic Management”, in proceedings of the 41st Digital Avionics Systems Conference (DASC), Portsmouth, VA, USA, Sep 2022. Best of Section Paper.
- C. C. Insaurralde et al., “Ontologies to Support Space Traffic Management Awareness”, in proceedings of the 43rd IEEE Aerospace Conference, Big Sky, MT, USA, Mar 2022.
- C. C. Insaurralde et al., “Situation Awareness Decision Support System for Air Traffic Management Using Ontological Reasoning”, Journal of Aerospace Information Systems, AIAA, vol. 19, no. 3, pp. 224-245, Feb 2022.

The dissemination plan for the fourth year of the project (extension) includes the preparation for submission of conference and journal papers and the submission of a US patent application (writing has already started).

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## Abbreviations and Acronyms

|         |                                                               |
|---------|---------------------------------------------------------------|
| AAO     | Avionics Analytics Ontology                                   |
| ADS-B   | Automatic Dependent Surveillance-Broadcast                    |
| AODSATM | AAO-based DSS for ATM                                         |
| APR     | Annual Performance Report                                     |
| ATC     | Air Traffic Controller                                        |
| ATM     | Air Traffic Management                                        |
| BMFA    | British Model Flying Association                              |
| CAA     | Civil Aviation Authority                                      |
| DSS     | Decision Support System                                       |
| FAA     | Federal Aviation Administration                               |
| FWD     | Fixed-Wing Drones                                             |
| ICAO    | International Civil Aviation Organization                     |
| NASA    | National Aeronautics and Space Administration                 |
| NextGen | Next Generation Air Transportation System                     |
| OWL     | Ontology Web Language                                         |
| RDF     | Resource Description Framework                                |
| RWD     | Rotary-Wing Drones                                            |
| SAW     | Situation AWAREness                                           |
| SESAR   | Single European Sky ATM Research                              |
| UAS     | Unmanned Aerial System                                        |
| UAV     | Unmanned Aerial Vehicle                                       |
| URREF   | Uncertainty Representation and Reasoning Evaluation Framework |

# 1 Introduction

An extension of Grant FA9550-19-1-7038 for a project entitled “Cognitive Decision Support for Avionics Analytics” (SmartAirSpace) has been requested and granted as there has been some unexpected delays from the Civil Aviation Authority (CAA) in addition to the pandemic restrictions. The hold-ups have had a huge impact on the outdoor trials with the project’s drones which are critical in Work Package (WP) 4 as initially planned in the last year of the Grant. Therefore, the report of activities from WP4 is done by means of two reports; Annual Performance Report (APR) 3 (current document) and an additional report for the extra year granted to the project. The latter is APR 4.

A cognitive model has been designed in WP1 from which the knowledge representation has been realized by means of the Avionics Analytics Ontology (AAO) developed in WP2. Both WPs have been reported in APR 1. The AAO is the main driver of a Decision Support System (DSS) for avionics analytics in Air Traffic Management (ATM). The AAO knowledge-based approach is meant to assist Air Traffic Controllers (ATCs) and pilots to deal with the ever-increasing workload due to unprecedented complex volume of data from airspace situations, challenging for example safety and cybersecurity. Other related approaches such as the Federal Aviation Administration (FAA) Next Generation Air Transportation System (NextGen) and the Single European Sky ATM Research (SESAR) use ontologies to support avionics, but with very little support from research groups to report on UAS cyber protection, including defense from drone swarms.

A framework prototype, as a proof-of-concept framework, has been developed in WP3 as reported in APR 2. It is built of a software application that includes the AAO and a hardware platform. The software application consists of (1) the AAO; a resource description framework/ontology web language (RDF/OWL) file, (2) an information manager to access (query) and retrieve (query results) information from the AAO, and (3) the interface to connect the AAO querying results with other systems or stakeholders, e.g., user interfaces to visualize information. The hardware platform consists of medium-sized drones: Fixed-Wing Drones (FWDs) and Rotary-Wing Drones (RWDs) equipped with Automatic Dependence Surveillance-Broadcast (ADS-B), and a computer as a Ground Operation Station (GOS) that monitors ADS-B communication and support Light Detection And Ranging (LIDAR) technology for detection of aircraft. The GOS runs the software application to provide autonomous decision-making support to users.

This document reports the research carried out in the third year of the project. It entails partial work done from the WP4 tasks due to the impact of the incurred delays as discussed at very beginning of this Section. WP4 provides an extensive performance evaluation of the framework developed in WP3. However, the scope of the results presented in this report are mainly from additional functionalities on the software application and setup of the hardware platform, both along minimal but essential verifications and validations carried out as much as it has been possible. The granted extension for the Grant will allow for the completion of the WP4 tasks which outcomes will complement the results presented in this report (APR 3).

The rest of the report is organized as follows. Section 2 briefly recaps the work from tasks carried out in previous work packages of the project; WP1, WP2, and WP3. Section 3 presents preliminary refinement works on the integration of the software Java packages that have been carried in WP3. Section 4 discusses specific verifications of different integrations of software and hardware carried out by means of tests. Section 5 discusses the updates made on the project plan with extensions and delays in some specific tasks as well as a task brought forward in the project. The final section provides a discussion on an assessment on the research carried out in the third year of the project as well as next research steps for the fourth year of the project (granted extension).

## **2 Background Work**

This section briefly recaps the work from tasks carried out in previous work packages of the project; WP1, WP2, and WP3.

### **2.1 WP1: Cognitive Model**

WP1 involves the design of a cognitive model. The knowledge-intensive modelling is meant to be the foundation of the understanding needed for Situation AWareness (SAW) about the surroundings of the operation context of the DSS. The identification of concepts and their relationships allows for the connectivity (cognitive paths) used for artificial knowledge reasoning by the DSS to provide with SAW and ultimately come up with a decision. This enables analysis of the impact of related concepts on each other across the cognitive model. The cognitional network of interconnected concepts is the pathway for reasoning in the decision-making process.

The main concern in aviation is safety in air navigation (airspace and flights). Hence, the unquestionable goal of the DSS is to support ATCs by making ATM decisions autonomously to have safe airspaces and flights. Therefore, the cross-impact analysis targets concepts and their relationships that play a role in aviation safety and how they are cross-related with (have an impact on) other concepts. The challenge is to identify key concepts (and their relationship with other concepts) as factors that have an impact on safety.

The focus for analysis of airspace situations is on intruders as aligned with the case study of this project. The study of the remaining airspace situations and other safety-related circumstances as well as how the DSS deals with them will be for future investigation. Therefore, the cross-impact analysis on the project case study develops the airspace situations where the challenge is to assure a safe airspace by avoiding collision between aircraft (manned/unmanned ones). The case study considers authorized aircraft (those which have clearance from controlling authorities of a notified airspace) and unauthorized aircraft (intruders).

The logic followed by the logical reasoning (cognitive logic) through the cognitive model to be aware of safety hazards due to aerial intruders is as follows (ordered steps): (1) discovery of intruders, (2) separation requirements, (3) collision countermeasures, and (4) aircraft collisions. Figure 1 shows conceptual aspects of the cognitive model for an airspace situation where potential intruders can get into a controlled airspace (project case study) and threat aviation safety.

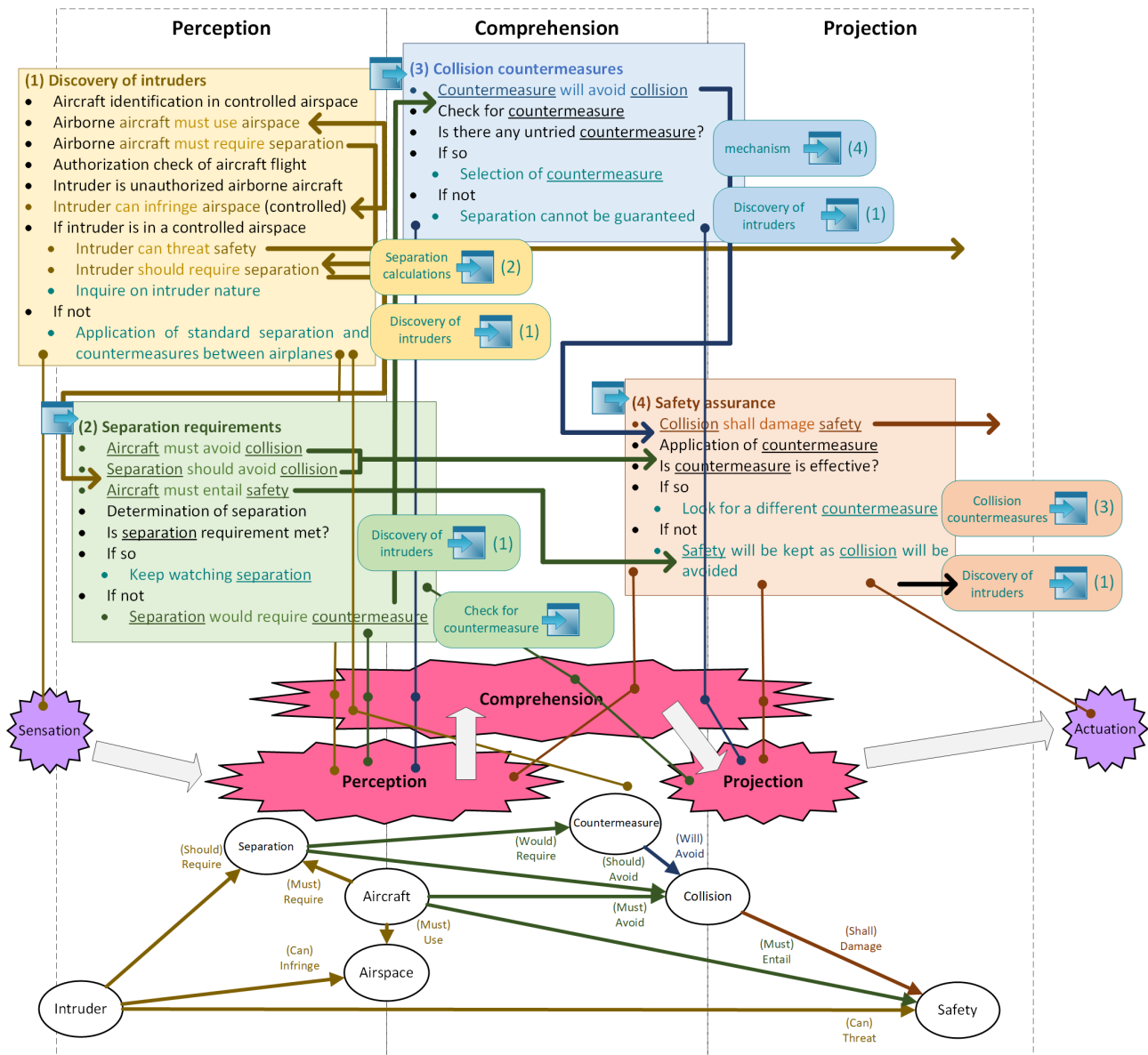


**Figure 1.** Cognitive model for the airspace situations with potential intruders.

## 2.2 WP2: Knowledge Representation

The cognitive model developed in WP1 is formally defined and specified by means of Description Language (DL) [1], and it is implemented by means of an ontology called Avionics Analytics Ontology (AAO) in WP2. The DL specification and its implementation by means of the AAO are approaches for the representation of knowledge. Semantic diagrams are meant to easily realize the connection between concepts. Figure 2 shows a graphical representation for knowledge in AAO.



makes decisions. It also includes a comparison of the AAO with the most aviation-related ontologies; the NASA ATM Ontology (ATMOnto) [3] and the ATM Information Reference Model (AIRM) ontology [4].

## 2.3 WP3: Framework Prototype

APR 2 reports activities from WP3 that involve technical details of a framework prototype to test AAO-based DSS for ATM (AODSATM) proposed by the project. The work presented in APR 2 entails outputs and outcomes from Work Package (WP3) which involves the development of a proof-of-concept framework built of a software application and a hardware platform.

The software application entails the AAO (developed in WP2), and algorithms to interact with the AAO, stakeholders and other systems. It consists of (1) the AAO; a resource description framework/ontology web language (RDF/OWL) file, (2) an information manager to access (query) and retrieve (query results) information from the AAO, and (3) the interface to connect the AAO querying results with other systems or stakeholders, e.g., user interfaces to visualize information.

The hardware platform entails small aircraft required to emulate different roles such as a commercial airplane which is about to takeoff and drones like intruders in the airspace nearby the airplane. It consists of medium-sized drones: Fixed-Wing Drones (FWDs) and Rotary-Wing Drones (RWDs) equipped with Automatic Dependence Surveillance-Broadcast (ADS-B), and a computer as a Ground Operation Station (GOS) that monitors ADS-B communication and support Light Detection And Ranging (LIDAR) technology for detection of aircraft. The GOS runs the software application to provide autonomous decision-making support to users.

The software-hardware integration mainly focuses on the link between the sensors (ADS-B receivers and LIDAR) and the software application. Figure 4 shows the deployment of the software application on the hardware platform. The figure is meant to show the allocation of Java package blocks on hardware blocks.

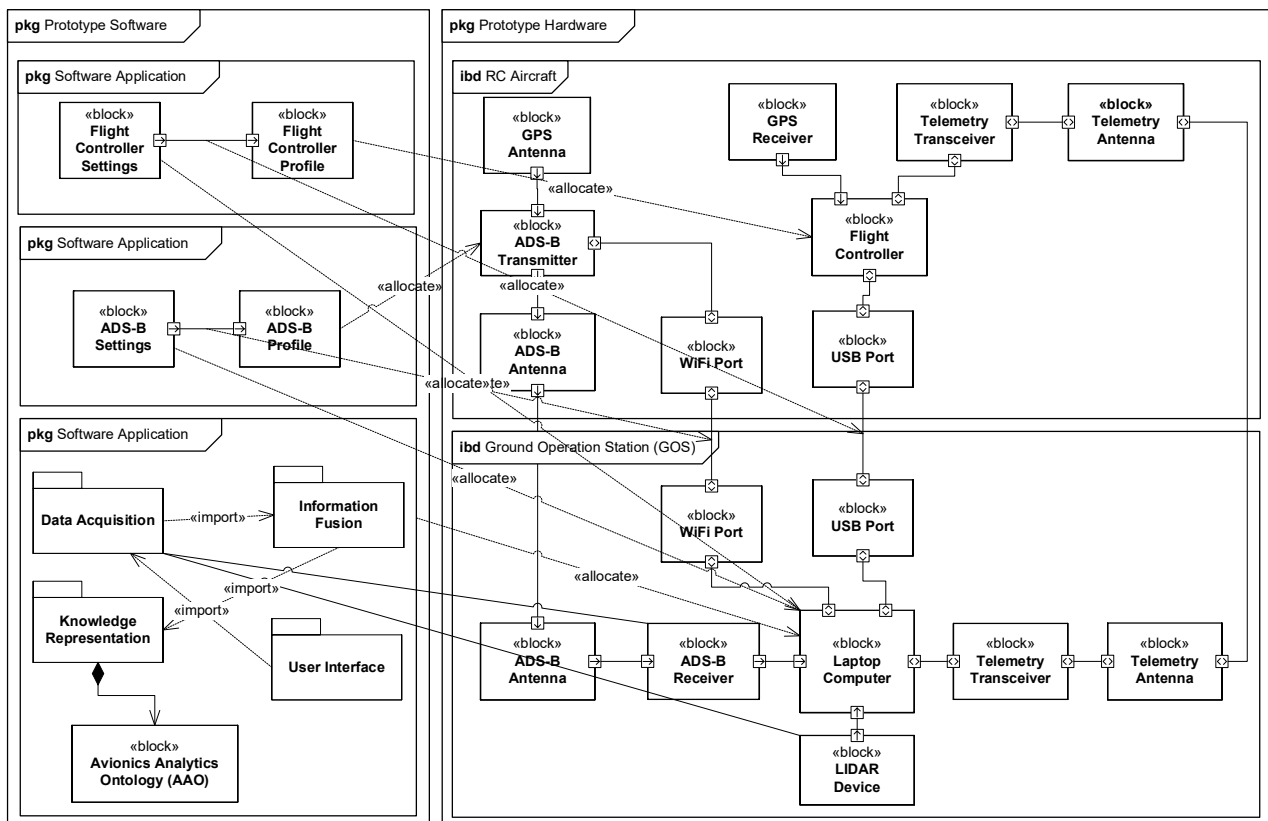


Figure 4. Software-hardware integration.

### 3 Integration of the Software Application

This Section presents preliminary refinement works on the integration of the software Java packages that have been carried in WP3. The practical integration of Java packages allows for reverse software engineering which impacts on the software modeling. Hence, some SysML diagrams presented in ARP 2 are updated.

#### 3.1 Data-Ontology Software Integration

The integration of the repository-ontology software connects two Java packages: the Information Repository and the Knowledge representation. The purpose of this integration is to update the AAO with the information stored in the aircraft record (a class called Record Storage in the Information Repository package in Figure 5). The figure (updated Figure 9 from APR 2) shows the Java packages of the software application updated as per its software realization (implementation and integration) in Java. The update relevant to the data-ontology software integration is that (1) the Data Acquisition package now imports the Knowledge Representation package instead the Information Repository package importing it and (2) that the methods from the Knowledge Representation package now have access to the Information Repository package through the Data Acquisition package.

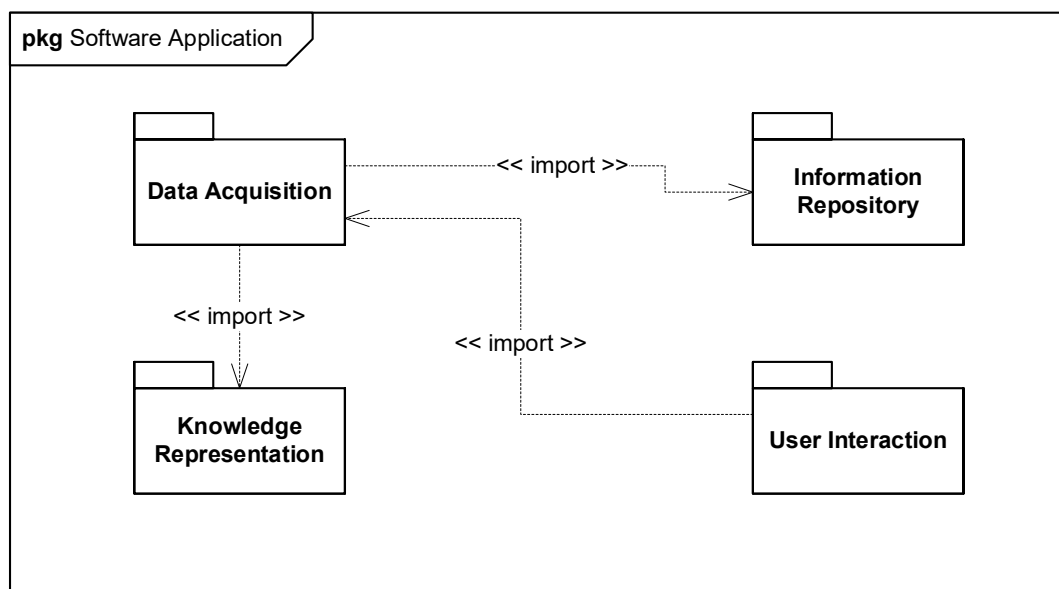


**Figure 5.** Java packages of the software application.

Figure 6 shows a structural representation of the connections between blocks (classes) that belong to packages shown in Figure 5. The figure also helps see the structure of the relation between packages and the updated connections between the Data Acquisition package and the Knowledge Representation package.

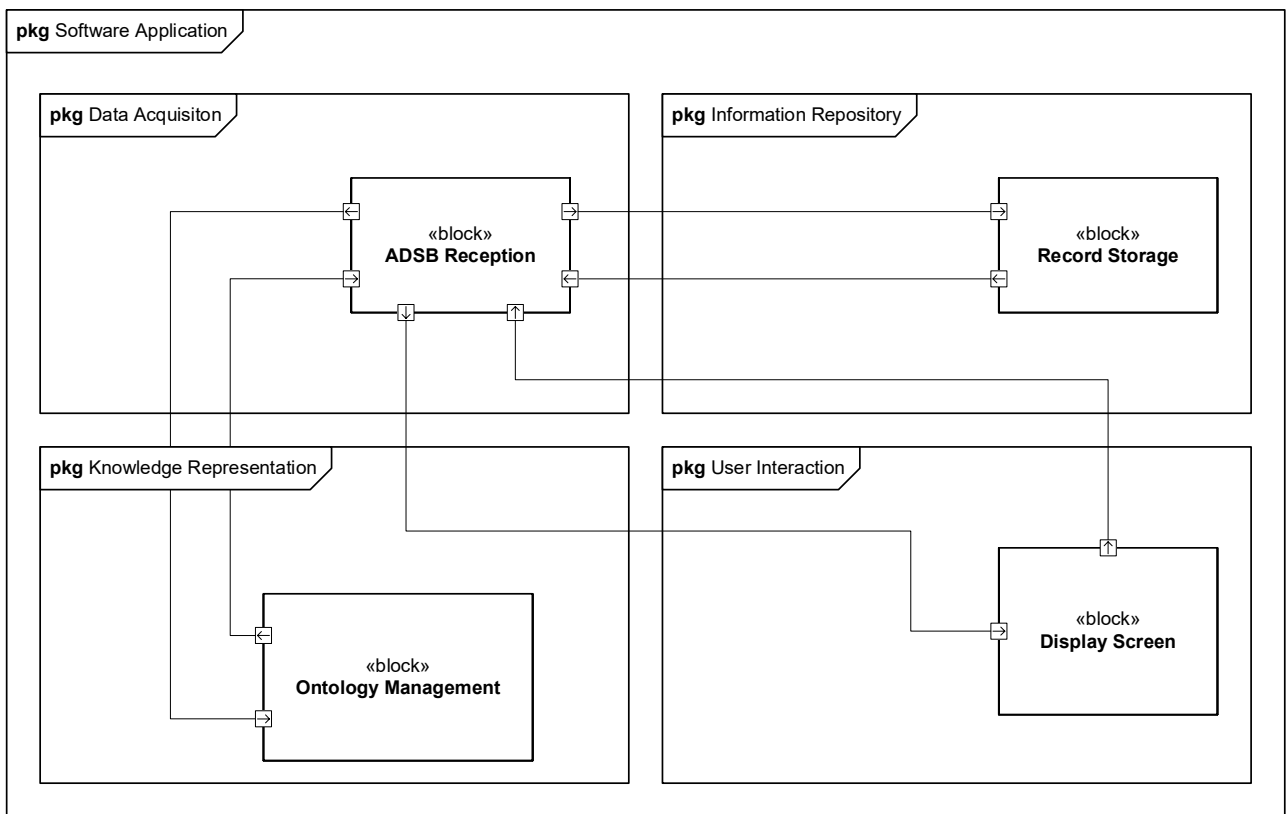


**Figure 6.** Currently realized interconnection between blocks (Java classes) of the software application.

The data received from the ADS-B receiver through its antenna are captured and stored in both, the Record Storage Java object (Information Repository package) and the Ontology Management Java object (Knowledge Representation package). Figure 7 shows an updated activity diagram to describe the control and data flow of the above functionality.

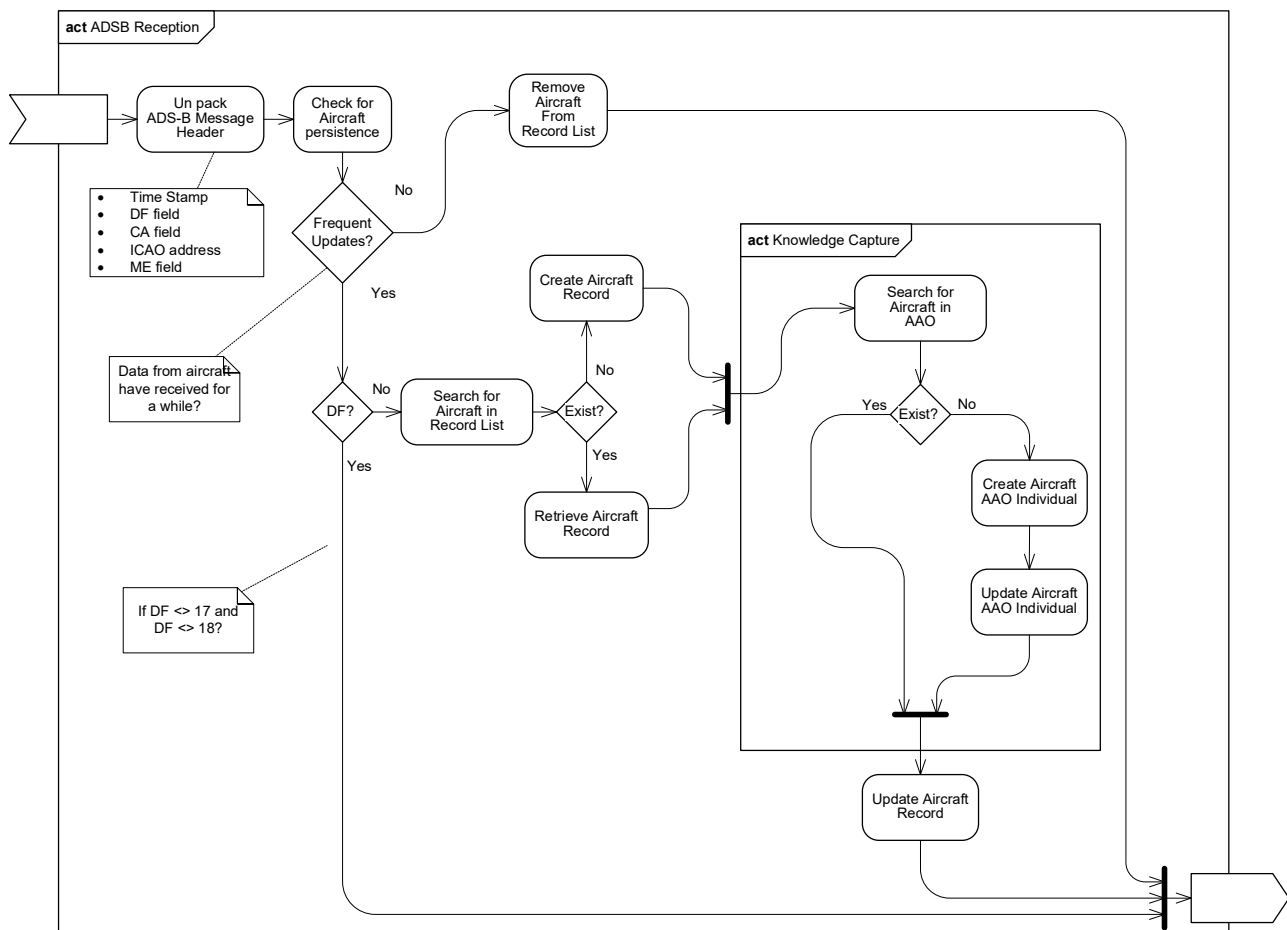


**Figure 7.** Behavior of the ADS-B Data acquisition software module (Java package).

In addition to the management of aircraft records in the ADS-B Reception method from the *ADSBReception* Java Class in the Information Repository Java package, the method now includes the management of AAO elements to update the AAO as needed based on the data received from the ADS-B receiver and to keep consistency between the aircraft records and the AAO elements.

### 3.2 Ontology-Display Software Integration

The integration of the ontology-display software connects two Java packages: the Knowledge Representation and the User Interaction. The purpose of this integration is to update the computer screen with the information provided by the reasoning queries running on the AAO (by means of a class called Ontology Management from the Knowledge Representation package in Figure 5 and Figure 6).

The update relevant to the ontology-display software integration is that (1) the Data Acquisition package now imports the Knowledge Representation package instead the Information Repository package importing it, and (2) that the methods from the User Interaction package now have access to the Information Repository package through the Data Acquisition package. The latter also includes mechanisms (functionality) to display query results on the user interface (screen).

Figure 8 highlights the updated on the structure of the Knowledge Representation java package that includes a main class called “*Ontology Management*” and the OWL file that implements the AAO.

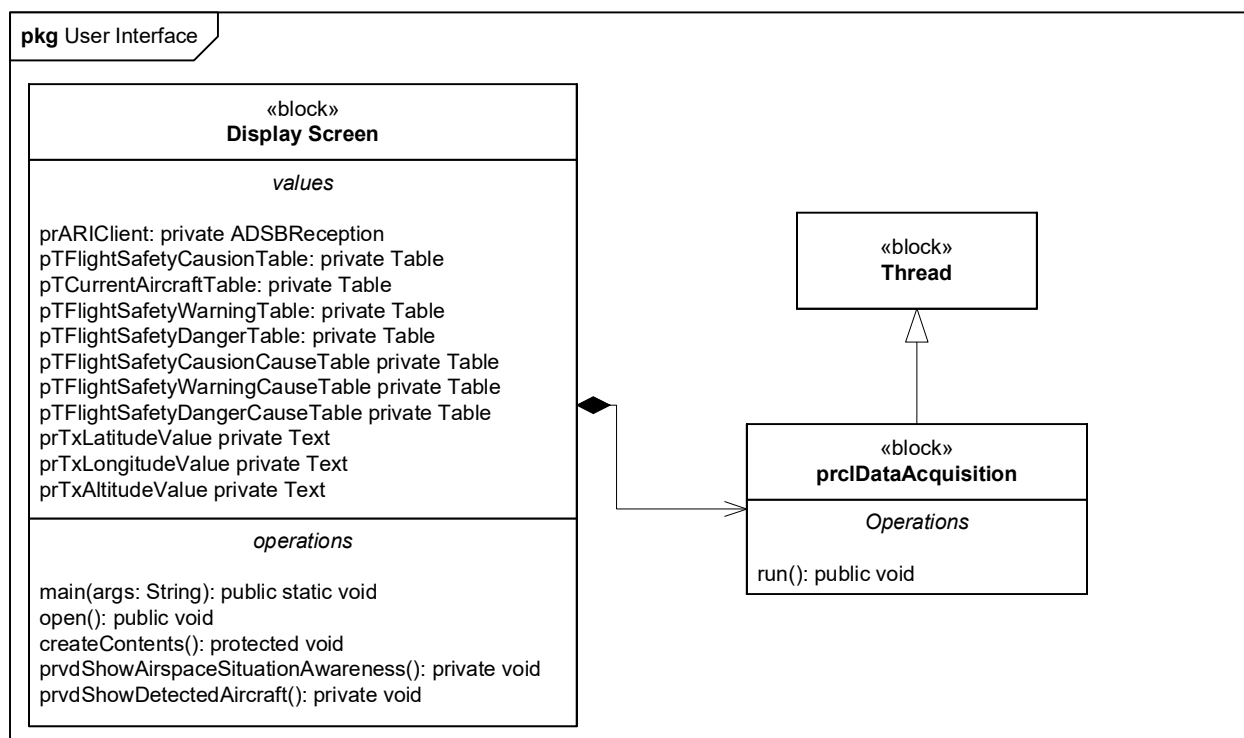


**Figure 8.** Structure of the User Interface software module (Java package).

Table 1 shows a description for the operations of the Display Screen block shown in Figure 8.

**Table 1.** Variables of the Display Screen block.

| Type                     | Variable                        | Description                                                      |
|--------------------------|---------------------------------|------------------------------------------------------------------|
| private<br>ADSBReception | prARIClient                     | Class to receive ADS-B data                                      |
| private Table            | pTFlightSafetyCautionTable      | Class to show flight safety cautions from the AAO queries.       |
| private Table            | pTCurrentAircraftTable          | Class to show current aircraft from the aircraft record.         |
| private Table            | pTFlightSafetyWarningTable      | Class to show flight safety warnings from the AAO queries.       |
| private Table            | pTFlightSafetyDangerTable       | Class to show flight safety dangers from the AAO queries.        |
| private Table            | pTFlightSafetyCautionCauseTable | Class to show flight safety caution causes from the AAO queries. |
| private Table            | pTFlightSafetyWarningCauseTable | Class to show flight safety warning causes from the AAO queries. |
| private Table            | pTFlightSafetyDangerCauseTable  | Class to show flight safety danger causes from the AAO queries.  |
| private Text             | prTxLatitudeValue               | Current latitude of the aircraft                                 |
| private Text             | prTxLongitudeValue              | Current Longitude of the aircraft                                |
| private Text             | prTxAltitudeValue               | Current altitude of the aircraft                                 |

Figure 9 shows the updated activity diagram to describe the control and data flow of the above functionality.

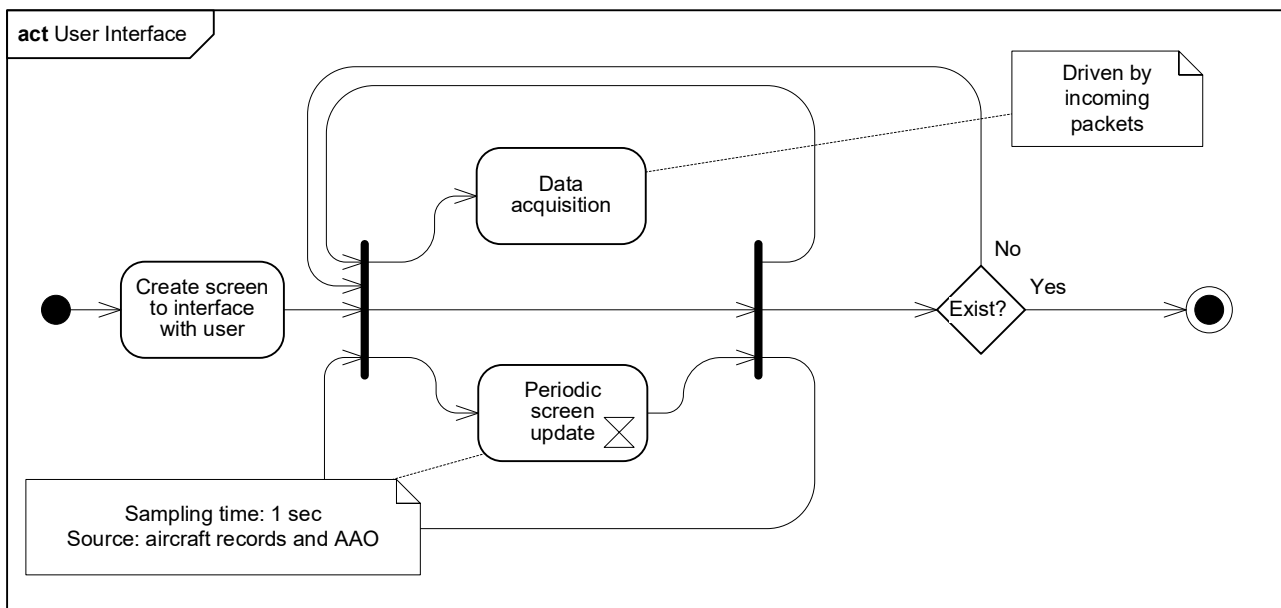


**Figure 9.** Behavior of the User Interface software module (Java package).

In addition to the management of the AAO elements through the ADS-B Reception method of the *ADSBReception* Java Class in the Information Repository Java package, the method now includes the management of AAO elements to update the AAO as needed based on the data received from the ADS-B receiver and to keep consistency between the aircraft records and the AAO elements.

## 4 Performance Evaluation

This Section discusses specific verifications of different integrations of software and hardware carried out by means of tests. The former target performance of the integration of the Java packages discussed in Section 3. The latter target performance of the integration of electronic equipment mounted on the drone structures.

### 4.1 Software Integration Testing

Basic test procedures are defined for each of the two integration of Java packages, i.e., data-ontology and ontology-display, both presented in Section 3 discussed in the following Subsections.

#### 4.1.1 Data-Ontology Software Testing

The aim of the testing of the data-ontology software integration is to check that the AAO actually manages to acquire data about the aircraft in the airspace, turn it into information, and store it as knowledge along with the AAO able to reason based on its own knowledge and the new one (just acquired) to conclude on airspace situations. This enables Situation Awareness (SAW) in the Decision Support System (DSS) to advise relevant stakeholders, e.g., pilots and Air Traffic Controllers (ATCs).

The process of capturing knowledge (i.e., acquiring data, turning it into information and storing it as knowledge) must be in real time. Thus, the DSS software application runs this process continuously to make sure the SAW provided is timely updated. The process triggers along with a process that keeps records of the aircraft which is driven the any incoming ADS-B message received.

The verification of the data-ontology software integration is carried out by testing the above knowledge capability and inspecting the data, information, and knowledge handled by the AAO and its interface mechanism (Knowledge Representation Java package) working in collaboration with the other Java packages in the software application.

The capture process with more details than in Figure 7 (and a focus on the knowledge capture logic) is shown in Figure 10.

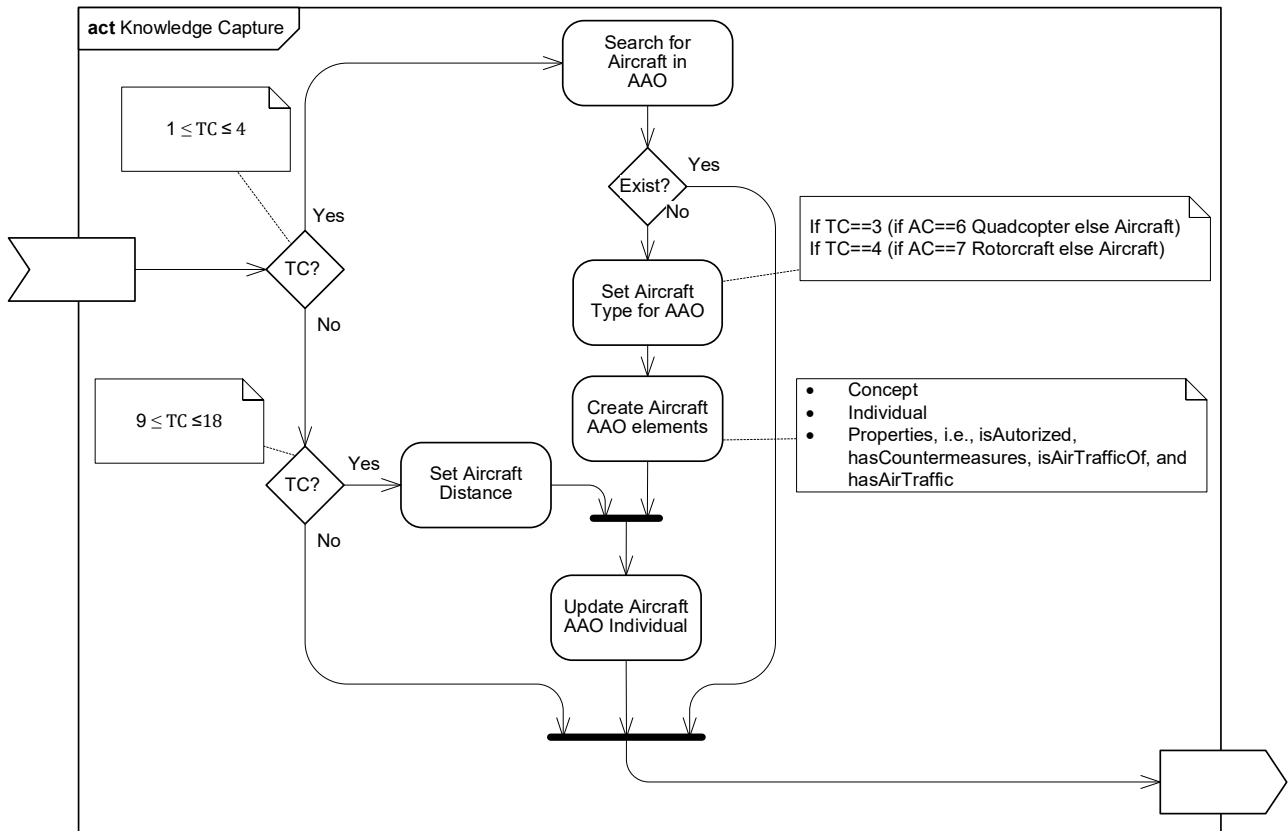


**Figure 10.** Knowledge capture process for the AAO.

The test consists of inspecting and check values in relevant variables following the flow indicated in Figure 7. The experimental results come from data gathered from commercial airplanes. Thus, not much hardware set up (other than the FlightAware dongle and its antenna [5]) is needed and the end results are like the ones expected although this functionality will be tested properly once all the requirements for it are in place. Figure 11 shows an example of the information obtained from the ADS-B device for a commercial airline airplane.

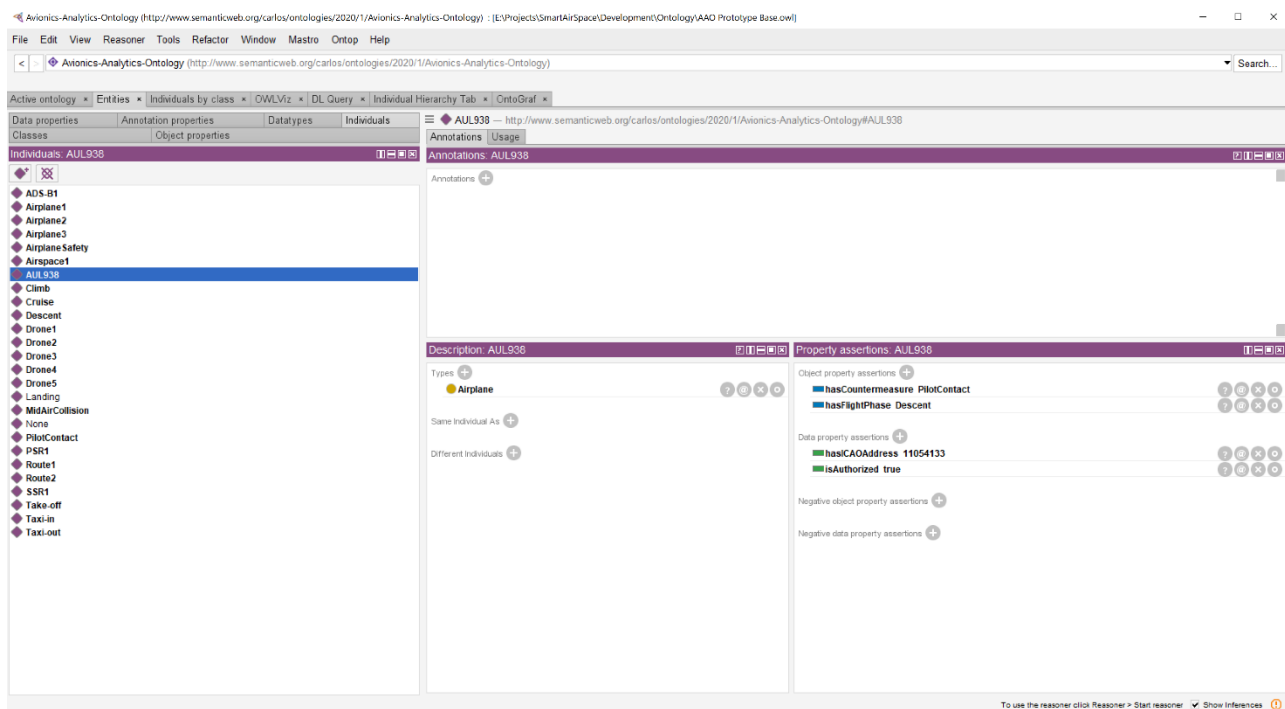


**Figure 11.** Details of aircraft on the AAO obtained from the ADS-B device.

The experimental results in Figure 11 are from Flight UA938 United Airlines; ICAO address: 11054133 in decimal (A8AC35 in hexadecimal). The airplane is in the flight phase “descent”. The test allows for the verification of the data and information gathered and incorporation of the aircraft details to the AAO as knowledge.

#### 4.1.2 Ontology-Display Software Testing

The aim of the testing of the ontology-display software integration is to check that the DSS actually manages to display results from the reasoning queries run on the AAO. This makes it possible to visualize SAW on the user interface of the DSS for stakeholders, e.g., pilots and Air Traffic Controllers (ATCs). The SAW is for the following aspects:

- Flight Safety Caution and its Cause
- Flight Safety Danger and its Cause
- Flight Safety Warning and its Cause

The process of picking up reasoning query results and displaying them must be in real time and in connection with the knowledge capturing process (just after it). Thus, the DSS software application runs this process continuously to make sure the SAW displayed is timely updated. The process is triggered by knowledge capturing process (driven by incoming ADS-B message received) as shown in Figure 9.

The verification of the ontology-display software integration is carried out by testing the above knowledge capability and inspecting the SAW information displayed on the DSS user interface. A simplified approach for testing assumes ADS-B messages (e.g., those from commercial airplanes) are from potentially hazardous drones if appropriate separations to assess distances are set as if the above airplanes are flying close a reference point on ground (playing the role of a taxied airplane ready for take-off). Figure 12 shows an example of the SAW information in which drones and aircraft have been specified in the AAO (manually added and not using ADS-B message information) to simulate an airspace situation.

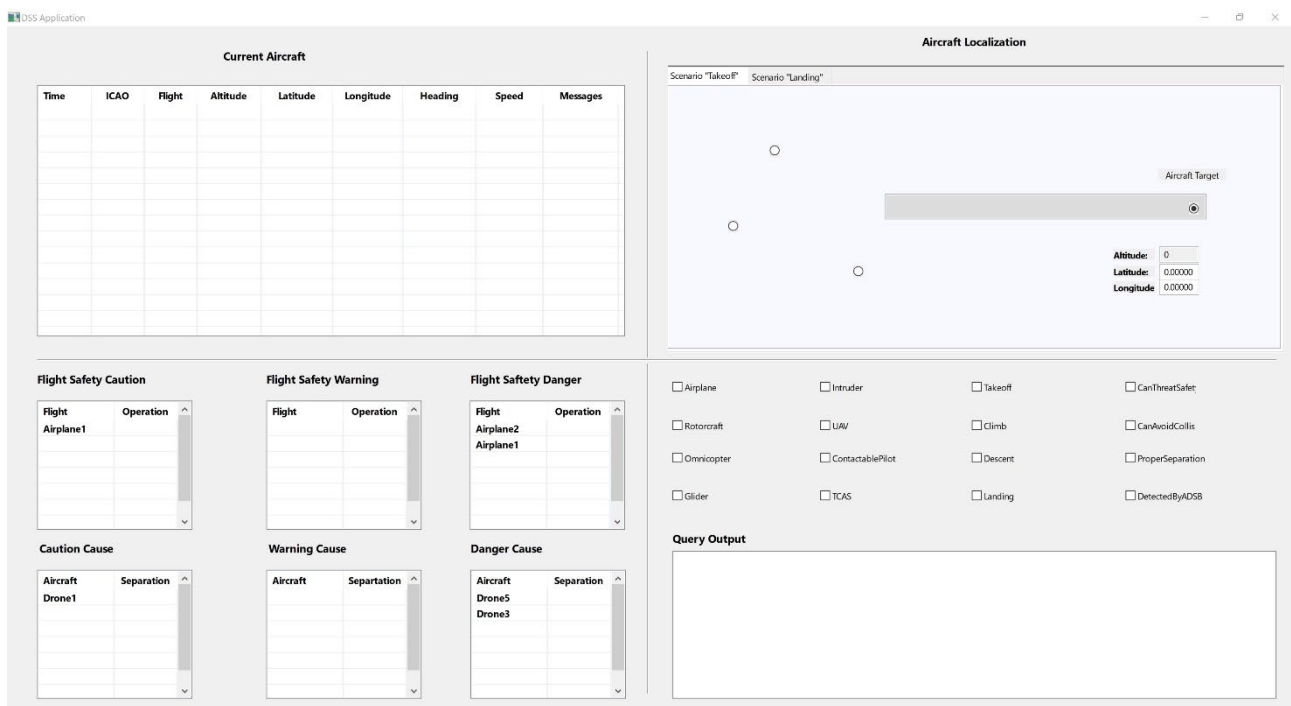


**Figure 12.** Results from the ontology-display integration test for flying vehicles added to the AAO.

The SAW displayed (bottom left quadrant of the screen) in Figure 12 shows (left to right) Drone 1 makes a “Flight Safety Caution” status on Aircraft 1 as the drone is flying close to the aircraft, but it does not mean any risk for the aircraft flight. Also, Drone 3 and Drone 5 are the ones putting on danger (“Flight Safety Danger” status) the flights of Airplane 1 and Airplane 2 as both drones are flying close to both aircraft.

Figure 13 shows an example of the SAW information in which ADSB-detected aircraft play the role of drones as if they are affecting the flight of Airplane 3 (a fictive airplane in question as a reference to check drones flying around).

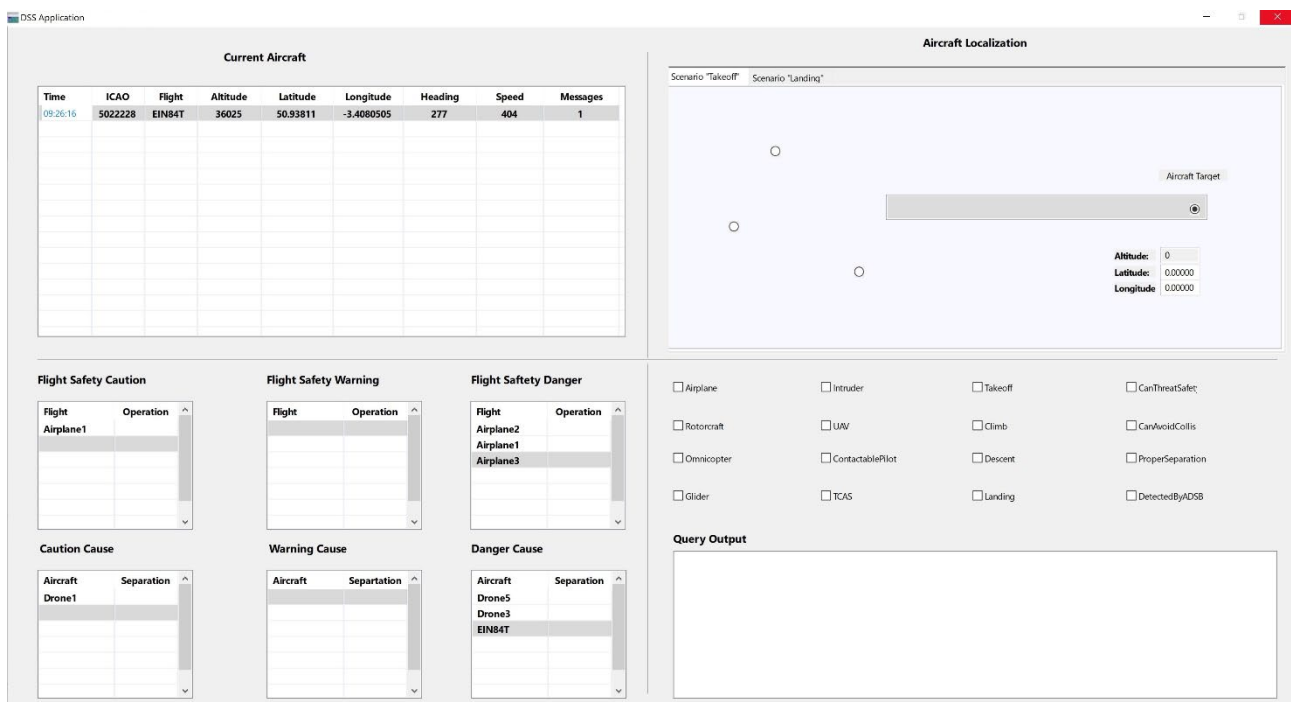


**Figure 13.** Results from the ontology-display integration test for aircraft playing as drones.

The experimental results in Figure 13 are from a scenario assuming Flight EIN84T (Aer Lingus); ICAO address: 5022228 in decimal (4CA214 in hexadecimal) plays a role as a drone that can potentially be a hazard for airplanes that are taxied in the end of a runway and about to take off (a fictive Airplane 3). Thus, the airplane is in the flight phase “take-off”. The distance is calculated from the above airplane and one that is assumed to be on ground and ready for take-off. Two situations are tested: (1) the distance between aircraft is larger than the required separation, and (2) the distance between aircraft is smaller than the required separation. The latter means the drone (commercial airplane playing the role of a drone) is flying close enough to the airplane taxied for take-off to raise a concern about flight safety. The test allows for the verification of the reasoning queries from the AAO, and the SAW information displayed in the DSS user interface.

## 4.2 Hardware Integration Testing

The testing of the hardware integration focuses on mounting the drone structures and relevant equipment on board. The former entails the assembly of the drone platform, and it is related to the mechanical part of the drones. The latter entails the connection of the electronic systems for control of the drone and communication of the drone with other devices. It is related to the drone avionics. Both integration processes and their testing include electromechanical components such as brushless motors and relevant sensors.

One of the drones used in the project is a X500-frame platform [6]; an electric-powered quadcopter called “Hornero” and coded RWD2 for the application scenarios. It is equipped with a Pixhawk 4 Mini flight controller, GPS antenna, telemetry equipment, four 2216 880KV brushless motors with 1045 propellers. Figure 14 shows an assembled X500 drone equipped with a SkyEcho 2 device [7] for ADS-B transmission.



**Figure 14.** X500 Quadcopter

The following tests have been carried out once the mechanical structure (frame) of the drone shown in Figure 14, the brushless motors and thrusters, and the electronic systems (power distribution module and flight controller) are mounted:

- Solidness of the drone frame by gently shaking the structure.
- Working of the brushless motors by switching them on and off.
- Attachment of the electronic systems on the frame by smoothly moving the drone as it is flying.

## 4.3 Software-Hardware Integration Testing

The testing of the software-hardware integration considers two combinations of software and hardware: (1) setup of the drones, (2) the link between the ADS-B transmitters-receivers and the software application, and (3) setup of the ICAO address on SkyEcho 2 devices.

The flight controller of the drones requires some basic settings for the drones to operate. The flight controller allows for autonomous navigation. However, manual control has been set for the first stage of trials. Figure 15 shows the user interface from the QGroundControl tool [8] that summarizes the drone configuration.

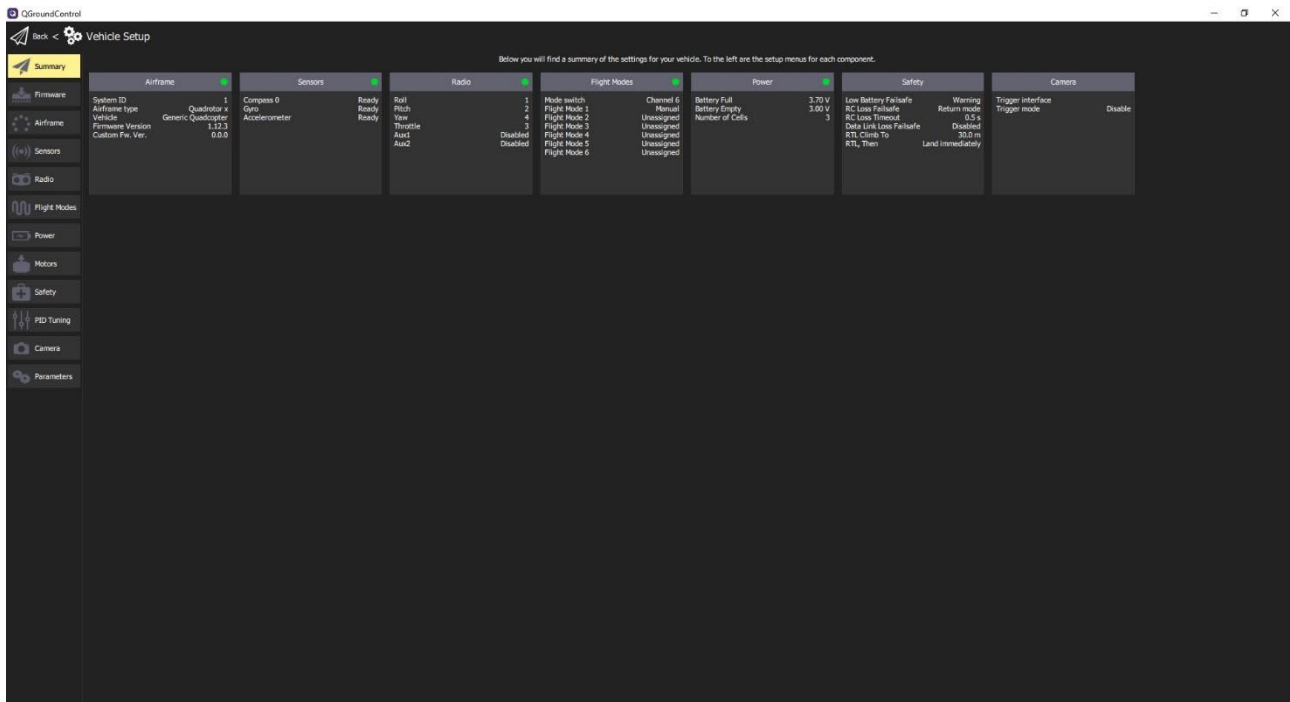


**Figure 15.** Summary of drone configuration (QGroundControl tool user interface)

Figure 16 shows the user interface from the QGroundControl tool to specify the airframe for drones.

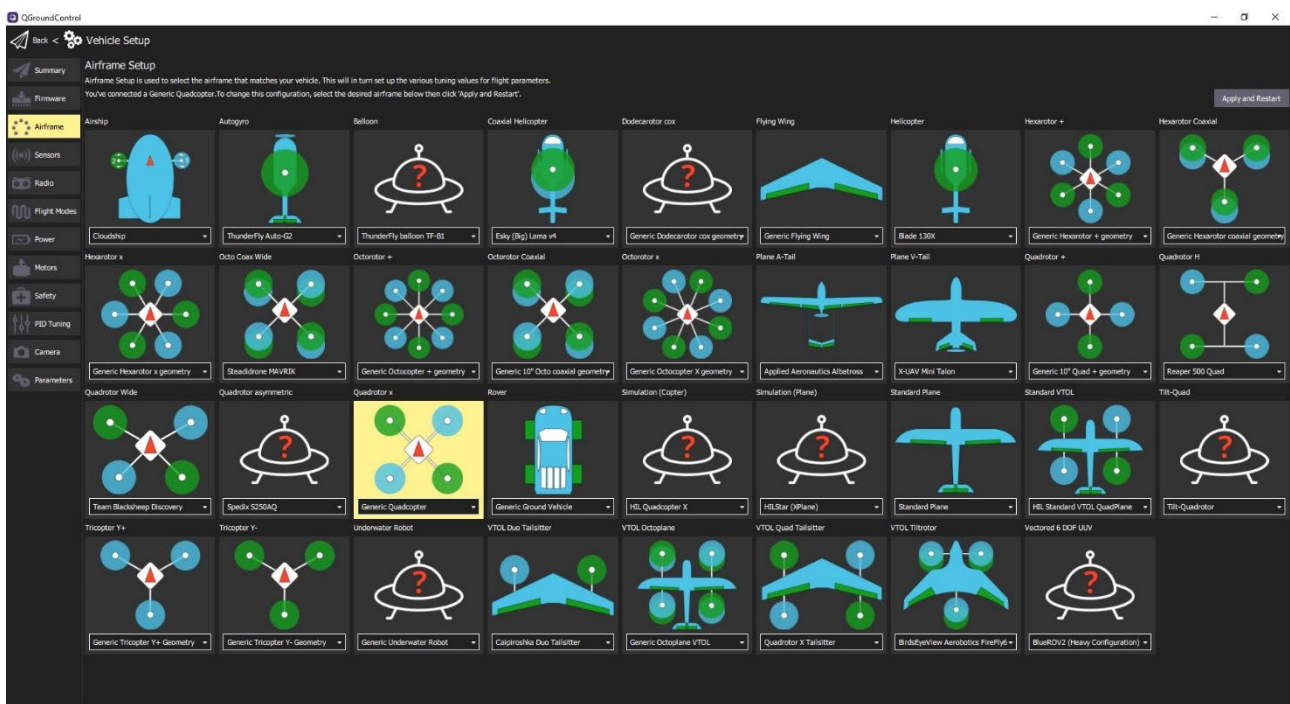


**Figure 16.** Airframe setup (QGroundControl tool user interface)

Data (including ADS-B packets) modulated (by aircraft transponder) at 1090 MHz are collected from the FlightAware dongle using the Dump1090 software decoder [9] which forwards the data through a server in port 30002. A client in the software application retrieves such data. The ADS-B server is installed in a computer which allows users to monitor the incoming packets. The ADS-B client is implemented and integrated in the software application, running a separate computer or the same computer that runs the DSS software application. The connection between the two computer is done by means of TCP/IP.

Tests on the above computer connection have been run to verify the correct data reception and transmission. Test cases and a list of planned test procedures for the prototype trials facilitates are presented in Section 3.4 from APR 2.

Figure 17 show the user interface to configure the ICAO address on the SkyEcho 2 devices.

**ADS-B Setup**  
 ✓ Configuration loaded.

**Setup**

|                      |                                                              |                              |                                                                                                               |
|----------------------|--------------------------------------------------------------|------------------------------|---------------------------------------------------------------------------------------------------------------|
| 1090ES Transmit:     | <input type="checkbox"/> Enable                              | Receiver Mode:               | <input checked="" type="radio"/> UAT<br><input type="radio"/> FLARM (EU ONLY)<br><input type="radio"/> 1090ES |
| ICAO Address (hex):  | <input type="text" value="4281FD"/>                          | Call sign:                   | <input type="text" value=""/>                                                                                 |
| FLARM ID (hex):      | <input type="text" value=""/>                                | Ownership Filter:            | <input type="checkbox"/> Filter ADS-B<br><input type="checkbox"/> Filter FLARM                                |
| Emitter Category:    | <input type="text" value="Light"/>                           | VFR Squawk:                  | <input type="text" value="7000"/>                                                                             |
| ADS-B In Capability: | <input type="checkbox"/> 1090ES <input type="checkbox"/> UAT | V <sub>SO</sub> (knots):     | <input type="text" value="10"/>                                                                               |
| Aircraft Length:     | <input type="text" value="L s 15 m"/>                        | Aircraft Width:              | <input type="text" value="W s 23 m"/>                                                                         |
| Lateral GPS Offset:  | <input type="text" value="Center"/>                          | Longitudinal GPS Offset (m): | <input type="text" value="0"/>                                                                                |
| SDA                  | <input type="text" value="1"/>                               |                              |                                                                                                               |

Apply

Reset to defaults

Main Page

**Figure 17.** Setting of the ICAO address

## 5 Updates on the Project Plan

This Section discusses the updates made on the project plan. They have been extensions and delays in some specific tasks as well as one of the tasks has been brought forward in the project.

### 5.1 Project Plan Overview

Three main updates have been done on the project plan: (1) some tasks have been extended; T3.1: Development of the Software Application as well as T3.2: Hardware-Software Integration, (2) Task 4.1 (T4.1) intitled “Definition of Test Cases” has been brought forward, and (3) some other tasks have been delayed; T4.2: Tests of Application Scenarios as well as T4.3: Analysis of Testing Results. Figure 18 shows the progress of the project in the reported year by means of a Gantt Chart.

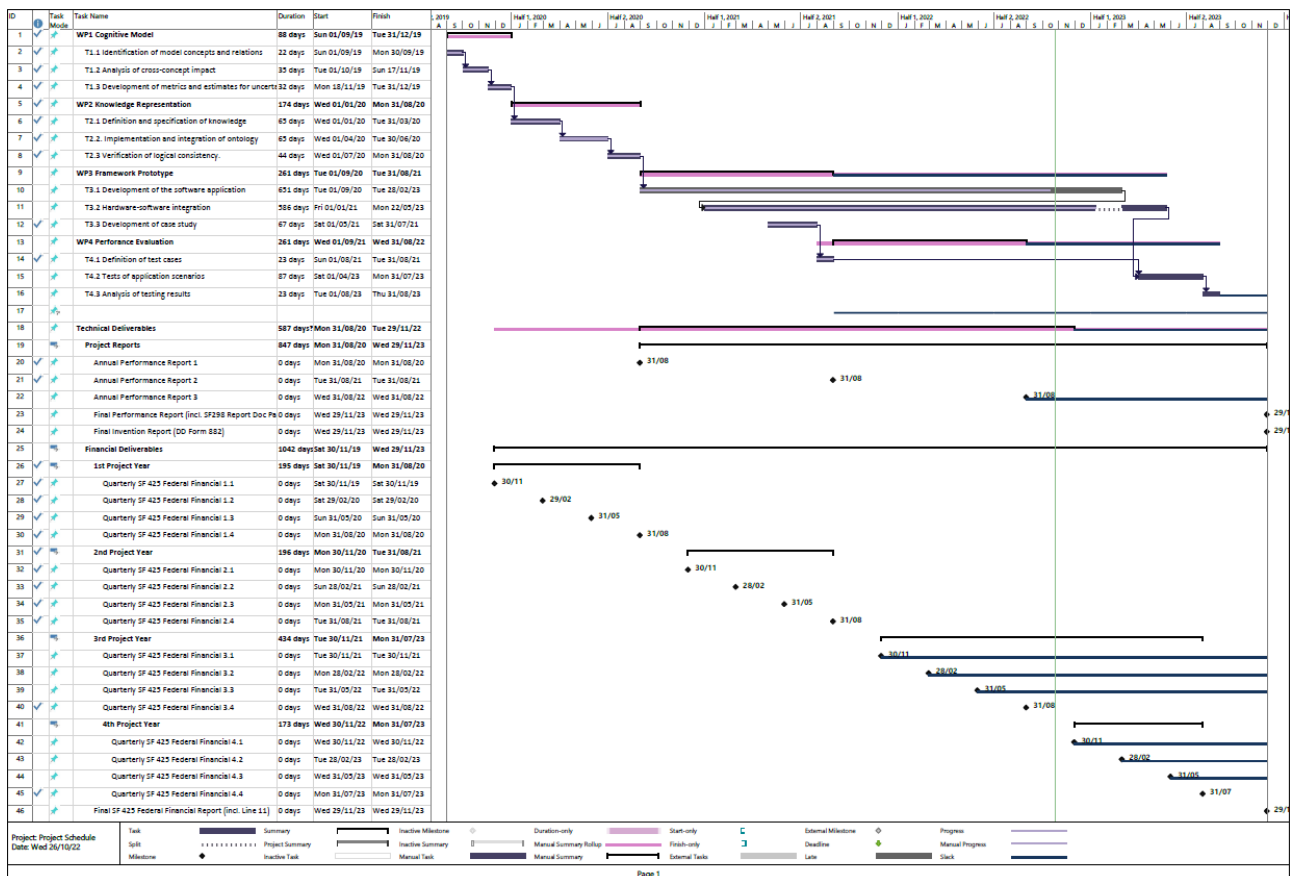


Figure 18. Project Gantt Chart.

Figure 18 also shows all the project reports as technical deliverables, including annual performance reports and quarterly financial reports.

## 5.2 T3.1: Development of the Software Application

Task 3.1 (T3.1) has been extended to implement and integrate pending functionalities as those discussed in Section 3 as well as to add and test extra planned capabilities that have not been possible to deal with because of the delay discussed in Section 1.

Modifications in T3.1 entails programming work to develop the following piece of software to be incorporated to the DSS software application:

1. **Display Screen:** programming work on a Java class (block in the Java package called “Display Screen” in Figure 19) entails the right half of the user interface. On the top right plane of the screen (Figure 12), real-time animation of the aircraft involved on the scenarios are meant to be displayed when experiments are carried out. On the bottom right plane of the screen (Figure 12), inputs from the user (e.g., ATC or pilot) are expected to be enabled so the user is able to input specific request as to queries on the AAO.
2. **LIDAR Sensing:** programming work on a new Java class (block called “LIDAR Sensing” in the Data Acquisition Java package in Figure 19) to implement functionality to deal with the data coming from the LIDAR device. It entails the development of algorithms to gather the LIDAR data and preprocess them as needed to make them available to the DSS software application.
3. **Information and Knowledge Fusion:** programming work on two new Java classes (a block called “Information Fusion” and another block called “Knowledge Fusion” in Figure 19). Both blocks are meant to merge inputs from the ADS-B and LIDAR sources as to aircraft detection and localization.

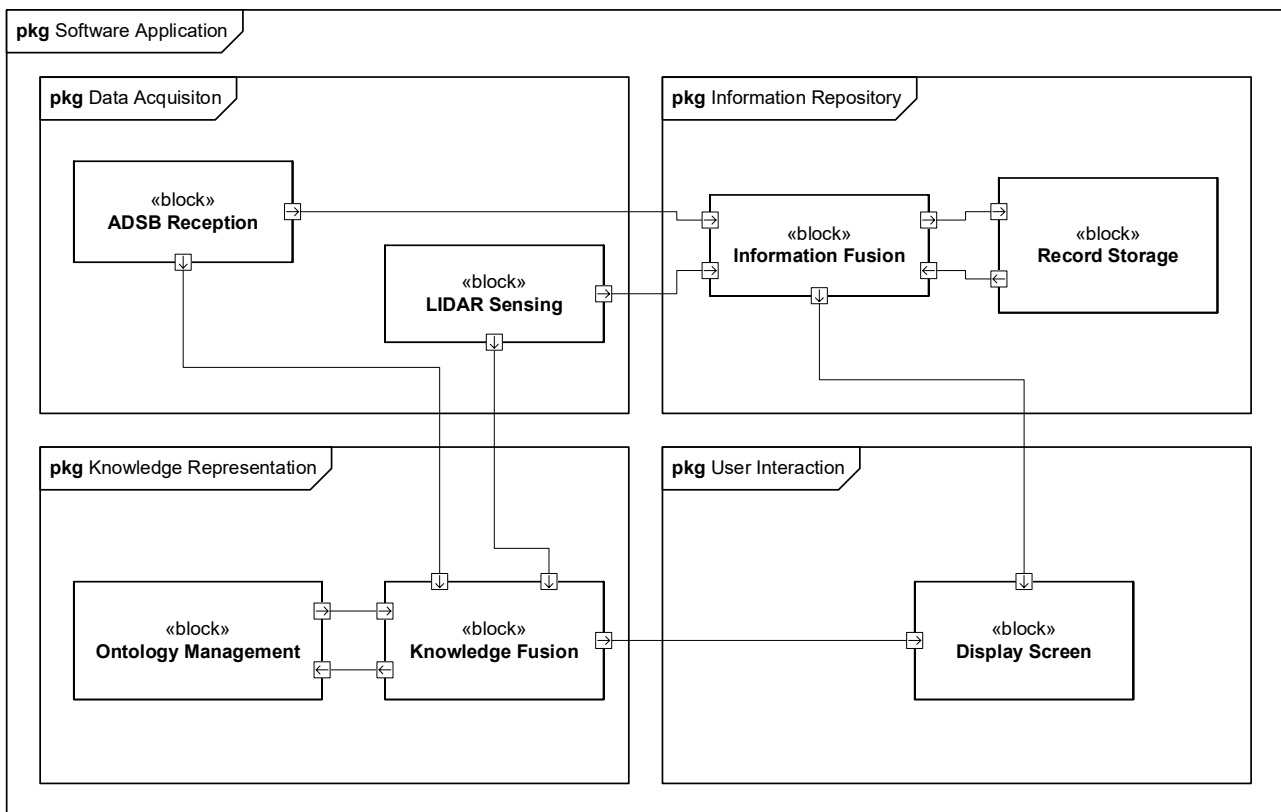


**Figure 19.** Interconnection between new blocks (Java classes) of the software application.

The new planned blocks (i.e., LIDAR Sensing, and Information and Knowledge Fusion) are meant to be developed as an extra and optional capability of the DSS software application. The LIDAR Sensing block is to allow for a comparison of sensing veracities (ADS-B vs LIDAR). The fusion blocks can either be included in the other block in the Java package (i.e., the Record Storage block merges Information Fusion block and the Ontology Management block merges Knowledge Fusion block) or even not being implemented.

### 5.3 T3.2: Hardware-Software Integration

Task 3.2 (T3.2) has been extended to integrate remaining hardware-software components (as those discussed in Figure 4). Modifications in T3.2 entails integration work to connect hardware components (from the DSS hardware platform) with each other as well as pieces of software (DSS software application) with the corresponding hardware.

The integration work entails the following hardware-software combinations:

1. Setting of new ADS-B devices.
2. Setting of new drones.
3. Setting of the LIDAR device.
4. Extra planned software capabilities such as the LIDAR Sensing block (discussed in previous Subsection) and the LIDAR device.

### 5.4 T4.1 Definition of Test Cases

In anticipation of the delay discussed in Section 1, T4.1 has been performed in WP3 and reported in APR 2. Test cases have been provided along with test procedures. T4.1 feeds T4.2 (Tests of Application Scenarios) which has been delayed in WP4 to be carried out in the four year of the project (granted extension).

The case study for AODSATM has application scenarios where the RWDs and the FWDs play different roles to simulate real airspace situations. Scenarios allow for different setups, including aircraft with contactable and non-contactable (remote) pilots.

Test cases for scenario 1 entail the FWDs either taking off or landing while the RWDs will be flying nearby the FWDs compromising flight safety. Test cases for scenario 2 entail the FWDs flying in an airspace where RWDs are flying close to the FWDs increasing chances of potential air collisions. The scenario tests also create an opportunity to check potential cyber threats such as jamming and spoofing attacks (including UAV swarm) as well as incorporation of information about weather conditions.

## **5.5 T4.2: Tests of Application Scenarios**

Task 4.2 (T4.2) is not only fed by Task 4.1 (T4.1) titled “Definition of Test Cases” which has been successfully completed but also by T3.2 titled “Hardware-Software Integration” which in turn depends on T3.1 (Development of the Software Application). T4.2 has been delayed as one of the previously required tasks (T3.2) has not finished due to the delay discussed in Section 1.

In preparation for the tests (trials with the framework prototype) and as part of T4.2, some paperwork has been done to obtain authorization from the relevant UK aviation authority (CAA) to fly drones in outdoor locations; ID flyer and ID operator as well as a British Model Flying Association (BMFA) membership which include a necessary insurance for the drones. This has also included the obtentions of required ICAO addresses for the ADS-B devices as well as permissions to transmit the ADS-B signal for which an Aircraft Radio license has been obtained.

The test cases from T4.1 consist of simulations (by means of a down-scaled framework prototype) of real ATM situations in scenario 1 and 2. The AODSATM can automatically detect (through grounded/airborne ADS-B and LIDAR) the above situations and autonomously advise accordingly. This advisory outcome can be communicated to the stakeholders, e.g., it can be visualized by ATCs to support their decisions on the above situations (also, aviators and pilots of remotely piloted aircraft could make use of this information).

The setup of the application scenarios from the use cases allows for verification of the surveillance systems for proper data acquisition as well as the verification of the SAW for different airspace situations in the application scenarios. The defined test procedures and test cases in APR 2 also allow for the refinement of the AAO by means of debugging any remaining malfunction of the AAO and simplifying the AAO when possible.

## **5.6 T4.3: Analysis of Testing Results**

Task 4.3 (T4.3) has been delayed as experimental results cannot be analyzed if T4.2 (Tests of Application Scenarios) has not been performed. T4.3 is scheduled to start just after T4.2 is finished although some preliminary analysis can be carried out as tests progress.

The analysis of the experimental results from testing is based on the test procedures and cases defined in T4.1. The analysis takes into account requirements from the fieldwork (prototype-based trials). However, it also considers any limitation or constraint due to operational restrictions within the context that tests are done, e.g., weather conditions and flight regulations.

# **6 The Way Travelled and Way Forward**

This section provides a discussion on an assessment on the research carried out in the third year of the project as well as next research steps for the fourth year of the project (granted extension).

## **6.1 Project Progress Assessment**

The work reported in this deliverable is from extended tasks from WP3 (i.e., T3.1 Development of the Software Application and T3.2 Hardwar-Software Integration) and work partially done from WP4 tasks (i.e., T4.2 Test of Application Scenarios). It has been on further development of the DSS software application and preliminary arrangements for the setup and evaluation of the application scenarios and the analysis of experimental results. This report also discusses the work in advance carried out for T4.1.

Programming work has done on the DSS software application; AAO management and user interface functionality. This has allowed the AAO to interact with the operational environment of the DSS as well as to show results on the display screen of the user's computer. While these two functions have been successfully implemented in, integrated to, and tested in the DSS software application, the coding in Java has faced delays as the Java library (OWL API [10]) for ontology management still has programming bugs that have diffculted the proper progress in the software development task (T3.1).

The preparatory work in T4.2 (Tests of Application Scenarios) has mainly been to have in place relevant documentation and permissions to carry out outdoor trials. The related paperwork has also involved hold-ups in responses to queries. This is in addition to the limitations because of the pandemic restrictions and comeback to regular activities.

Overall, some progress has been made but it has been affected by delays due to causes that are not directly coming from the allocated resources. They are rather from the pandemic restrictions and CAA communications.

## 6.2 Next Research Work

While an Avionics Analytics Ontology (AAO) has been developed as an essential cognitive engine of a Decision Support System (DSS) for avionics analytics in the first year of the project (WP1 and WP2), there is still some work pending from second year of the project (WP3) for T3.1 (Development of the Software Application) in the fourth year of the project (granted extension). Such a programming work effort is described in Subsection 5.2. Additionally, the remaining work from T4.2 and T4.3 in WP 4 will be carried out.

The evaluation will be carried out in outdoor facilities (discussed in APR 2) as ADS-B devices require GPS signal to work. It will be performed according to the model aircraft regulations from the CAA (CAP 658: Model Aircraft: A Guide to Safe Flying) and general air navigation regulations (CAP 393: The Air Navigation Order 2016 and Regulations and the). Data will be gathered from the outdoor trials to then be analyzed and reported in the Final Performance Report (FPR).

In general, the next stage in the fourth year of the project will be to complete WP3 Tasks and WP4 Tasks. This will also allow for improvement and refinement of the cognitive model (WP1) and the AAO (WP2).

## References

- [1] F. Baader, I. Horrocks, U. Sattler, "Description Logics", Ch. 3 in Handbook of Knowledge Representation, Elsevier, 2007. Available at <http://www.cs.ox.ac.uk/ian.horrocks/Publications/download/2007/BaHS07a.pdf>.
- [2] J. C. Beall, G. Restall, Logical Consequence The Stanford Encyclopedia of Philosophy, Fall 2009.
- [3] R. M. Keller, The NASA Air Traffic Management Ontology, Technical Documentation, NASA/TM-2017-219526, 2017.
- [4] S. Wilson, R. Suzic, and S. Van der Stricht, "The SESAR ATM information reference model within the new ATM system," in 2014 Integrated Communications, Navigation and Surveillance Conference (ICNS) Conference Proceedings, 2014.

- [5] FlightAware Pro Stick and Pro Stick Plus - High Performance USB SDR ADS-B Receivers, available at <https://uk.flightaware.com/adsb/prostick>.
- [6] Holybro X500 Pixhawk 4 Mini 500mm Wheelbase Frame Kit Combo 2216 880KV Motor 1045 Propeller for RC Drone, assembly guide available at [http://www.holybro.com/manual/Holybro\\_X500\\_FrameKit\\_AssemblyGuide.pdf](http://www.holybro.com/manual/Holybro_X500_FrameKit_AssemblyGuide.pdf).
- [7] SkyEcho 2 Installation and Pilot's Guide, available at <https://uavionix.com/downloads/skyecho/SkyEcho-User-and-Installation-Guide.pdf>.
- [8] Ground Control Station, available at <http://qgroundcontrol.com>.
- [9] Dump 1090: a Mode S decoder specifically designed for RTLSDR devices, available at <https://github.com/antirez/dump1090>.
- [10] The OWLAPI, available at <https://owlapi.sourceforge.net>

# **SmartAirSpace**

**Cognitive Decision Support for Avionics Analytics**

## **Performance Report**

### **Performance Evaluation (Part II)**

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FA9550-19-1-7038

1 Sep 2022 – 31 Aug 2023

## Summary

This report presents the research carried out within the fourth year (extension) of the project entitled “Cognitive Decision Support for Avionics Analytics” supported by the Air Force Office of Scientific Research under award number FA9550-19-1-7038. Overall, it reports the progress on Work-Package (WP) 4 tasks which have been unfortunately affected by delays due to the pandemic restrictions and paperwork required by the UK Civil Aviation Agency (CAA). The report entails outputs and outcomes from WP4 which mainly involves technical preparation and testing trials to fly the project’s drones as part of activities for the outdoor trials on the framework prototype developed in WP3 and reported on APR 2. The application software of the Decision Support System (DSS) used for the trials includes the Avionics Analytics Ontology (AAO) developed in WP2 and reported on APR 1. The work presented also includes technical details of different stages of the testing process (i.e., pre/in/post-missions) for several configurations of the framework prototype of the AAO-based DSS for ATM (AODSATM) proposed by the project. A discussion on the experimental testing results is also presented.

## Dissemination

### Publications

The research in the fourth year of the project has made possible the publication of three papers: two conference papers and a journal paper as follows.

- C. C. Insaurralde et al., “Avionics Analytics Ontology Experimental Results from Preliminary Tests of a Decision Support System for Avionics Analytics”, 24th Integrated Communications, Navigation and Surveillance Conference, Herndon, Virginia, USA, Apr 2024.
- C. C. Insaurralde et al., “Experimental Situation-Awareness Results from Downscaled Framework Prototype of Drone-Based Takeoff Scenarios”, Aerospace, MPDI, to be submitted.

### Sessions

- Distinguished Lecture, , some material for lecture on “Ontological Decision-Making Support for Air Traffic Management”, available at <https://ieee-aess.org/presentation/lecture/ontological-decision-making-support-air-traffic-management>, Nov 2023.
- AESS FREE Tutorial, “Intelligent Cyber-Physical Systems for Integrated Air and Space Transport Operations”, some material for Section 6, <https://2023.dasconline.org/tutorials>, Oct 2023.

### Patents

- Preparing an application for a US Patent for the AAO.

## **Acknowledgement**

Thanks very much to the University of the West of England (UWE), Bristol which allowed me to work on this project and the Research, Business and Innovation (RBI) team for helping with paperwork and administration of the project. Special thanks for the UWE Finance Office that helped with the purchases for the project.

Very big thanks to the AFOSR for trusting in this project and providing the financial support.

Hugh thanks to the South Wales Radio Control Society (SWRC) and members (David, Mark, and Ian) who helped to run the field trials by supporting and flying the RC drones as needed.

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## Abbreviations and Acronyms

|         |                                                               |
|---------|---------------------------------------------------------------|
| AAO     | Avionics Analytics Ontology                                   |
| ADS-B   | Automatic Dependent Surveillance-Broadcast                    |
| AODSATM | AAO-based DSS for ATM                                         |
| APR     | Annual Performance Report                                     |
| ATC     | Air Traffic Controller                                        |
| ATM     | Air Traffic Management                                        |
| BMFA    | British Model Flying Association                              |
| CAA     | Civil Aviation Authority                                      |
| DSS     | Decision Support System                                       |
| FAA     | Federal Aviation Administration                               |
| FWD     | Fixed-Wing Drone                                              |
| ICAO    | International Civil Aviation Organization                     |
| NASA    | National Aeronautics and Space Administration                 |
| NextGen | Next Generation Air Transportation System                     |
| OWL     | Ontology Web Language                                         |
| RDF     | Resource Description Framework                                |
| RWD     | Rotary-Wing Drone                                             |
| SAW     | Situation AWareness                                           |
| SESAR   | Single European Sky ATM Research                              |
| UAS     | Unmanned Aerial System                                        |
| UAV     | Unmanned Aerial Vehicle                                       |
| URREF   | Uncertainty Representation and Reasoning Evaluation Framework |
| GPS     | Global Position System                                        |
| FS      | Flight Safety                                                 |
| FSC     | Flight Safety Caution                                         |
| FSW     | Flight Safety Warning                                         |
| FSD     | Flight Safety Danger                                          |
| MAV     | Manned Air Vehicle                                            |
| SWRCS   | South Wales Radio Control Society                             |
| OTR     | Office Trial Run                                              |
| GTR     | Garden Trial Run                                              |
| PTR     | Park Trial Run                                                |
| FTR     | Field Trial Run                                               |

## 1 Introduction

Grant FA9550-19-1-7038 for a project entitled “Cognitive Decision Support for Avionics Analytics” (SmartAirSpace) has been granted a one-year extension as stated in Performance Report (APR) 3 – Part F. Hence, the outdoor trials from WP4 (using the project’s drones) have been delayed being carried out in year four of the project. Thus, related activities from WP4 are reported on APR 3 – Part II (current document).

A cognitive model has been designed in WP1 from which the knowledge representation has been realized by means of the Avionics Analytics Ontology (AAO) developed in WP2. Both WPs have been reported on APR 1. The AAO is the main driver of a Decision Support System (DSS) for avionics analytics in Air Traffic Management (ATM). The AAO knowledge-based approach is meant to assist Air Traffic Controllers (ATCs) and pilots to deal with the ever-increasing workload due to unprecedented complex volume of data from airspace situations, challenging for example safety and cybersecurity. Also, a framework prototype, as a proof-of-concept framework, has been developed in WP3 as reported on APR 2. The software application entails the DSS application (AAO, its managing mechanisms to access query and retrieve query results information from the AAO, and the user interface to display the AAO querying results to the system stakeholders) and an Automatic Dependence Surveillance-Broadcast (ADS-B) collection application. The hardware platform consists of two rotary-wing drones and two fixed-wing drones equipped with ADS-B, and a computer that runs the DSS and ADS-B collection software application. The computer plays the role of a ground operation station to monitor ADS-B communications for aircraft detection. WP4 provides an extensive performance evaluation of the framework developed in WP3. The results presented in APR 3 – Part F are mainly from verifying additional functionalities on the software application and setup of the hardware platform.

This document reports on the research carried out in the fourth year of the project. It entails the work done from the WP4 tasks that cannot be done in the third year of the project due to the incurred delays as discussed at very beginning of this Section. The granted extension for the Grant has allowed for the completion of the WP4 tasks which outcomes complement the results presented in the previous report (APR 3 – Part F) and are now reported in this report.

The rest of the report is organized as follows. Section 2 briefly recaps the use cases and application scenarios considered in the project. Section 3 presents details of the set of testing trials to evaluate the framework prototype. Section 4 discusses the office-testing trials carried out and the experimental results obtained from them. Section 5 discusses the garden-testing trials carried out and the experimental results obtained from them. Section 6 discusses the park-testing trials carried out and the experimental results obtained from them. Section 7 discusses the field-testing trials carried out and the experimental results obtained from them. The final section provides a discussion on an assessment on the research carried out in the fourth year of the project as well as next research steps for steps aligned with this project.

## 2 Case Study

This Section recaps the application scenarios by recalling use case 1 (scenario 1.1 and scenario 1.2) and use case 2 (scenario 2.1 and scenario 2.2) that are introduced in Section 3 of APR 2.

### 2.1 Use Case 1: Application Scenario 1.1

The flight phase considered in application Scenario 1.1 is the take-off of an airplane (Manned Air Vehicle or MAV) from a runway while drones (UAVs) are flying nearby the runway with a potential chance of becoming dangerous for the airplane flight as they are considered “intruders”. The airplane is assumed to be known as an air vehicle, e.g., it could well represent a commercial aircraft such a Boeing 737 from an airliner. The drones are recreational quadcopters, and a fixed-wing drone. Figure 1 shows application Scenario 1.1 from the aircraft take-off use case 1.

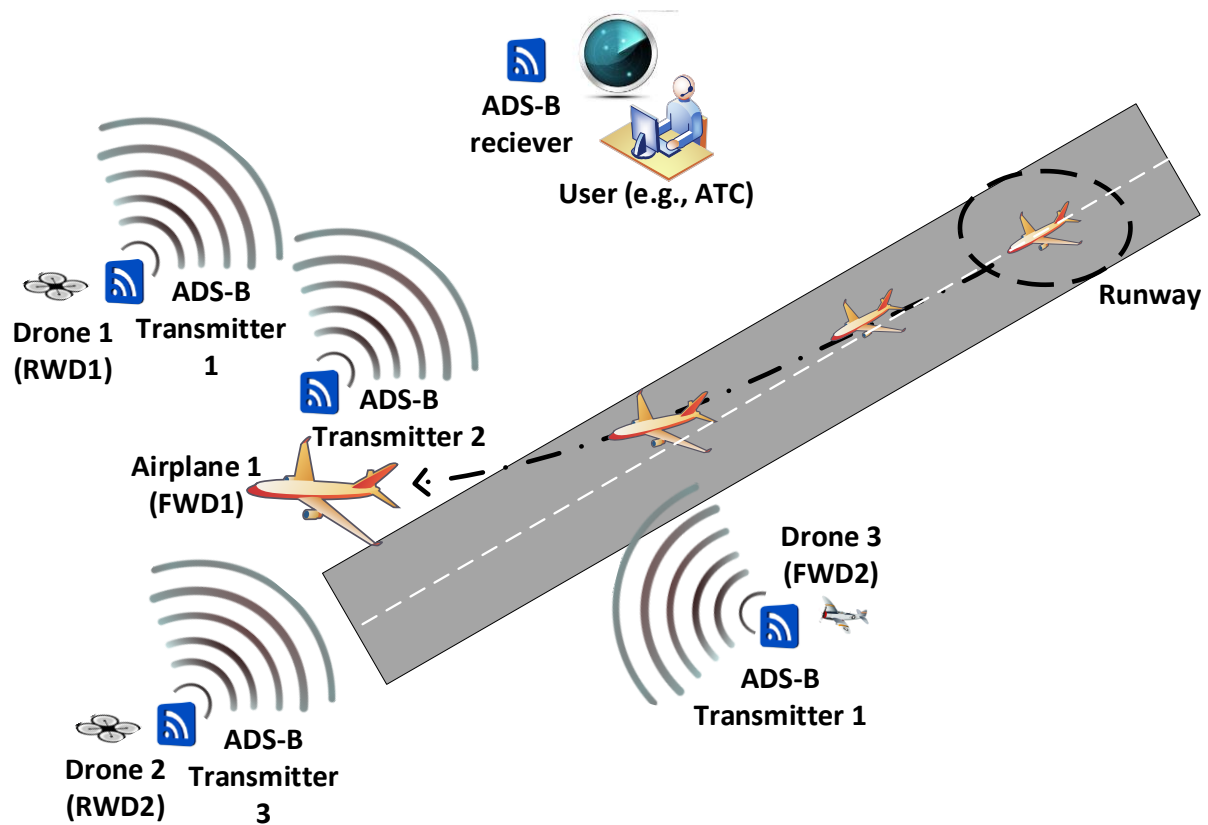


**Figure 1.** Airspace situation in aircraft take-off application scenario 1.1.

One of the three drones has a contactable remote pilot while the remaining drones have a non-contactable remote pilot. The contactable remote pilot can cooperate with the ATC to avoid collision with the airplane. In addition, the drones that have no pilot contact are equipped with ADS-B. The airplane also has ADS-B as per aviation regulation. The initial position of the airplane is taxiing in one end of the runway, and it is ready for take-off. The drones are initially located as shown in Figure 1.

Aircraft localization is essential for collision avoidance and is carried out by means of surveillance radars and cutting-edge technologies such as ADS-B and by LIDAR technology. Surveillance systems based on ADS-B and LIDAR devices (ADSB transmitters/receiver and PSR) are shown in Figure 1.

## 2.2 Use Case 1: Application Scenario 1.2

The flight phase considered in application Scenario 1.2 is the landing of an airplane (manned air vehicle) to a runway while drones (UAVs) are flying nearby the runway with a potential chance of becoming dangerous for the airplane flight as they are considered “intruders”. The airplane is assumed to be a known air vehicle, e.g., it could well represent a commercial aircraft such as an Airbus 350 from an airliner. The drones are two recreational quadcopters, and a fixed-wing drone. Figure 2 shows the Aircraft landing application Scenario 1.2.

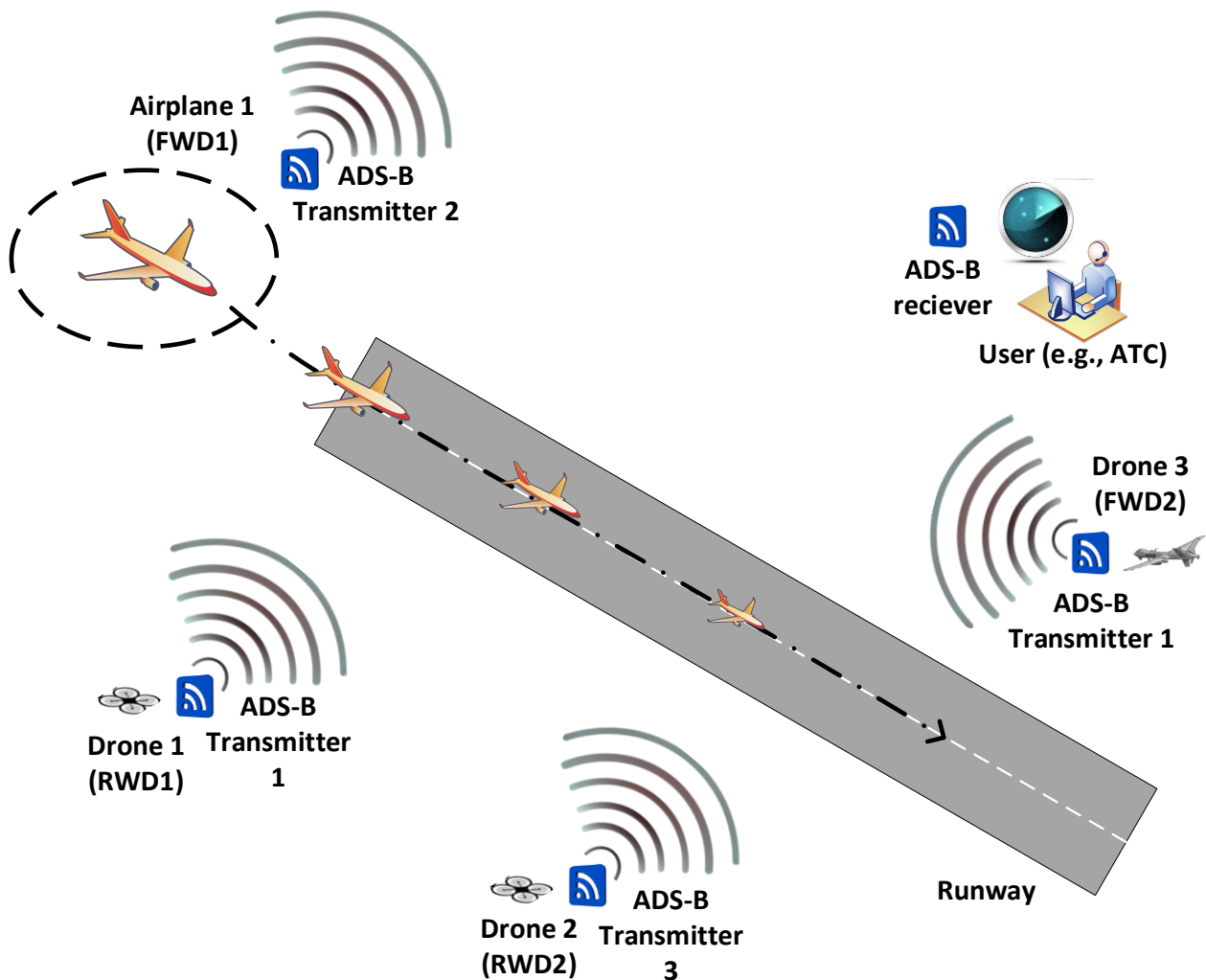


**Figure 2.** Airspace situation in aircraft Landing application scenario 1.2.

Two of the three drones have a contactable remote pilot while the remaining drone has a non-contactable remote pilot. The contactable remote pilots can cooperate with the ATC to avoid collision with the airplane. In addition, the drones that have no pilot contact are equipped with ADS-B. The airplane also has ADS-B as per aviation regulation. The initial position of the airplane is approaching the runway, and it is getting ready for landing. The drones are initially located as shown in Figure 2. Aircraft localization is carried out by means of surveillance radars and cutting-edge technologies such as ADS-B, and by LIDAR technology. Surveillance systems based on ADS-B and LIDAR devices (ADS-B transmitters/receiver and PSR) are shown in Figure 2.

### 2.3 Use Case 2: Application Scenario 2.1

The flight phase considered in application Scenario 2.1 is the climbing of an airplane (manned air vehicle) from a runway while drones (UAVs) are flying nearby the runway with a potential chance of becoming dangerous for the airplane flight as they are considered “intruders”. The airplane is assumed to be known air vehicle, e.g., it could well represent a commercial aircraft such a Boeing 747 from an airliner. Drones are two recreational quadcopters, and a fixed-wing drone. Figure 3 shows application Scenario 2.1 of the use case 2.

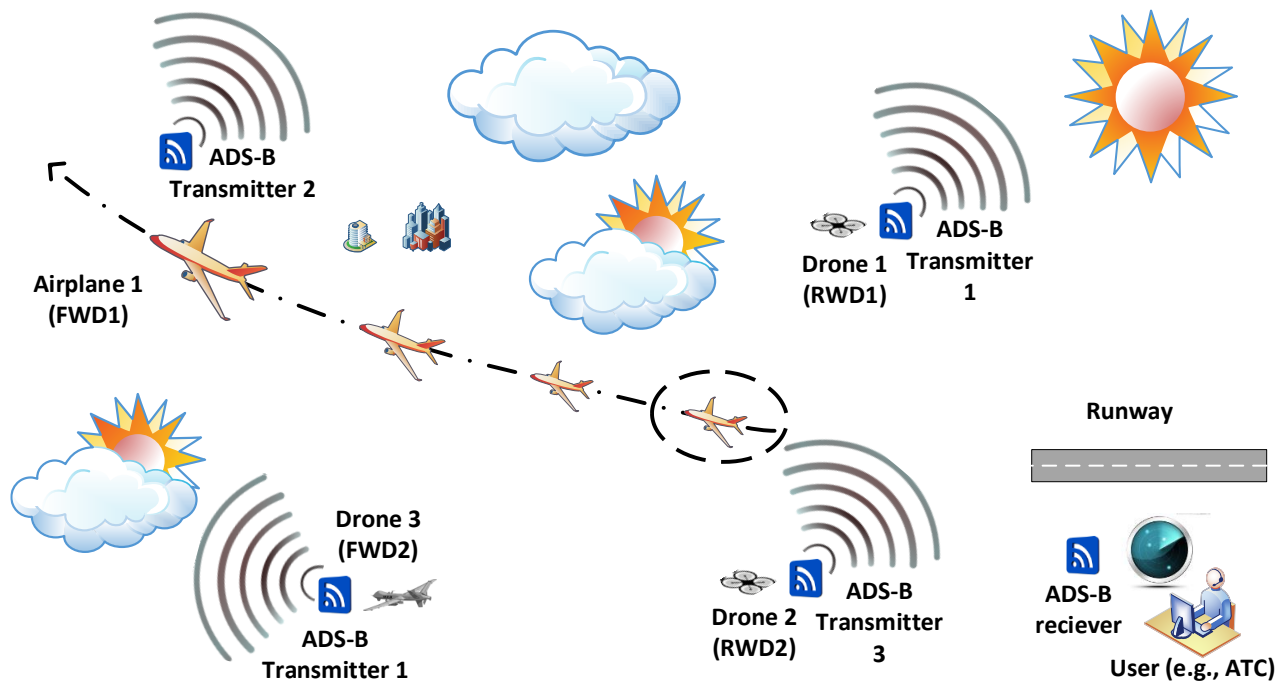


**Figure 3.** Airspace situation in aircraft climbing application scenario 2.1.

One of the three drones has a contactable remote pilot while the remaining drones have a non-contactable remote pilot. The contactable remote pilot can cooperate with the ATC to avoid collision with the airplane. In addition, the drones that have no pilot contact are equipped with ADS-B. The airplane also has ADS-B as per aviation regulation. The initial position of the airplane is taxied in one end of the runway, and it is ready for take-off. The drones are initially located as shown in Figure 3.

## 2.4 Use Case 2: Application Scenario 2.2

The flight phase considered in application Scenario 2.2 is the descending of an airplane (manned air vehicle) to a runway while drones (UAVs) are flying nearby the runway with a potential chance of becoming dangerous for the airplane flight as they are considered “intruders”. The airplane is assumed to be known air vehicle, e.g., it could well represent a commercial aircraft such an Airbus 380 from an airliner. Drones are two recreational quadcopters, and a fixed-wing drone. Figure 4 shows application Scenario 2.2 of the use case 1.

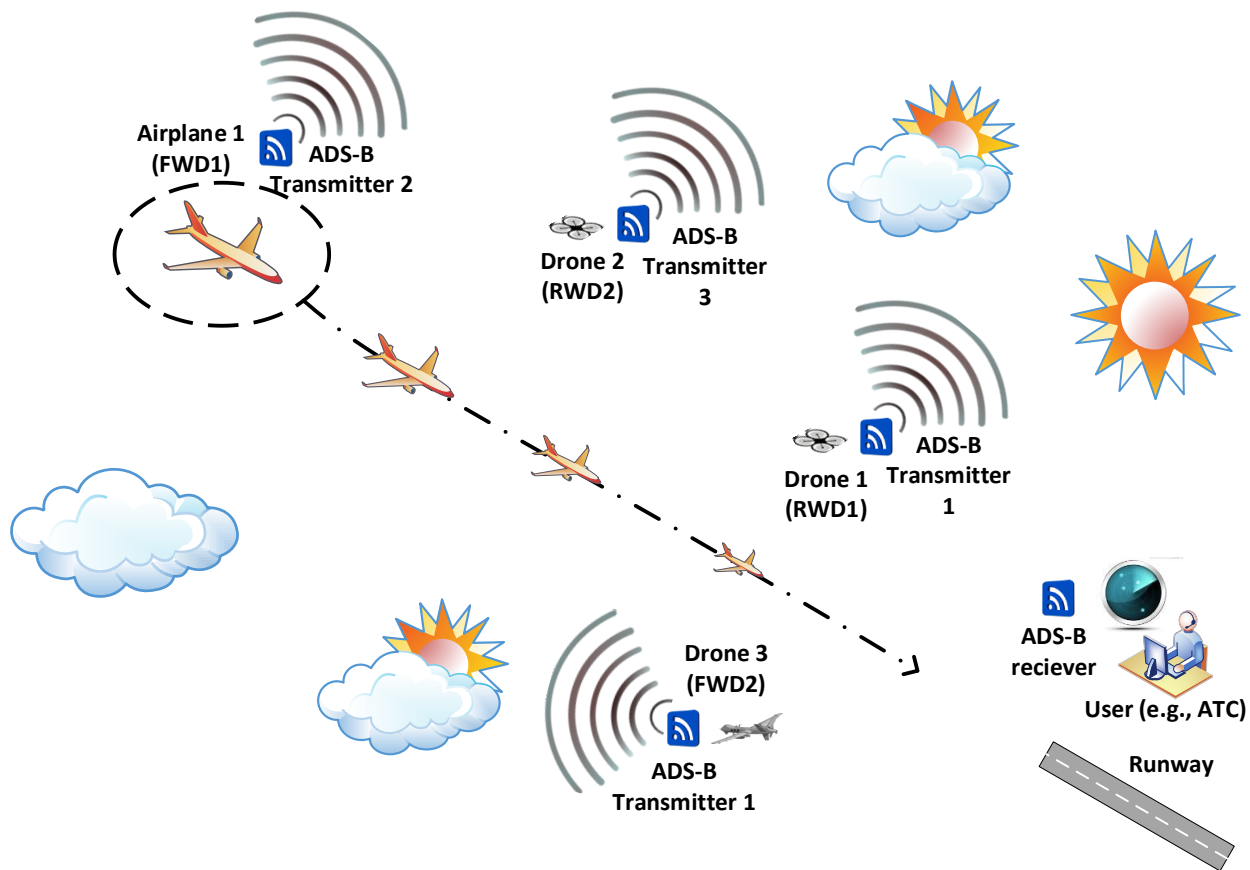


**Figure 4.** Airspace situation in aircraft descending application scenario 2.2.

Two of the three drones have a contactable remote pilot while the remaining drone has a non-contactable remote pilot. The contactable remote pilots can cooperate with the ATC to avoid collision with the airplane. In addition, the drones that have no pilot contact are equipped with ADS-B. The airplane also has ADS-B as per aviation regulation. The initial position of the airplane is approaching the runway, and it is getting ready for landing. The drones are initially located as shown in Figure 4.

### 3 Evaluation of the Framework Prototype

This section recalls the analytics behind the planned testing and introduces the trials as well as the different configurations of the framework prototype to carry out the tests.

#### 3.1 Testing Analytics

The application scenarios of the use cases from the project's case study presented in section 2 are meant to reproduce or simulate realistic airspace situations. They consider factors related to loss of separation that influences air-navigation safety and collision avoidance as a mechanism to mitigate problems caused by such factors. Hence, the operational context is based on airspace situations where the challenge is to assure a safe airspace by avoiding collision between aircraft (manned/unmanned ones).

Figure 5 shows a flowchart for the logic of the analysis carried out by the DSS to be aware of any potential air collision between aircraft.

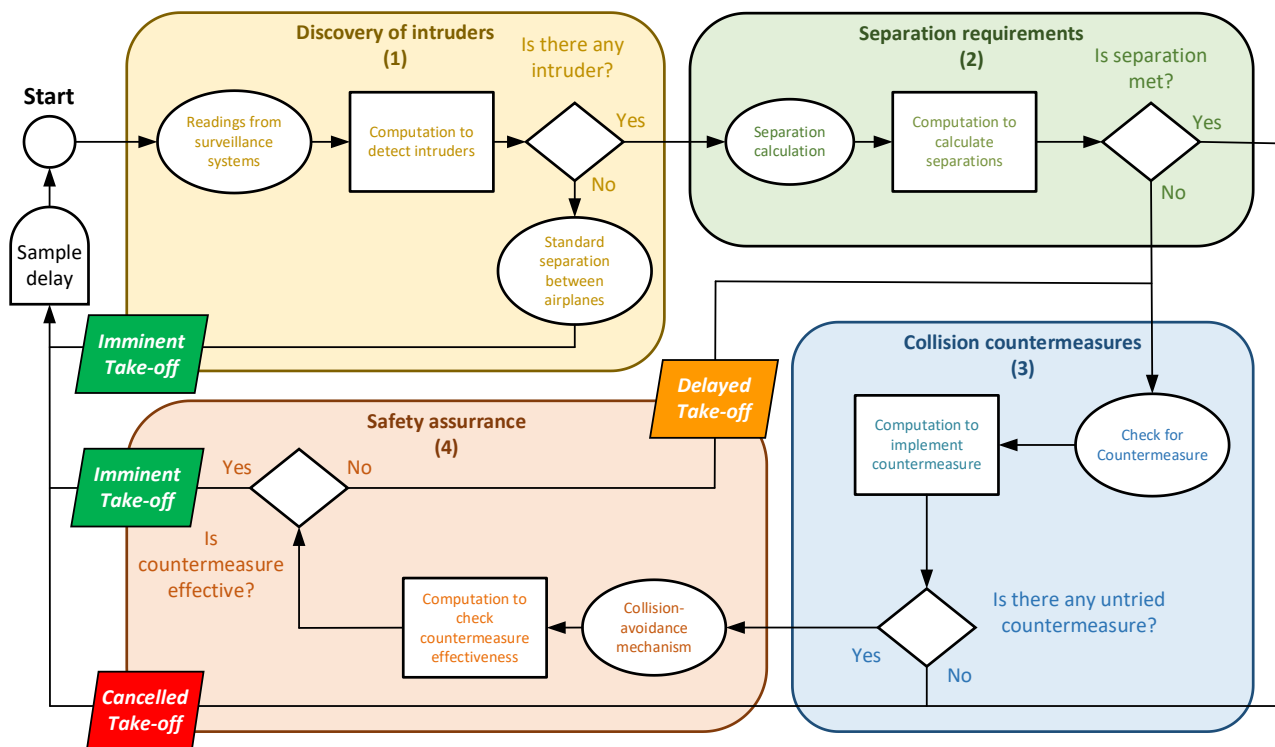


**Figure 5.** Analytical process for identification of potential air collision.

The DSS is basically a software application that is meant to work alongside an ATC who oversees and controls the airspace based on input information from sensors (e.g., radars) and receptors (e.g., ADS-B receivers) and communicates with pilots. It analyzes inputs and produces a SAW output to support the decisions made by the ATC for a given airspace situation. The DSS software application runs the analytical process in Figure 5 continuously in the application scenarios.

The framework prototype is tested by means of testing trials that implement the application scenarios presented in Section 2 and are defined and specified for different places (locations). The trials are incrementally progressive tests of functionalities and operation of the framework prototype. They are as follows:

- **Office-Testing Trials:** the purpose of these trials is to initially test basic functionalities and operation of the framework prototype as to providing SAW for invented airspace situations and supposed aircraft involved in application scenario 1.1 (before moving to the next evaluation level; garden's trials). These trials are carried out without using physical drones equipped with an ADS-B transmitter due to the payload limitation and weight of the drones to fly in residential areas. A full description of these trials is in section 4.
- **Garden-Testing Trials:** the purpose of these trials is to test basic functionalities and operation of the framework prototype by testing additional prototype hardware for application scenarios 1.1. and 1.2 (before moving to the next evaluation level; park's trials). These trials are carried out without using physical drones equipped with an ADS-B transmitter due to the payload limitation and weight of the drones to fly in residential areas. A full description of these trials is in section 5.
- **Park-Testing Trials:** the purpose of these trials is to initially test advanced functionalities and operation of the framework prototype by testing additional prototype hardware for application scenario 1.1. (before moving to the next evaluation level; field's trials) and 1.2 (before moving to the next evaluation level; field's trials). These trials are carried out using physical drones equipped with an ADS-B transmitter as the trials are carried out in non-residential areas and far from people. A full description of these trials is in section 6.

- **Field-Testing Trials:** the purpose of these trials is to test advanced functionalities and operation of the framework prototype by testing additional prototype hardware for application scenarios 1.1, 1.2, 2.1, and 2.2. These trials are carried out using physical drones equipped with an ADS-B transmitter as the trials are carried out in non-residential areas and far from people. A full description of these trials is in section 7.

Figure 6 shows the context of the framework prototype for the testing trials. Each of the above trials has its own configuration of the framework prototype.

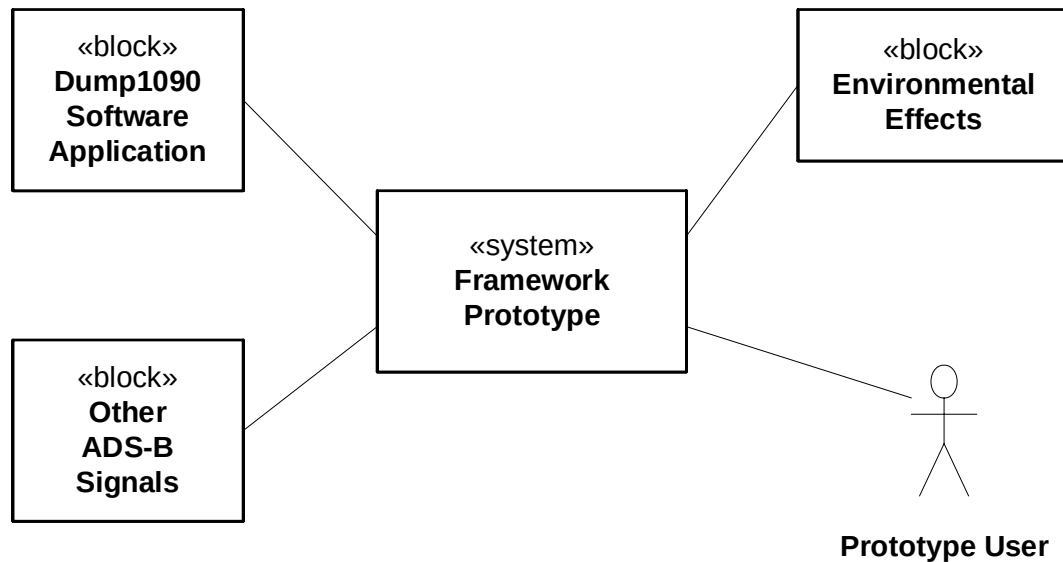


Figure 6. System context in the testing trials.

### 3.2 Framework Prototype

Figure 7 shows the main software pieces (Appendix A) and hardware parts (Appendix B) of the full framework prototype (including all the elements for the possible configurations).

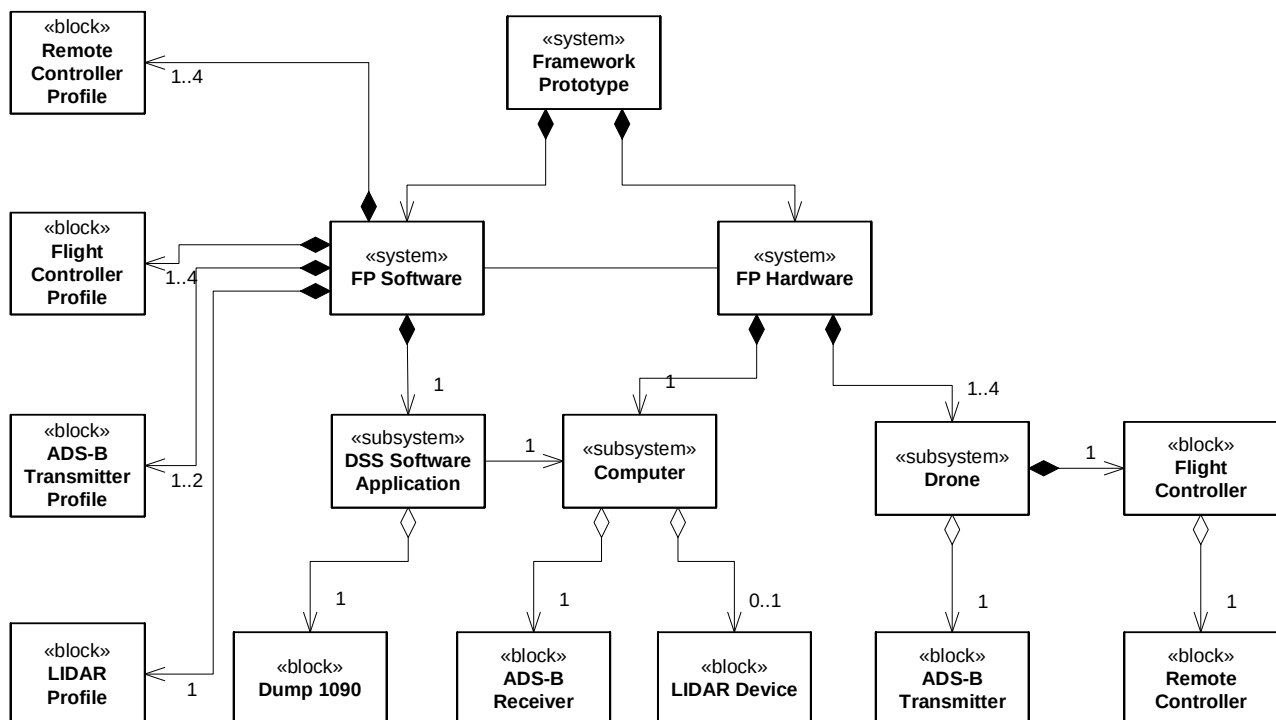


Figure 7. Structure of the framework prototype.

The testing trials implement totally or partially the application scenarios for which they have different configurations of the framework prototype. Figure 8 shows semantic relations between the different prototype configuration and application scenarios.

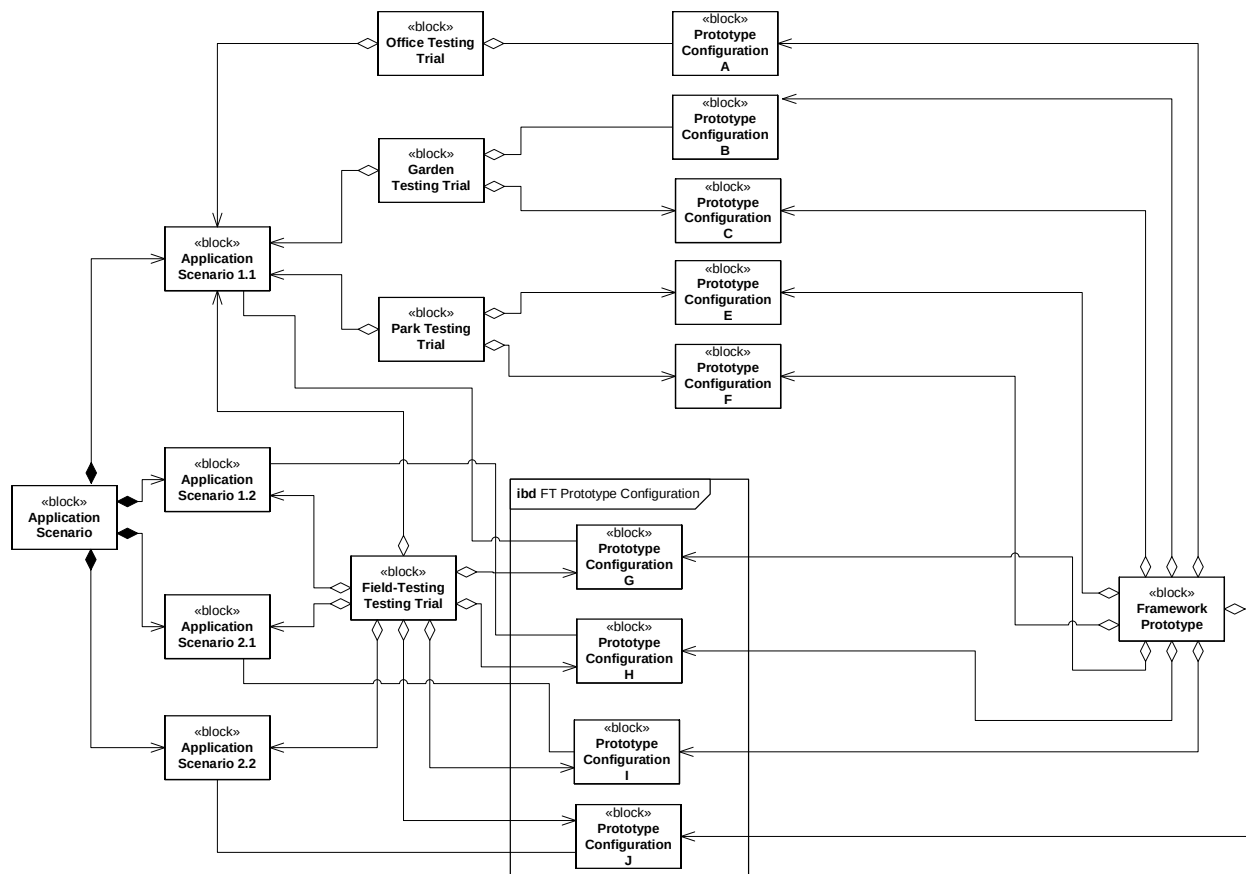


**Figure 8.** Derivations of framework prototypes.

The testing trials are aligned with the test cases from the prototype evaluation plan in the APR 2. Table 1 presents the different framework prototype configuration for the testing trials.

**Table 1.** Summary of test cases for the planned trials.

| Use Case | Application Scenario | Testing Trial  | Prototype Configuration | Flight Phase |
|----------|----------------------|----------------|-------------------------|--------------|
| 1        | 1.1                  | Office Testing | A                       | Take-off     |
|          |                      | Garden Testing | B                       |              |
|          |                      | Park Testing   | D                       |              |
|          |                      | Field Testing  | F, F, G, H              |              |
|          | 1.2                  | Garden Testing | C                       | Landing      |
|          |                      | Park Testing   | E                       |              |
| 2        |                      | 2.1            | Field Testing           |              |
|          | F                    |                |                         |              |
|          | 2.2                  | H              |                         | Descending   |
|          |                      | F              |                         |              |

Table 2 presents the use of drones and equipment from the framework prototype for the different configurations of it.

**Table 2.** Summary of the prototype configurations for the testing trials.

|       | ADS-B       | Office Testing | Garden Testing |   | Park Testing |   | Field Testing |   |   |   |
|-------|-------------|----------------|----------------|---|--------------|---|---------------|---|---|---|
| FPC   | N/A         | A              | C              | D | D            | E | F             | F | G | H |
| GOS   | Receiver    | x              | x              | x | x            | x | x             | x | x | x |
| RWD1  | Transmitter | x              | x              | x | x            | x |               | x |   |   |
|       | No          |                |                |   |              |   |               |   |   |   |
| RWD2  | Transmitter |                |                |   |              | x | x             | x |   | x |
|       | No          |                |                |   |              |   |               |   |   |   |
| RWD3  | Transmitter |                |                |   |              | x | x             | x |   | x |
|       | No          |                |                | x |              |   |               |   |   |   |
| FWD1  | Transmitter |                | x              | x | x            | x | x             | x | x | x |
|       | No          |                |                |   |              |   |               |   |   |   |
| FWD2  | Transmitter |                |                | x |              |   |               |   | x | x |
|       | No          |                |                |   |              |   |               |   |   |   |
| LIDAR | N/A         |                |                | x |              |   |               |   |   |   |

Table 3 presents the use of drones and their roles for the different runs of the trials proposed and what use cases and application scenarios are involved in each run of the trials; Office-Testing Run (OTR), Garden-Testing Run (GTR), Park-Testing Run (PTR), and Field-Testing Run (FTR).

**Table 3.** Summary of the runs for the testing trials.

| Trial          | Run  | FPC | Drone |      |       |      | UC1   |       | UC2    |       |
|----------------|------|-----|-------|------|-------|------|-------|-------|--------|-------|
|                |      |     | RWD1  | RWD2 | FWD1  | FWD2 | AS1.1 | AS1.2 | AS.2.1 | AS2.2 |
| Office Testing | OTR1 | A   | UAV*  |      | MAV** |      | x     |       |        |       |
|                | OTR2 |     | UAV*  |      | MAV** |      | x     |       |        |       |
| Garden Testing | GTR1 | B   | UAV*  |      | MAV*  |      | x     |       |        |       |
|                | GTR2 | C   | UAV*  |      | MAV*  |      | x     | x     |        |       |
| Park Testing   | PTR1 | D   | UAV   |      | MAV   |      | x     |       |        |       |
|                | PTR2 |     | UAV   |      | MAV   |      | x     |       |        |       |
|                | PTR3 | E   | UAV   | UAV  | MAV   |      |       | x     |        |       |
|                | PTR4 |     | UAV   | UAV  | MAV   |      |       | x     |        |       |
| Field Testing  | FTR1 | F   |       | UAV  | MAV   |      | x     |       |        |       |
|                | FTR2 |     | UAV   | UAV  | MAV   |      | x     | x     | x      | x     |
|                | FTR3 |     | UAV   | UAV  | MAV   |      | x     | x     | x      | x     |
|                | FTR4 | G   |       |      | MAV   | UAV  | x     |       |        |       |
|                | FTR5 | H   |       | UAV  | MAV   | MAV  | x     | x     | x      | x     |
|                | FTR6 |     |       | UAV  | MAV   | UAV  | x     | x     | x      | x     |
|                | FTR7 |     |       | UAV  | MAV   | UAV  | x     | x     | x      | x     |

\* No drone, only ADS-B transmitter moving by hand

\*\* No drone, no ADS-B transmitter (fixed set waypoint to represent taxied FWD1)

Table 4 presents how the different trials implement the application scenarios with more complexity (more functionalities and operations are tested) as they go from office testing to field testing.

**Table 4.** Incrementally progressive testing.

| UC | AS  | Drones (Assumed/Real) |    |    |    | Quantity of Drones |      |      |              | Airplane Ref Move |    |    |     | Airplane Ref Flight |    |    |     |
|----|-----|-----------------------|----|----|----|--------------------|------|------|--------------|-------------------|----|----|-----|---------------------|----|----|-----|
|    |     | OT                    | GT | PT | FT | OT                 | GT   | PT   | FT           | OT                | GT | PT | FT  | OT                  | GT | PT | FT  |
| 1  | 1.1 | AD                    |    | RD | RD | 1R                 |      | 1R1F | 2R1F<br>1R2F | N                 |    | Y  | N/Y | N                   |    | N  | N/Y |
|    | 1.2 |                       | AD | RD | RD |                    | 1R1F | 2R1F | 2R1F<br>1R2F |                   | Y  | Y  | Y   | N                   | N  | N  | Y   |
| 2  | 2.1 |                       |    |    | RD |                    |      |      | 2R1F<br>1R2F |                   |    |    | Y   |                     |    |    | Y   |
|    | 2.2 |                       |    |    | RD |                    |      |      | 2R1F<br>1R2F |                   |    |    | Y   |                     |    |    | Y   |

UC: Use Case    AS: Application Scenario    OT: Office Testing    GT: Garden Testing

PT: Park Testing    FT: Field Testing    AD: Assumed Drone    RD: Real Drone

The experimental results from the Office Testing trials and the Garden Testing trials show the latitude, longitude, and altitude data normalized according to the standard normalization approach in Equation 1.

$$Value_{normalized} = \frac{Value_{original} - Value_{min}}{Value_{max}} \quad \text{Equation 1}$$

All the scenarios from the trials require the creation (addition) and destroy (removal) of individuals such as aircraft (e.g., airplanes and drones) in the AAO of the DSS as needed depending on airspace situation. The case study has two use cases that involve authorized aircraft (those which have clearance from controlling authorities of a notified airspace) and unauthorized aircraft (intruders).

## 4 Office Testing Trials

This section discusses details from the office testing trials, including technical specifications and experimental results.

### 4.1 General Aspects of the Trails

The office testing trials involve a computer (GOS) running the Dump1090 software application and the DSS software application. The latter (along with the GOS) works as a reference point for an assumed quadcopter (RWD1) flying around it. Thus, the GOS has a specific location and plays the role of any crewed fixed-wing aircraft (MAV) on ground taxied in one extreme of a runway and ready for take-off (e.g., a commercial airplane). RWD1 plays the role of a UAV that is assumed to fly outdoors in different airspace areas near the GOS. The assumption of the existence of RWD1 in place is simulated as an ADS-B Transmitter represents it but RWD1 is not physically used. The moves of RWD1 are simulated by moving the ADS-B Transmitter with a hand as if it were the real RWD1.

Table 5 shows the details of the office testing task carried out. The specification presented in this table applies to all the office testing trials.

**Table 5.** General information for office testing trials.

|                             |                                                   |
|-----------------------------|---------------------------------------------------|
| <b>Testing Location</b>     | Home                                              |
| <b>Testing Facility</b>     | (Indoor) home office and (outdoor) garden space   |
| <b>System Context</b>       | Figure 6                                          |
| <b>Use case</b>             | Use Case 1: Take-off and Landing (Figure 1)       |
| <b>Application Scenario</b> | Derived from Application Scenario 1.1 (Figure 10) |
| <b>Prototype</b>            | A (Table 2)                                       |

| Configuration               |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|-----------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Hardware Platform</b>    | <ul style="list-style-type: none"> <li>• ADS-B Receiver – FlightAware Pro Stick Plus (Figure 94)</li> <li>• ADS-B Transmitter – uAvionix EchoSky 2 (Figure 95)</li> <li>• RWD1 (simulated drone flight; taken by hand to different positions)</li> <li>• FWD1 (simulated airplane taxied for take-off at the GOS location)</li> <li>• GOS computer</li> </ul>                                                                                                                                                                                                                                                                            |
| <b>Software Application</b> | <ul style="list-style-type: none"> <li>• DSS software application</li> <li>• Dump1090 application</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| <b>Testing Equipment</b>    | Radiation Detector: GQ Electronics EMF Meter [15]                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| <b>Testing Area</b>         | <ul style="list-style-type: none"> <li>• 27 m x 21 m = 567 m<sup>2</sup></li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| <b>Testing Setup</b>        | <ul style="list-style-type: none"> <li>• DSS software application is up and running in the GOS.</li> <li>• ADS-B Receiver is power on as it is plugged in the GOS computer.</li> <li>• ADS-B Transmitter is power on.</li> <li>• RWD1 is assumed to be initially landed and in an initial given position.</li> <li>• FWD1 is assumed to be taxied in one of the extreme of the runway.</li> </ul>                                                                                                                                                                                                                                        |
| <b>Testing Limitations</b>  | <ul style="list-style-type: none"> <li>• Drones that are allowed to fly in the nearby neighbourhood are small (&lt;250 grs) and are not able to carry the ADS-B transmitter payload. Thus, their flights (in these trials) are simulated by taking the ADS-B transmitters by hand in the case of RWD1 (UAV).</li> <li>• FWD1 (MAV) is landed and does not have an ADS-B transmitter but its location must be set manually by getting readings from a GPS and combining them with the coordinates provided by Google Maps.</li> <li>• Small outdoor area for testing that reduces possible locations for the simulated drones.</li> </ul> |

Table 6 presents details of the framework prototype configuration for the office testing trial. The runs of the trials are for RWD1 with and without countermeasure (PilotContact). The integrated transmitter is placed outdoor while the GOS is placed indoor for these trials. However, the trials are called Office Testing trials because FWD1 is assumed to be taxied and indoor, but the ADS-B transmitter must be outdoor due to the GPS signal it requires.

**Table 6.** Prototype configuration for the office testing trial.

|              | Role           | ADS-B                  | Authorization | Countermeasure      | Traffic | Flight              | Place        |
|--------------|----------------|------------------------|---------------|---------------------|---------|---------------------|--------------|
| <b>GOS</b>   | Operator unit  | Receiver + antenna     | N/A           | N/A                 | N/A     | N/A                 | Home office  |
| <b>RWD1</b>  | (Supposed) UAV | Integrated transmitter | No            | None / PilotContact | FWD1    | Landed / airborne   | Garden space |
| <b>RWD2</b>  | Not used       |                        |               |                     |         |                     |              |
| <b>RWD3</b>  | Not used       |                        |               |                     |         |                     |              |
| <b>FWD1</b>  | (Supposed) MAV | No                     | Yes           | PilotContact        | RWD1    | Taxied for take-off | Garden space |
| <b>FWD2</b>  | Not used       |                        |               |                     |         |                     |              |
| <b>LIDAR</b> | Not used       |                        |               |                     |         |                     |              |

The office-testing trials entail two runs: OTR1 and OTR2. OTR1 is useful to obtain the very first data for application scenario 1.1. The office testing trials are carried out for prototype configuration A and B. The following subsection shows the updates and changes for the different prototype configuration of the office testing trials carried out.

## 4.2 Trials for Prototype Configuration A

The very first run of the office testing trials is OTR1 and it is carried out is based on configuration A of the framework prototype. The following subsection discuss details of the trials.

### 4.2.1 Technical Details of the Trails

Table 7 shows specific information on the context of the trials for prototype configuration A in addition to the specifications shown in Table 5.

**Table 7.** Additional information for office testing trial for prototype configuration A (OTR1).

|                              |                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Date and Time</b>         | Thu, 26 Jan 2023, 16:30 - 17:00                                                                                                                                                                                                                                                                                                                                                                                                                           |
| <b>Weather Condition*</b>    | Partially clouded, 7 °C, 1033.00mb, 71%, 13 km/h, 10 km                                                                                                                                                                                                                                                                                                                                                                                                   |
| <b>Environment Radiation</b> | <p>The following measures are with the ADS-B transmitter off</p> <ul style="list-style-type: none"> <li>• (Indoor) home office <ul style="list-style-type: none"> <li>○ EMF: 0.1mG</li> <li>○ EF: 1 V/m</li> <li>○ RF: 0.001 – 0.061 mW/m<sup>2</sup></li> </ul> </li> <li>• (Outdoor) garden space <ul style="list-style-type: none"> <li>○ EMF: 0 - 0.2mG</li> <li>○ EF: 0 - 2 V/m</li> <li>○ RF: 0.001 – 0.500 mW/m<sup>2</sup></li> </ul> </li> </ul> |

\* Source: <https://www.foreca.com>

Figure 6 shows the context of the framework prototype for the office testing trial with prototype configuration A.

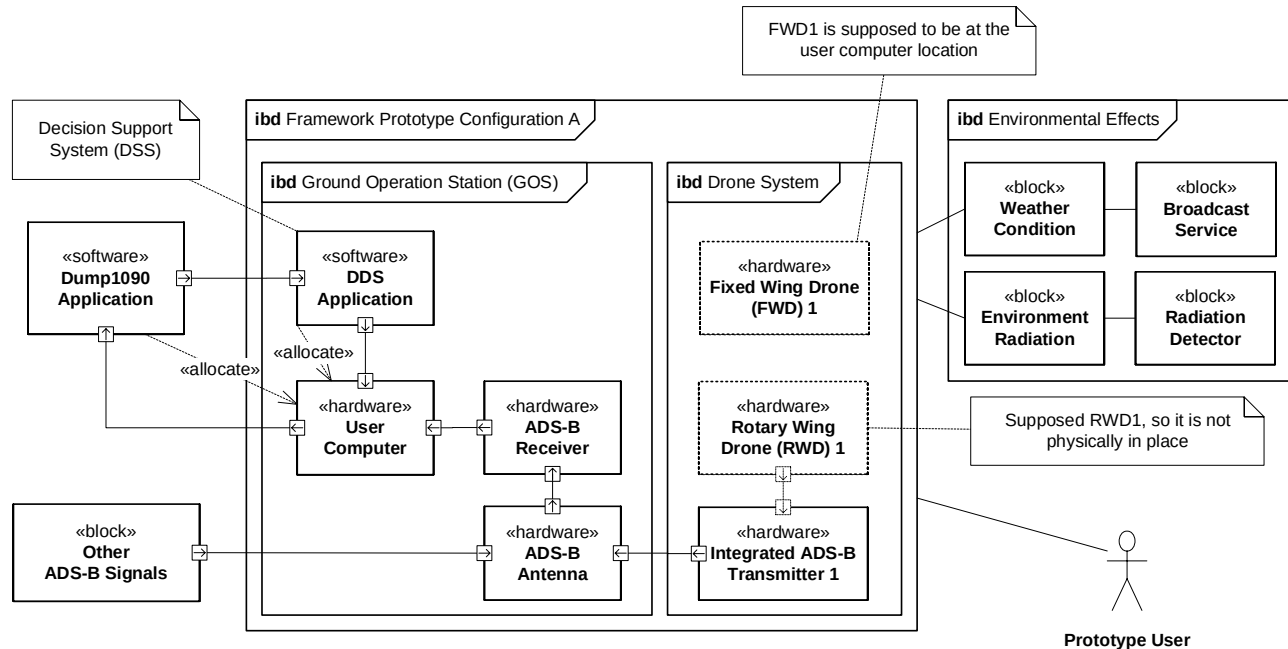


**Figure 9.** Prototype configuration A for the office testing trial.

Figure 10 shows details of the interaction between key elements from the application scenario of the framework prototype for the office testing trial with prototype configuration A.

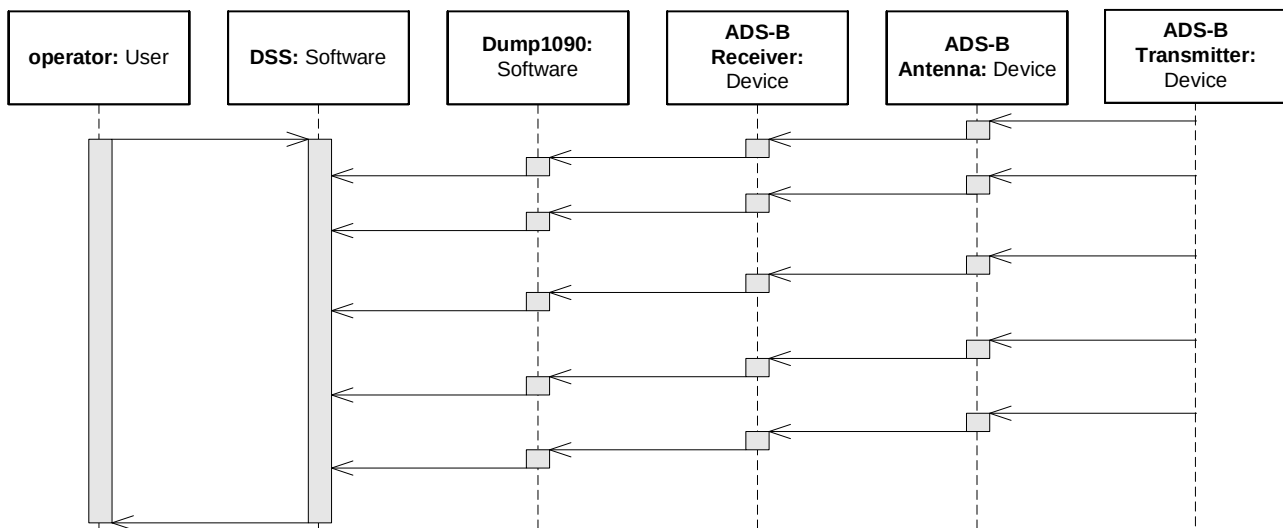


**Figure 10.** Application scenario in the office testing trial.

Table 8 presents the test cases for the office testing trials that use prototype configuration A.

**Table 8.** Summary of test cases for the office testing trials.

| Mission Phase | Use Case | Application Scenario | Prototype Configuration | Test Case                                   |
|---------------|----------|----------------------|-------------------------|---------------------------------------------|
| Pre-mission   | 1        | 1.1                  | A                       | ADS-B RF link (Table 9)                     |
|               |          |                      |                         | IP/TCP data link (Table 10)                 |
| In-Mission    | 1        | 1.1                  |                         | SAW of RWD1 with countermeasures (Table 11) |
|               |          |                      |                         | SAW of RWD1 without countermeasures         |
| Post-mission  | 1        | 1.1                  |                         | DSS information logging (Table 12)          |

#### 4.2.2 Pre-Mission Phase

The purpose of the pre-mission office testing for prototype configuration A is to check the functions of the framework prototype are correct and the right operation of it by means of two test cases:

- ADS-B RF link between an ADS-B transmitter (UAvionix EchoSky 2) device (assumed onboard RWD1) and the ADS-B receiver (FlightAware Pro Stick Plus) device connected to the GOS.
- IP/TCP Data link between the Dump1090 application (assumed onboard RWD1) and the DSS software application. Both applications run in the GOS. This testing is also to check if the DSS is fully operational.

The test procedure for the ADS-B RF link test case requires: (1) the ADS-B receiver has the proper settings as presented on page 23 of APR 3 – Part F, and (2) the Dump1090 application [13] is up and running, and. Table 9 shows the test procedure for the ADS-B link test case (as introduced in Table 8) in the pre-mission office testing trial.

**Table 9.** Test procedure for ADS-B RF link check.

| Test Step | User Action                                                                       | Expected Results                                                                       | Observed Results                                                                | Result Status                                                                          |
|-----------|-----------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|---------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|
| 1         | Run the Dump1090 application in the GOS                                           | The Dump1090 application should be up and running                                      | The Dump1090 application is up and running                                      | The Dump1090 application keeps up and running                                          |
| 2         | Switch the ADS-B transmitter on                                                   | The ADS-B transmitter should be on                                                     | The ADS-B transmitter is on                                                     | The ADS-B transmitter keeps on                                                         |
| 3         | Check the ADS-B transmitter send correct data out                                 | The ADS-B transmitter should send correct data out (ADS-B light is blinking in green)  | The ADS-B transmitter sends correct data out (ADS-B light is blinking in green) | The ADS-B transmitter keeps sending correct data out                                   |
| 4         | Check the Dump1090 application receives the ADS-B data from the ADS-B transmitter | The Dump1090 application should be receiving the ADS-B data from the ADS-B transmitter | The Dump1090 application is receiving the ADS-B data from the ADS-B transmitter | The DSS software application keeps receiving the ADS-B data from the ADS-B transmitter |
| 5         | Switch the ADS-B transmitter off                                                  | ADS-B transmitter should be off                                                        | ADS-B transmitter is off                                                        | ADS-B transmitter keeps off                                                            |
| 6         | Stop the Dump1090 application in the GOS                                          | The Dump1090 application should be down and off                                        | The Dump1090 application is down and off                                        | The Dump1090 application keeps down and off                                            |

The test procedure for the DSS software application functioning test case requires: (1) the ADS-B receiver is connected to the GOS computer, (2) the Dump1090 application is up and running, and (3) the DSS software application is up and running in the GOS. Table 10 shows the test procedure for the DSS software application test case (as introduced in Table 1) in the pre-missing office testing trial.

**Table 10.** Test procedure for IP/TCP data link check.

| Test Step | User Action                                                                                                               | Expected Results                                                                                                             | Observed Results                                                                                                       | Result Status                                                                                              |
|-----------|---------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------|
| 1         | Run the Dump1090 application in the GOS                                                                                   | The Dump1090 application should be up and running                                                                            | The Dump1090 application is up and running                                                                             | The Dump1090 application keeps up and running                                                              |
| 2         | Run the DSS software application in the GOS                                                                               | The DSS software application should be up and running                                                                        | The DSS software application is up and running                                                                         | The DSS software application keeps up and running                                                          |
| 3         | Check the Dump1090 are connected with each other using TCP/IP protocol                                                    | The Dump1090 application and the DSS software application should be TCP/IP connected with each other                         | The Dump1090 application and the DSS software application are TCP/IP connected with each other                         | Both applications keep connected with each other using the TCP/IP protocol                                 |
| 4         | Check if the aircraft displayed by the Dump1090 application are also shown on the DSS software application user interface | The user interface of the DSS software application should display aircraft (equipped with ADS-B) flying in the near airspace | The user interface of the DSS software application displays aircraft (equipped with ADS-B) flying in the near airspace | The DSS software application keeps displaying properly all the corresponding aircraft in the near airspace |

|   |                                                                                                                                  |                                                                                                                                                               |                                                                                                                                                        |                                                                                                                                       |
|---|----------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|
| 5 | Check if the information displayed for each aircraft in the Dump1090 application matches the one on the DSS software application | The Dump1090 application and the DSS software application should show the same information of each aircraft (equipped with ADS-B) flying in the near airspace | The Dump1090 application and the DSS software application show the same information of each aircraft (equipped with ADS-B) flying in the near airspace | The Dump1090 application and the DSS software application keeps displaying the same information on each aircraft in the near airspace |
| 6 | Check if the DSS software application displays airspace SAW involving aircraft                                                   | Some airspace SAW should be displayed in the DSS software application                                                                                         | Airspace SAW is displayed in the DSS software application                                                                                              | The DSS software application keeps displaying SAW spotted                                                                             |
| 7 | Check if the DSS software application can log the information received from aircraft                                             | The DSS software application should be able to log correct information from aircraft                                                                          | The DSS software application can log correct information from aircraft                                                                                 | The DSS software application keeps logging information from aircraft properly                                                         |
| 8 | Stop the DSS software application in the GOS                                                                                     | The DSS software application should be down and off                                                                                                           | The DSS software application is down and off                                                                                                           | The DSS software application keeps down and off                                                                                       |
| 9 | Stop the Dump1090 application in the GOS                                                                                         | The Dump1090 application should be down and off                                                                                                               | The Dump1090 application is down and off                                                                                                               | The Dump1090 application keeps down and off                                                                                           |

#### 4.2.3 In-Mission Phase

The purpose of the in-mission office testing for prototype configuration A is to check the correct functioning and operation of the DSS by means of two main test cases: SAW of RWD1 (represented by an ADS-B transmitter) with countermeasures and SAW of RWD1 without countermeasures.

The test procedure for the test case on SAW of RWD1 with countermeasures requires: (1) the ADS-B transmitter is positioned on the floor (assuming RWD1 is landed), (2) the ADS-B transmitter is off, (3), the ADS-B dongle is connected to the GOS computer, (4) the Dump1090 application is up and running, and (5) the DSS software application is up and running in the GOS. Table 11 shows the steps for the test case on SAW of RWD1 with countermeasures (as introduced in Table 1) for the in-mission office testing.

**Table 11.** Test procedure for SAW of assumed RWD1 with countermeasures.

| Test Step | User Action                                                                        | Expected Results                                                                                     | Observed Results                                                                               | Result Status                                                              |
|-----------|------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------|
| 1         | Run the Dump1090 application in the GOS                                            | The Dump1090 application should be up and running                                                    | The Dump1090 application is up and running                                                     | The Dump1090 application keeps up and running                              |
| 2         | Run the DSS software application in the GOS                                        | The DSS software application should be up and running                                                | The DSS software application is up and running                                                 | The DSS software application keeps up and running                          |
| 3         | Check the Dump1090 and the DSS are connected with each other using TCP/IP protocol | The Dump1090 application and the DSS software application should be TCP/IP connected with each other | The Dump1090 application and the DSS software application are TCP/IP connected with each other | Both applications keep connected with each other using the TCP/IP protocol |

|    |                                                                                                                                                                |                                                                                                                      |                                                                                                                |                                                                                                                       |
|----|----------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------|
| 4  | Place the ADS-B transmitter on the ground (as if RWD1 is landed), then switch it on                                                                            | The ADS-B transmitter should be on                                                                                   | The ADS-B transmitter is on                                                                                    | The ADS-B transmitter keeps on                                                                                        |
| 5  | Check if the DSS software application displays SAW involving RWD1 accordingly                                                                                  | SAW of RWD1 should be displayed in the DSS software application                                                      | SAW of RWD1 is displayed in the DSS software application                                                       | The DSS software application keeps displaying SAW of RWD1                                                             |
| 6  | Check the DSS software application receives the ADS-B data from the ADS-B transmitter                                                                          | DSS software application should receive the ADS-B data from the ADS-B transmitter                                    | The DSS software application receives the ADS-B data from the ADS-B transmitter                                | The DSS software application keeps receiving the ADS-B data from the ADS-B transmitter                                |
| 7  | Start moving the ADS-B transmitter as if RWD1 is flying around in locations close to the GOS                                                                   | The DSS software application should provide SAW of the ADS-B transmitter (simulating RWD1 flying around)             | The DSS software application provides SAW of the ADS-B transmitter (simulating RWD1 flying around)             | The DSS software application keeps providing SAW of the ADS-B transmitter (simulating RWD1 flying around)             |
| 8  | Try to get the ADS-B transmitter in an airspace zone that is not hazardous for an assumed airplane taking off (assumed to be taxed in the location of the GOS) | The DSS software application should accordingly provide SAW of the ADS-B transmitter (simulating RWD1 flying around) | The DSS software application accordingly provides SAW of the ADS-B transmitter (simulating RWD1 flying around) | The DSS software application keeps providing SAW accordingly of the ADS-B transmitter (simulating RWD1 flying around) |
| 9  | Try to get the ADS-B transmitter in an airspace zone that is hazardous for an assumed airplane taking off (assumed to be taxed in the location of the GOS)     | The DSS software application should accordingly provide SAW of the ADS-B transmitter (simulating RWD1 flying around) | The DSS software application accordingly provides SAW of the ADS-B transmitter (simulating RWD1 flying around) | The DSS software application keeps providing SAW of the ADS-B transmitter (simulating RWD1 flying around) accordingly |
| 10 | Place the ADS-B transmitter on the ground (as if RWD1 is landed)                                                                                               | The DSS software application should keep providing SAW accordingly for the ADS-B transmitter (RWD1 simulated)        | The DSS software application keeps providing SAW accordingly for the ADS-B transmitter (RWD1 simulated)        | The DSS software application keeps providing SAW accordingly for the ADS-B transmitter (RWD1 simulated)               |
| 11 | Switch ADS-B transmitter off                                                                                                                                   | The ADS-B transmitter should be off                                                                                  | The ADS-B transmitter is off                                                                                   | The ADS-B transmitter keeps of                                                                                        |
| 12 | Check if the DSS software application accordingly does not display SAW involving RWD1                                                                          | SAW of RWD1 should not be displayed in the DSS software application                                                  | SAW of RWD1 is not displayed in the DSS software application                                                   | The DSS software application keeps not displaying SAW of RWD1                                                         |

The test procedure for the test case on SAW of RWD1 without countermeasures is very similar to the one shown in Table 11 for SAW of RWD1 with countermeasures. The only different is that RWD1 is now set to have countermeasures, e.g., a remote pilot.

#### 4.2.4 Post-Mission Phase

The purpose of the post-mission office testing for prototype configuration A is to have a main test case to know whether the DSS can log the information broadcasted by the ADS-B transmitter. The test procedure for this test case requires: (1) assumption RWD1 is landed, and (2) the ADS-B transmitter assumed on board RWD1 is kept on. Table 12 shows the steps for this test case (as introduced in Table 1) for the post-mission office testing.

**Table 12.** Test procedure for DSS information logging.

| Test Step | User Action                                                                         | Expected Results                                                                 | Observed Results                                                   | Result Status                                                             |
|-----------|-------------------------------------------------------------------------------------|----------------------------------------------------------------------------------|--------------------------------------------------------------------|---------------------------------------------------------------------------|
| 1         | Stop the DSS software application in the GOS                                        | The DSS software application should be properly down and off                     | The DSS software application is properly down and off              | The DSS software application keeps down and off                           |
| 2         | Check if the DSS software application has logged the information received from RWD1 | The DSS software application should be able to log correct information from RWD1 | The DSS software application can log correct information from RWD1 | The DSS software application keeps logging information from RWD1 properly |
| 3         | Stop the Dump1090 application in the GOS                                            | The Dump1090 application should be down and off                                  | The Dump1090 application is down and off                           | The Dump1090 application keeps down and off                               |

#### 4.2.5 Experimental Results from OTR1

Figure 11 and Figure 15 present the experimental results from the OTR1 of the office testing trials (in-mission phase) with the latitude, longitude, and altitude normalized as per Equation 1. The figures also show details of areas (flight waypoints) which means hazards of potential collision between aircraft (RW1 and FWD1; both assumed). The closest distance that the aircraft can be without becoming a hazard is set at 270.

Figure 11 shows the trajectory produced by the ADS-B transmitter when simulating the RWD1 flight with the following setting: aircraft unauthorized to fly, and countermeasure (PilotContact) for possible mid-air collision. RWD1 is assumed to take off right ahead of the runway (straight line in dark grey) where FWD1 is assumed to be taxied (blue cross) at all the time.

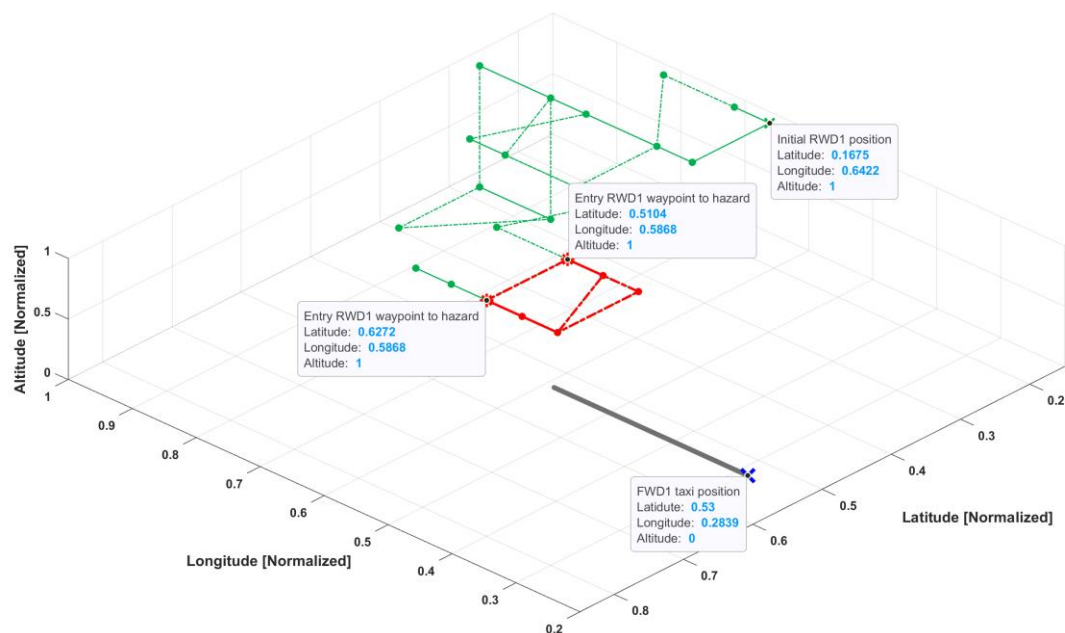


**Figure 11.** ADSB-based localization for SA of RWD1 with countermeasure in OTR1.

The RWD1 trajectory in green means there is no hazard, and it is displayed in the user interface of the DDS software application as “Flight Safety” in Figure 12. The RWD1 trajectory in red means there is hazard, and it is displayed in the user interface of the DDS software application as “Flight Safety Caution” in Figure 13.

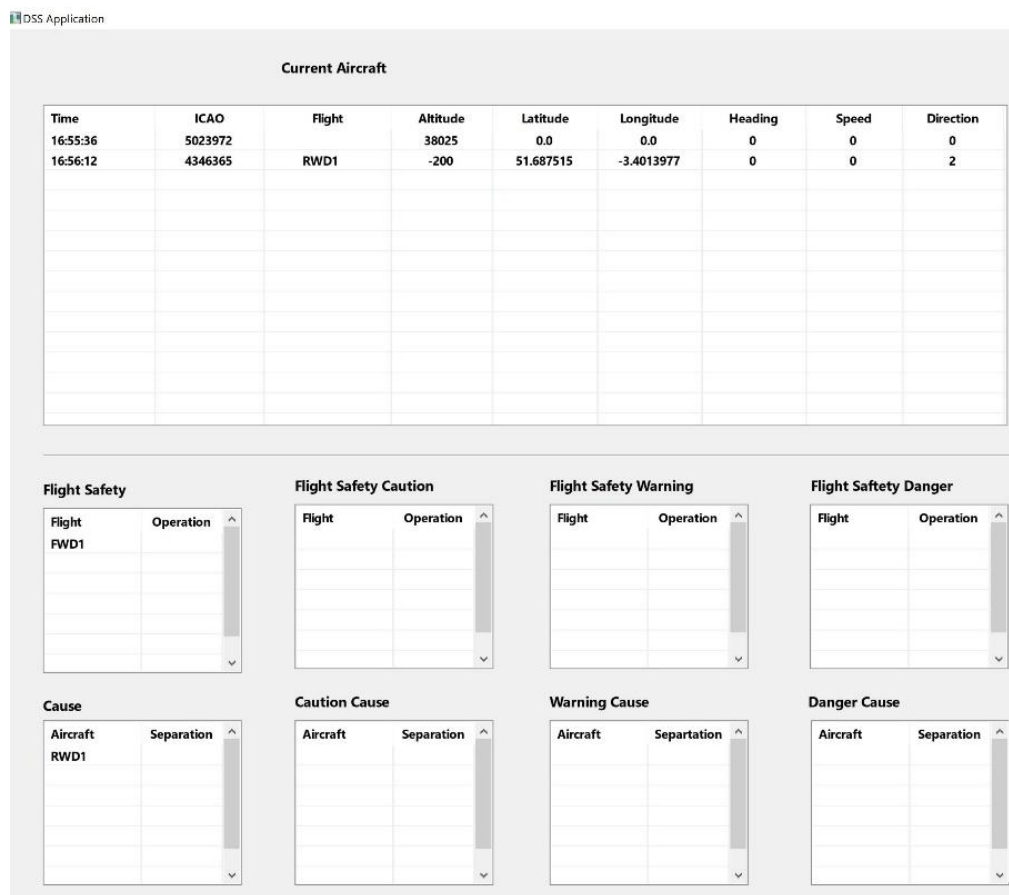


**Figure 12.** DDS user interface from OTR1 of the office testing trial (SA: Flight Safety).

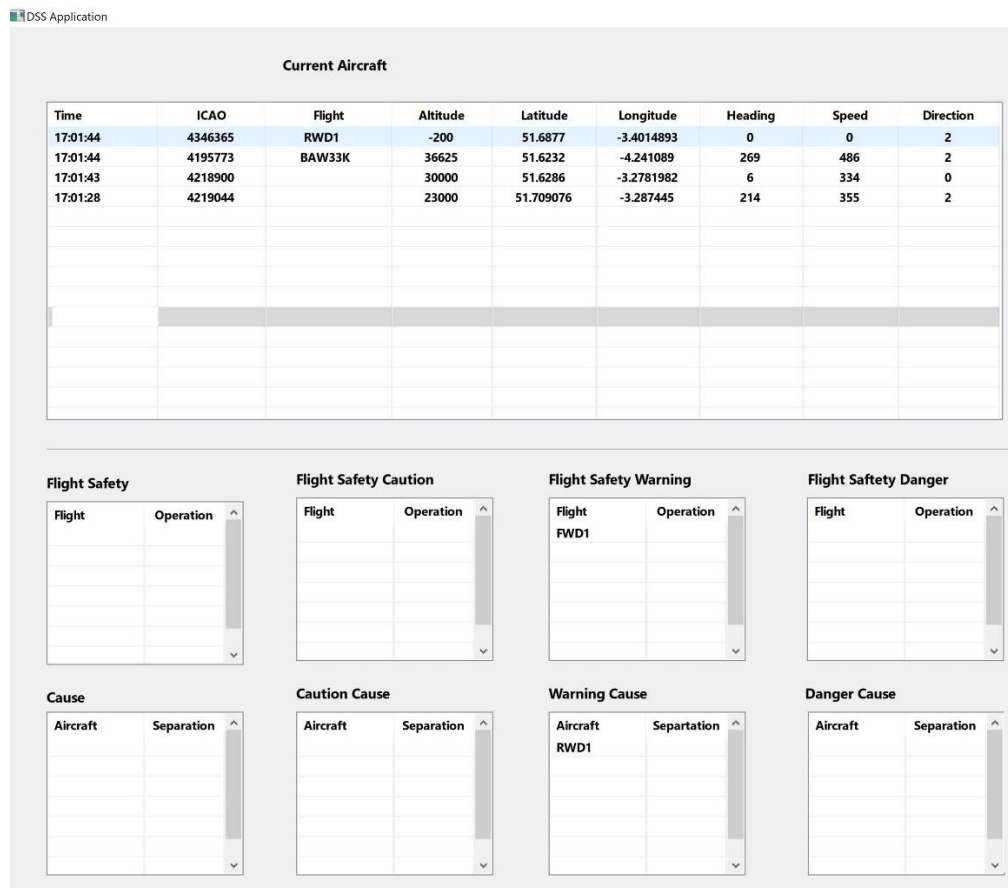


**Figure 13.** DSS user interface for OTR1 of the office testing trial (SA: Flight Safety Warning).

Figure 14 shows details of RWD1 (Types: Quadcopter) in the AAO during the OTR1 of the office testing trial with SAW advising “Flight Safety Warning”. This is a screenshot at sample 335 and it is when the distance between RWD1 and FWD1 is 245 units (*hasDistance* 245). The ICAO address of RWD1 in decimal (*hasICAOAddress* 4346365) as well as that RWD1 is not authorized to fly nearby FWD1 (*isAuthorized* false) are also displayed as data property assertions. RWD1 is set to have countermeasure (*hasCountermeasure* PilotContact), and the fact that RWD1 is part of the FWD1 air traffic is set as soon as RWD1 is reported around (*isAirTrafficOf* FWD1). Both are displayed as object proper assertions.

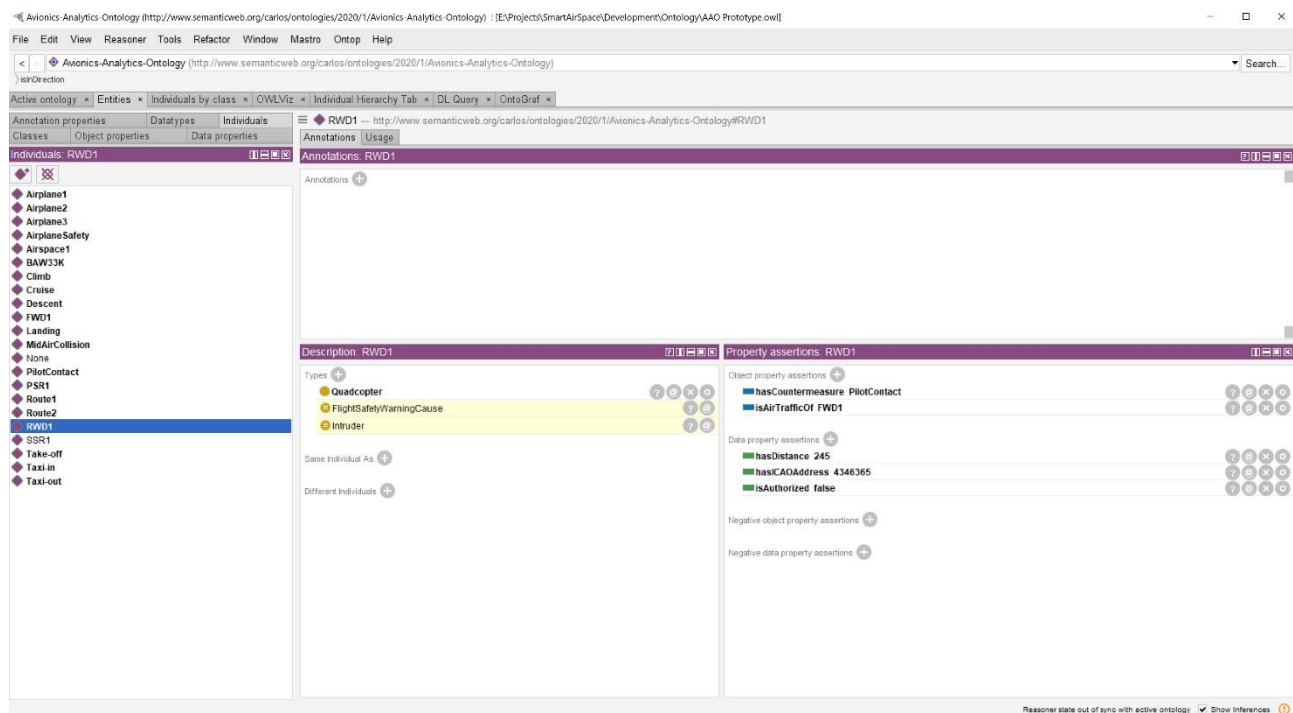


**Figure 14.** RWD1 details in Protégé for OTR1 of the office testing trial (SA: Flight Safety Warning).

Figure 15 shows the trajectory produced by the ADS-B transmitter when simulating the RWD1 flight with the following setting: aircraft unauthorized to fly, and no countermeasure (none) for possible mid-air collision. RWD1 is assumed to take off right ahead (on the right) of the runway (straight line in dark grey) where FWD1 is assumed to be taxied (blue cross) at all the time.

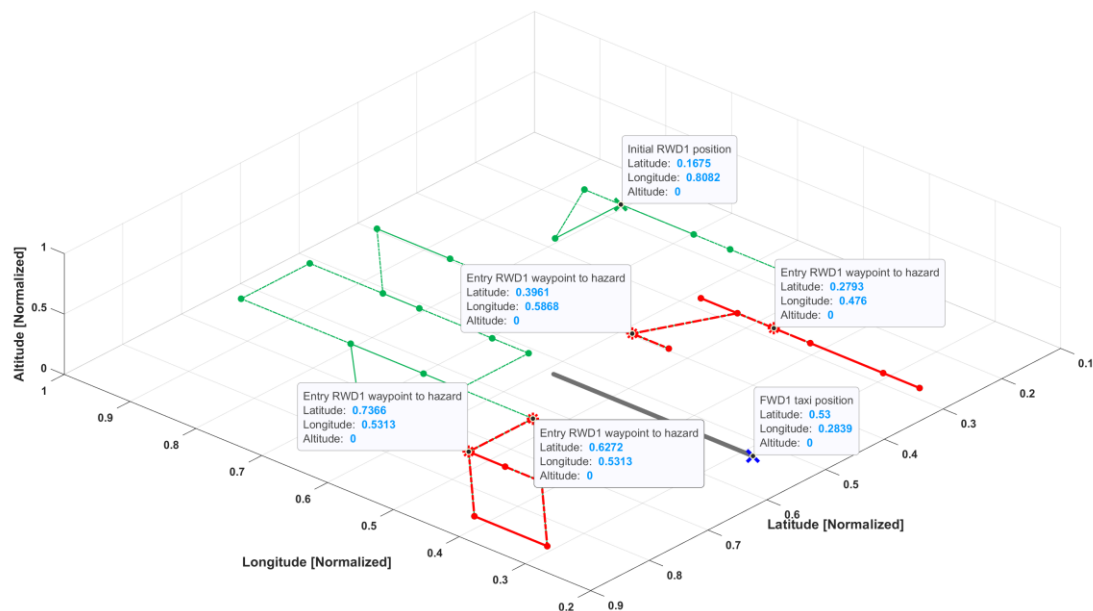


**Figure 15.** ADSB-based localization for SA of RWD1 without countermeasure in OTR1.

The RWD1 trajectory in green means there is no hazard, and it is displayed in the user interface of the DDS software application as “Flight Safety Caution” in Figure 16. The RWD1 trajectory in red means there is hazard, and it is displayed in the user interface of the DDS software application as “Flight Safety Danger” in Figure 17.

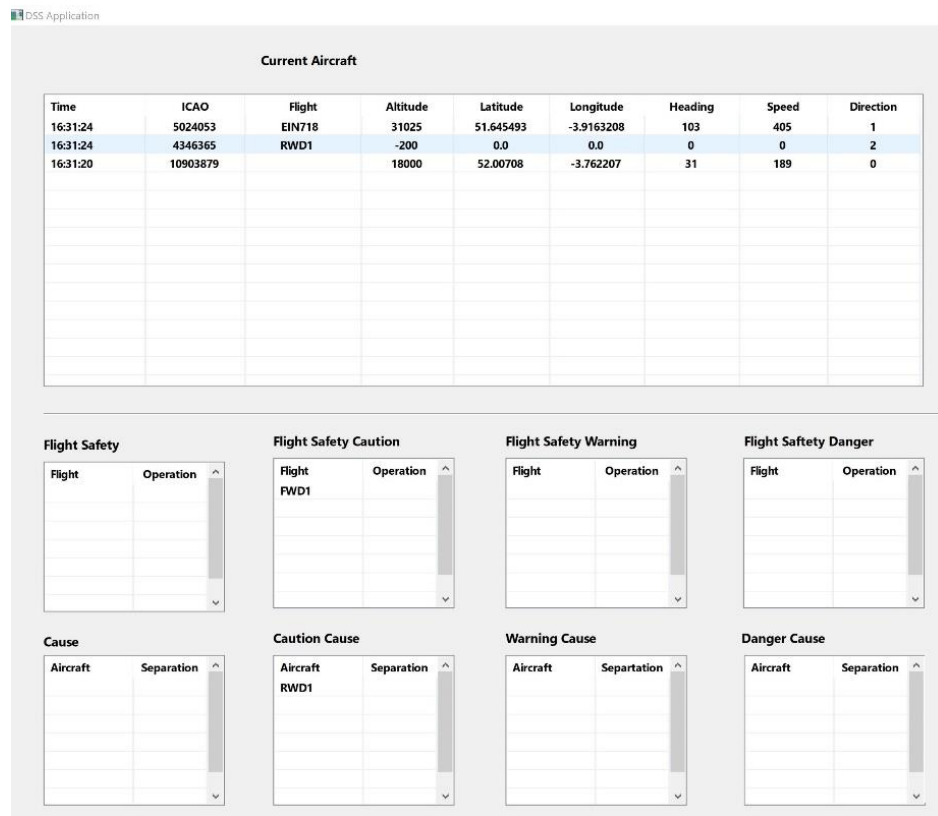


**Figure 16.** DSS user interface from OTR1 of the office testing trial (SA: Flight Safety Caution).

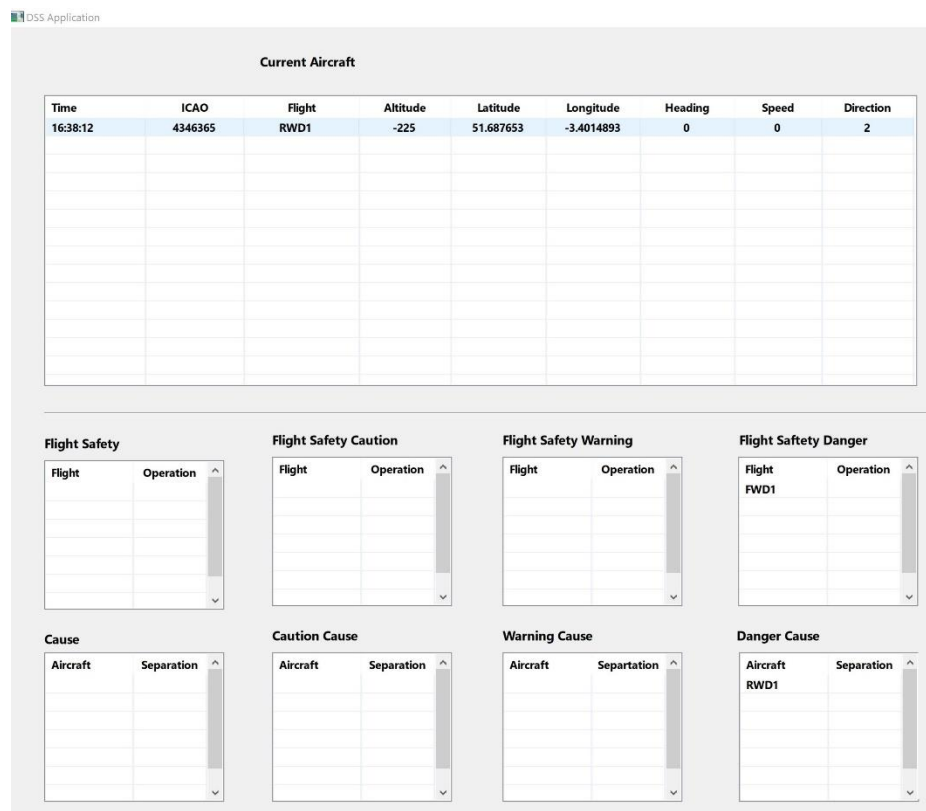


**Figure 17.** DSS user interface for OTR1 of the office testing trial (SA: Flight Safety Caution Danger).

Figure 18 shows details of RWD1 (Types: Quadcopter) in the AAO during the OTR1 of the office testing trial with SAW advising “Flight Safety Danger”. This is a screenshot at sample 132 and it is when the distance between RWD1 and FWD1 is 298 units (*hasDistance* 132). The ICAO address of RWD1 in decimal

(*hasCAOAddress* 4346365) as well as that RWD1 is not authorized to fly nearby FWD1 (*isAuthorized* false) are also displayed as data property assertions. RWD1 is not set to have countermeasure (*hasCountermeasure* None), and the fact that RWD1 is part of the FWD1 air traffic is set as soon as RWD1 is reported around (*isAirTrafficOf* FWD1). Both are displayed as object proper assertions.

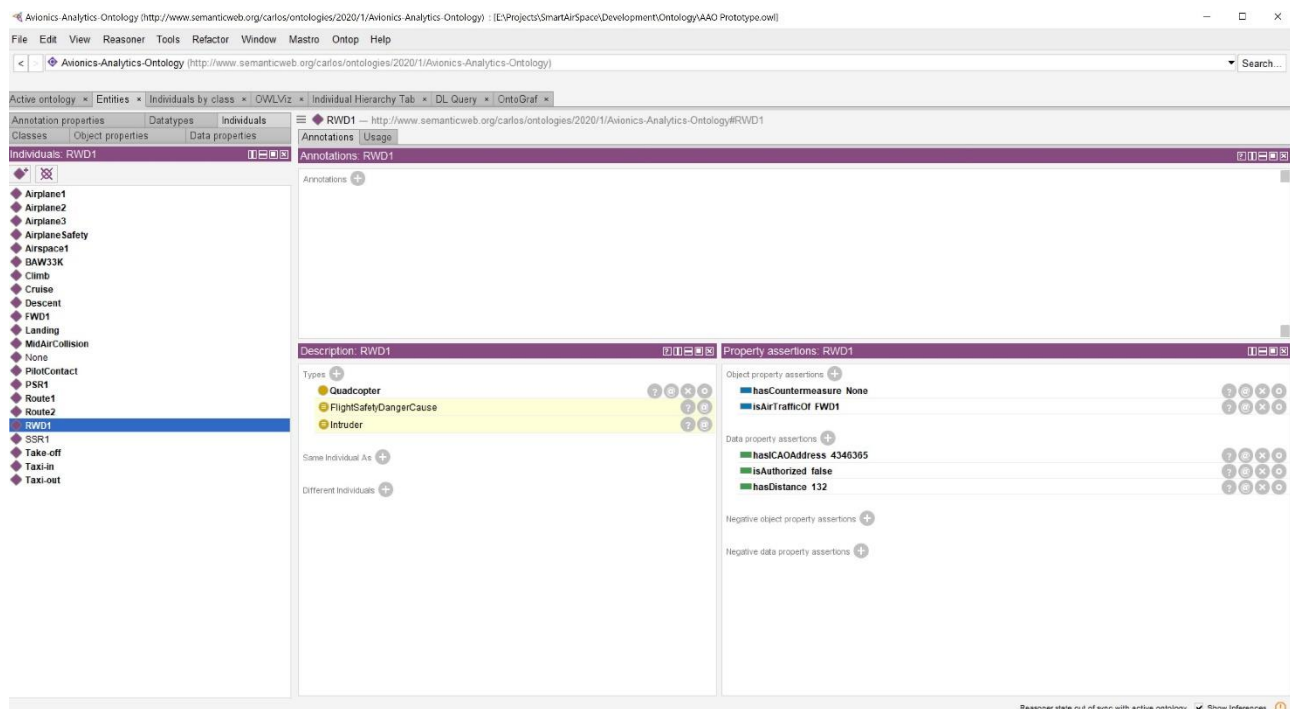


Figure 18. RWD1 details in Protégé for OTR1 of the office testing trial (SA: Flight Safety Danger).

#### 4.2.6 Experimental Results from OTR2

The office testing trials are repeated using a different critical distance between aircraft (RWD1 and FWD1). It is set to 378 units for the repetition (OTR2) of the office testing trials instead of 270 units. The purpose of this change is to adjust the sensitivity of the SAW process.

Table 13. Office testing trial for prototype configuration A (update for repetition).

|                              |                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Date and Time</b>         | Mon, 6 Feb 2023, 16:45 - 17:15                                                                                                                                                                                                                                                                                                                                                                                                            |
| <b>Weather Condition*</b>    | Clear, 3 °C, 1038.00mb, 87%, 9 km/h, 10 km                                                                                                                                                                                                                                                                                                                                                                                                |
| <b>Environment Radiation</b> | <p>The following measures are with the ADS-B transmitter off</p> <ul style="list-style-type: none"> <li>(Indoor) home office <ul style="list-style-type: none"> <li>EMF: 0-0.1mG</li> <li>EF: 1-2 V/m</li> <li>RF: 0.001 – 0.003 mW/m<sup>2</sup></li> </ul> </li> <li>(Outdoor) garden space <ul style="list-style-type: none"> <li>EMF: 0.1 mG</li> <li>EF: 0 - 2 V/m</li> <li>RF: 0.001 – 0.05 mW/m<sup>2</sup></li> </ul> </li> </ul> |

Figure 19 and Figure 22 present the experimental results from the OTR1 of the office testing trials (in-mission phase) with the latitude, longitude, and altitude normalized as per Equation 1. The figures also show details of areas (flight waypoints) which means hazards of potential collision between aircraft (RW1 and FWD1; both assumed). The closest distance that the aircraft can be without becoming a hazard is set at 378 (*hasDistance* 378).

Figure 19 shows the trajectory produced by the ADS-B transmitter when simulating the RWD1 flight with the following setting: aircraft unauthorized to fly, and countermeasure (PilotContact) for possible mid-air collision. RWD1 is assumed to take off right ahead of the runway (straight line in dark grey) where FWD1 is assumed to be taxied (blue cross) at all the time.

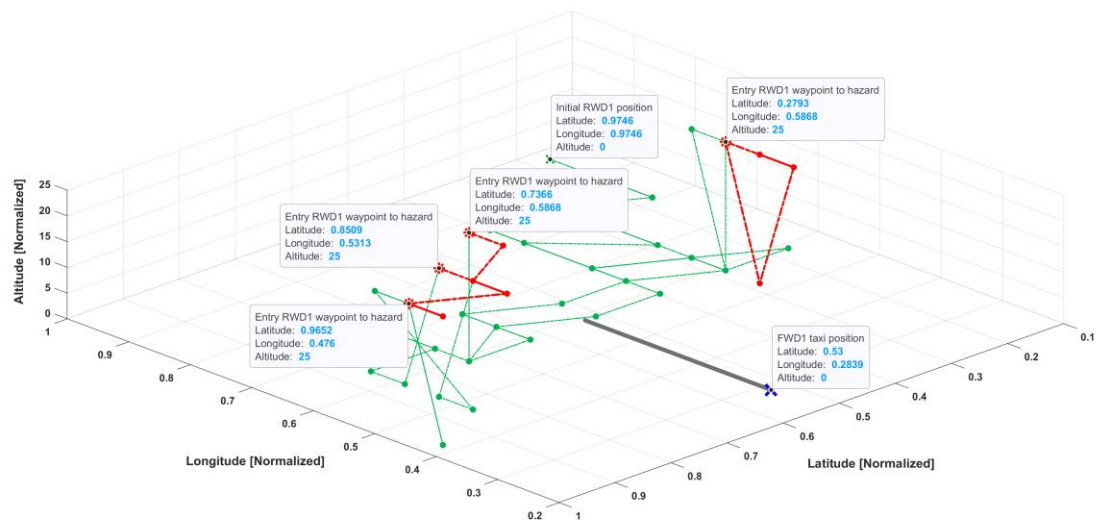


**Figure 19.** ADSB-based localization for SA of RWD1 with countermeasure in repetition.

The RWD1 trajectory in green means there is no hazard, and it is displayed in the user interface of the DDS software application as “Flight Safety” in Figure 20. The RWD1 trajectory in red means there is hazard, and it is displayed in the user interface of the DDS software application as “Flight Safety Caution” in Figure 21.

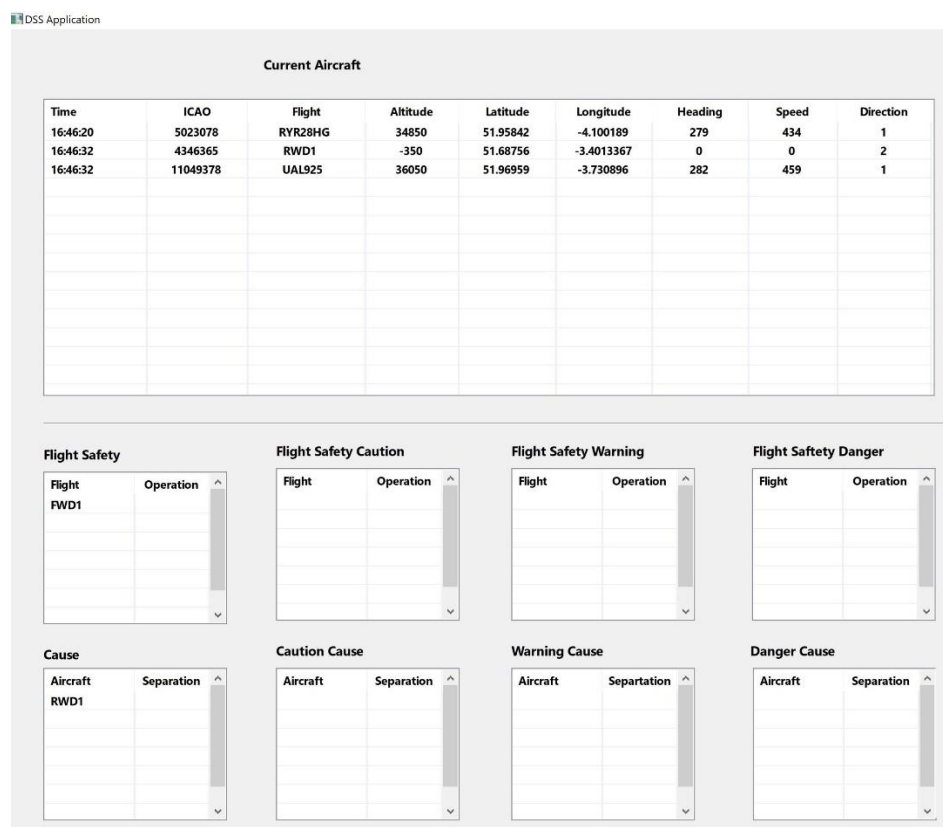


**Figure 20.** DDS user interface from repetition of the office testing trial (SA: Flight Safety).

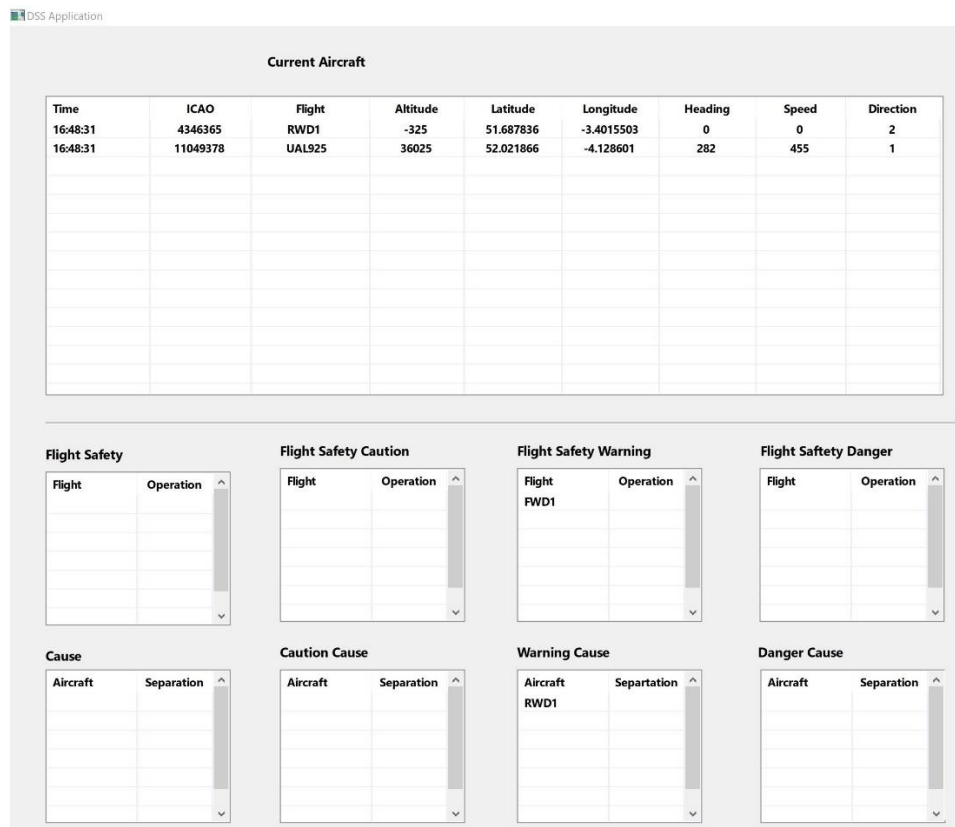


**Figure 21.** DSS user interface for repetition of the office testing trial (SA: Flight Safety Warning).

Figure 22 shows the trajectory produced by the ADS-B transmitter when simulating the RWD1 flight with the following setting: aircraft unauthorized to fly, and no countermeasure (none) for possible mid-air collision. RWD1 is assumed to take off right ahead (on the right) of the runway (straight line in dark grey) where FWD1 is assumed to be taxed (blue cross) at all the time.

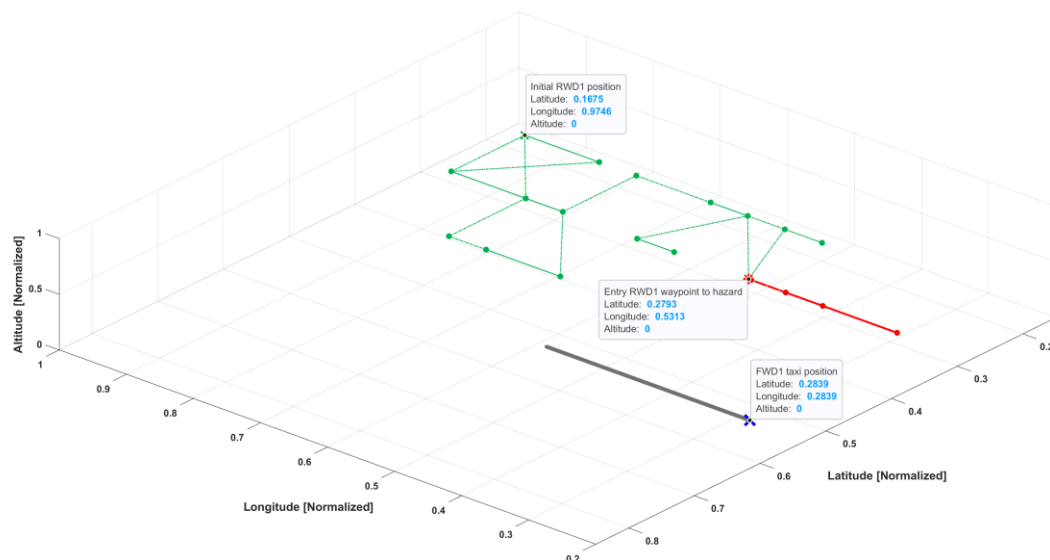


**Figure 22.** ADSB-based localization for SA of RWD1 without countermeasure in repetition.

The RWD1 trajectory in green means there is no hazard, and it is displayed in the user interface of the DDS software application as “Flight Safety” in Figure 23. The RWD1 trajectory in red means there is hazard, and it is displayed in the user interface of the DDS software application as “Flight Safety Caution” in Figure 24.

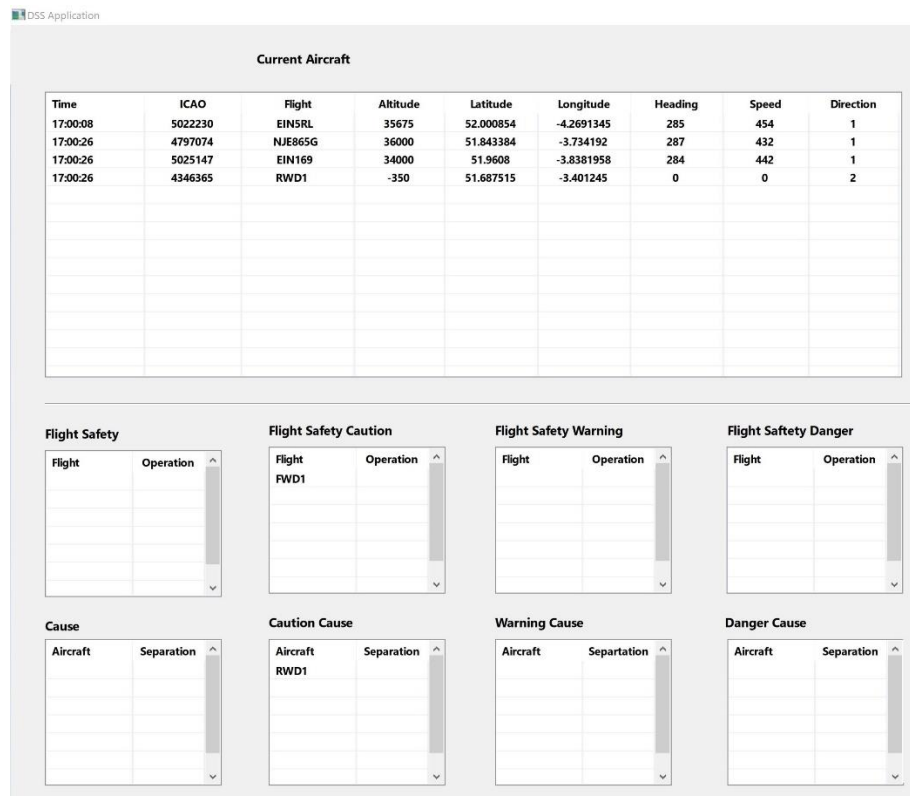


**Figure 23.** DSS user interface from repetition of the office testing trial (SA: Flight Safety Caution).

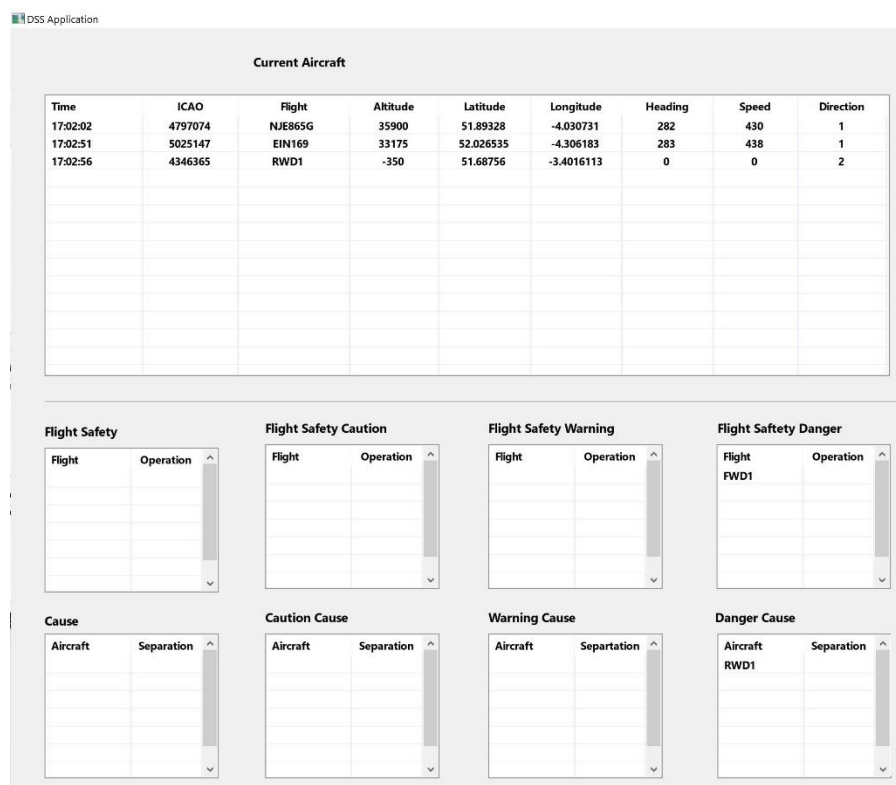


**Figure 24.** DSS user interface for repetition of the office testing trial (SA: Flight Safety Caution Danger).

### 4.3 Discussion on Experimental Office Results

The constraints set by the testing limitations as discussed in Table 5 do not invalid the experimental results as the fact of not having the physical drones along with the ADS-B transmitters and human begins taken the devices as if the drones are flying is transparent for the AAO embedded in the DSS software application running in the GOS computer connected to the ADS-B receiver.

The location of the simulated FWD1 is adjusted based on the GPS obtained for it and the information provided by Google Maps. Such a location is also compared with the ones provided by the ADS-B messages from RWD1 to check if the distance between aircraft is coherent.

One of the main challenges when running the office trials is accuracy in locations provided by the Global Position System (GPS) embedded in the ADS-B transmitter (Figure 95). The typical 1-metre deviation provided by the GPS plus the small garden area used for the trials (as introduced in Table 5), make a combination that has an important impact on the measure of the locations of RWD1 (simulated by moving a ADS-B transmitter with a hand). This problem also affects the altitude, which is produce by a barometric pressure sensor (in the ADS-B transmitter) combined by the altitude information provided by the GPS. The altitude readings only change around 7 feet (a bit more than 2 meters) and it does not happen every time that difference of altitude happens. Therefore, 0 unit of altitude (normalized with the minimum altitude) in the experimental results does not mean RWD1 (simulated) moves (flies) toughing the floor or nearly doing it. It rather means their altitude can well be in a range 0-7 feet from the floor. This altitude problem does not affect FWD1 as it is assumed to be place and immobile on ground (taxied for take-off).

The RWD1 waypoint (shown as a dot in Figure 11 and Figure 19) can be a single waypoint or multiple waypoints received by the ADS-B receiver (Figure 94). The connecting lines between them are meant to show the RWD1 trajectory without specifying the RWD1 direction. This means RWD1 flies between connected waypoints (dots) but it does not mean the displayed flight path is exactly the one taken by RWD1. The waypoint-defined path is to show the RWD1 flight.

The increase of the critical distance between the drone (RWD1) and the airplane (FWD1) provides a more reasonable sensitivity of the DSS that can be seen in the experimental results. In the OTR1, hazardous waypoints of RWD1 are closer to FWD1 than in the repetition, e.g., for the case of RWD1 with countermeasure in Figure 11 (OTR1) , and Figure 19 (OTR2).

The experience from the office testing trials helps do the subsequent testing trials. The experimental results from these trials enable to the garden testing trials as a further evaluation stage of the framework prototype.

## 5 Garden Testing Trials

This section discusses details from the garden testing trial, including technical specifications and experimental results.

### 5.1 General Aspects of the Trails

The garden testing trial involves a computer (GOS) running the Dump1090 software application and the DSS software application. The GOS has a specific location, and it is assumed to be next to ATCs for its use. The GOS's location does not affect SAW of the aircraft involved in this trial. RWD1 is assumed to fly outdoor in different airspace areas near and around FWD1 while it is assumed to be landing. FWD1 plays a role of any aircraft (e.g., a commercial airplane) landing. FWD1 is airborne at the beginning of the test and ends up landed in a runway. The reference point (FWD1) to check distance for potential collision is mobile in this testing trial.

The assumption of the existence of RWD1 and FWD1 is simulated as an ADS-B Transmitter represents each of them (two transmitters) but RWD1 and FWD1 are not physically used. The moves of them are simulated by moving the ADS-B Transmitters with a hand as they were the real aircraft.

Table 14 shows the details of the garden testing task carried out. The specification presented in this table applies to all the garden testing trials. The following subsection show the updates and changes for the different prototype configurations used for the garden testing trials.

**Table 14.** General information for office testing trials.

|                                |                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|--------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Testing Location</b>        | Garden                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <b>Testing Facility</b>        | (Indoor) home office and (outdoor) garden space                                                                                                                                                                                                                                                                                                                                                                                            |
| <b>System Context</b>          | Figure 6                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| <b>Use case</b>                | Use Case 1: Take-off and Landing (Section 2)                                                                                                                                                                                                                                                                                                                                                                                               |
| <b>Application Scenario</b>    | Derived from Application Scenario 1.2 (Figure 2)                                                                                                                                                                                                                                                                                                                                                                                           |
| <b>Prototype Configuration</b> | B, C (Table 2)                                                                                                                                                                                                                                                                                                                                                                                                                             |
| <b>Hardware Platform</b>       | <ul style="list-style-type: none"> <li>• ADS-B Receiver – FlightAware Pro Stick Plus (Figure 94)</li> <li>• ADS-B Transmitter – uAvionix EchoSky 2 (Figure 95)</li> <li>• RWD1 (simulated drone flight; taken by hand to different positions)</li> <li>• FWD1 (simulated airplane flight with landing; taken by hand to different positions)</li> <li>• GOS computer</li> <li>• LIDAR (only used for prototype configuration C)</li> </ul> |
| <b>Software Application</b>    | <ul style="list-style-type: none"> <li>• DSS software application</li> <li>• Dump1090 application</li> </ul>                                                                                                                                                                                                                                                                                                                               |
| <b>Testing Equipment</b>       | Radiation Detector: GQ Electronics EMF Meter [15]                                                                                                                                                                                                                                                                                                                                                                                          |
| <b>Testing Area</b>            | <ul style="list-style-type: none"> <li>• 27 m x 21 m = 567 m<sup>2</sup></li> </ul>                                                                                                                                                                                                                                                                                                                                                        |
| <b>Testing Setup</b>           | <ul style="list-style-type: none"> <li>• DSS software application is up and running in the GOS.</li> <li>• ADS-B Receiver is power on as it is plugged in the GOS computer.</li> <li>• ADS-B Transmitter is power on.</li> <li>• RWD1 is assumed to be initially landed and in an initial given position.</li> <li>• FWD1 is assumed to be landing and heading to the runway.</li> </ul>                                                   |
| <b>Testing Limitations</b>     | <ul style="list-style-type: none"> <li>• Drones that are allowed to flight nearby neighbourhood are small (&lt;250 grs) and are not able to carry the ADS-B transmitter payload. Thus, their flights (in these trials) are simulated by taken the ADS-B transmitters by hand in the case of RWD1 (UAV) and FWD1 (MAV).</li> <li>• Small outdoor area for testing that reduces possible locations for the simulated drones.</li> </ul>      |

Table 15 presents details of the framework prototype configuration for the garden testing trial. The run of this trial is done for RWD1 with and without countermeasure (PilotContact). The integrated transmitters are placed outdoor while the GOS is placed indoor for these trials. However, the trials are called Garden Testing trials because FWD1 is assumed to be taxied and indoor, but the ADS-B transmitters must be outdoor due to the GPS signal it requires.

**Table 15.** Prototype configuration for the garden testing trial.

|            | <b>Role</b> | <b>ADS-B</b> | <b>Authorization</b> | <b>Countermeasure</b> | <b>Traffic</b> | <b>Flight</b> | <b>Place</b> |
|------------|-------------|--------------|----------------------|-----------------------|----------------|---------------|--------------|
| <b>GOS</b> | Operator    | Receiver +   | N/A                  | N/A                   | N/A            | N/A           | Home         |

|              |                                         |                        |     |                     |      |                   |              |
|--------------|-----------------------------------------|------------------------|-----|---------------------|------|-------------------|--------------|
|              | unit                                    | antenna                |     |                     |      |                   | office       |
| <b>RWD1</b>  | (Supposed) AUV                          | Integrated transmitter | No  | None / PilotContact | FWD1 | Landed / airborne | Garden space |
| <b>RWD2</b>  | Not used                                |                        |     |                     |      |                   |              |
| <b>RWD3</b>  | Not used                                |                        |     |                     |      |                   |              |
| <b>FWD1</b>  | (Supposed) MAV                          | Integrated transmitter | Yes | PilotContact        | RWD1 | Landing / landed  | Garden space |
| <b>FWD2</b>  | Not used                                |                        |     |                     |      |                   |              |
| <b>LIDAR</b> | Only used for prototype configuration C |                        |     |                     |      |                   |              |

The garden-testing trials entail two runs: GTR1 and GTR2, both for prototype configuration B.

## 5.2 Trials for Prototype Configuration B

The very first garden testing trial carried out is GTR1 and it is based on configuration B of the framework prototype. The following subsection discuss details of the trial.

### 5.2.1 Technical Details of the Trails

Table 16 shows information in addition to the specifications shown in Table 14 to provide details from

**Table 16.** Additional information for office testing trial for prototype configuration C (GTR1).

|                              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Date and Time</b>         | Thu, 6 Mar 2023, 16:00 - 16:30                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <b>Weather Condition*</b>    | cloudy, 6 °C, 1005.00mb, 83%, 21 km/h, 10 km                                                                                                                                                                                                                                                                                                                                                                                                                       |
| <b>Environment Radiation</b> | <p>The following measures are with the ADS-B transmitter(s) off</p> <ul style="list-style-type: none"> <li>• (Indoor) home office <ul style="list-style-type: none"> <li>○ EMF: 0.0 - 0.1mG</li> <li>○ EF: 2 V/m</li> <li>○ RF: 0.002 – 0.060 mW/m<sup>2</sup></li> </ul> </li> <li>• (Outdoor) garden space <ul style="list-style-type: none"> <li>○ EMF: 0 - 0.1mG</li> <li>○ EF: 0 - 1 V/m</li> <li>○ RF: 0.001 – 0.181 mW/m<sup>2</sup></li> </ul> </li> </ul> |

\* Source: <https://www.foreca.com>

Figure 25 shows the context of the framework prototype for the garden testing trial with prototype configuration C.

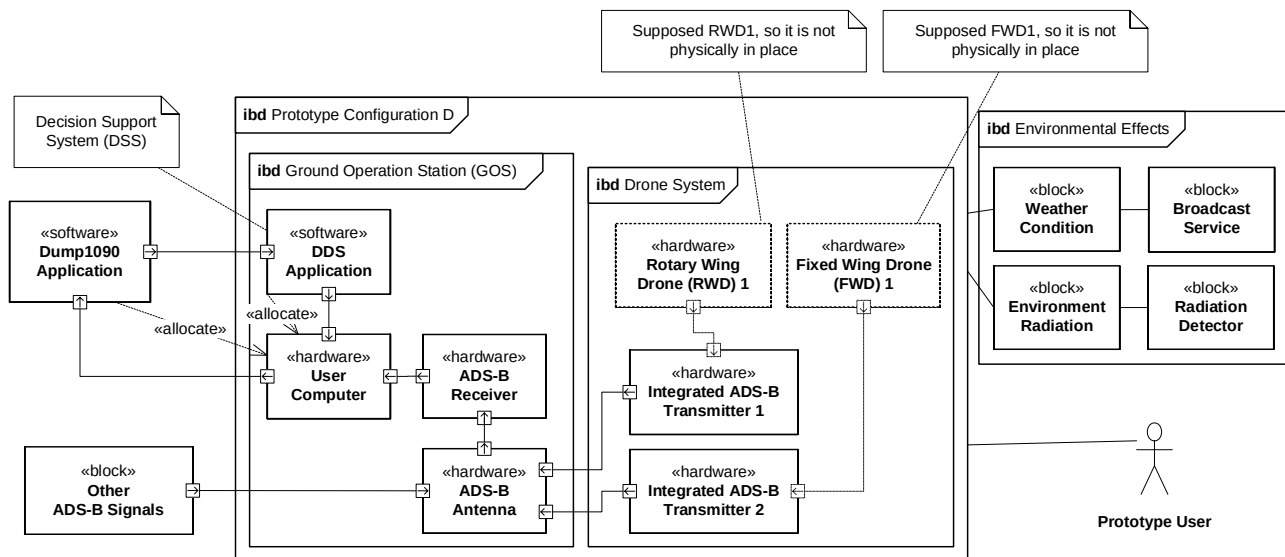


**Figure 25.** Prototype configuration B for the garden testing trial (GTR1).

Figure 10 shows details of the interaction between key elements from the application scenario of the framework prototype for the office testing trial with prototype configuration B.

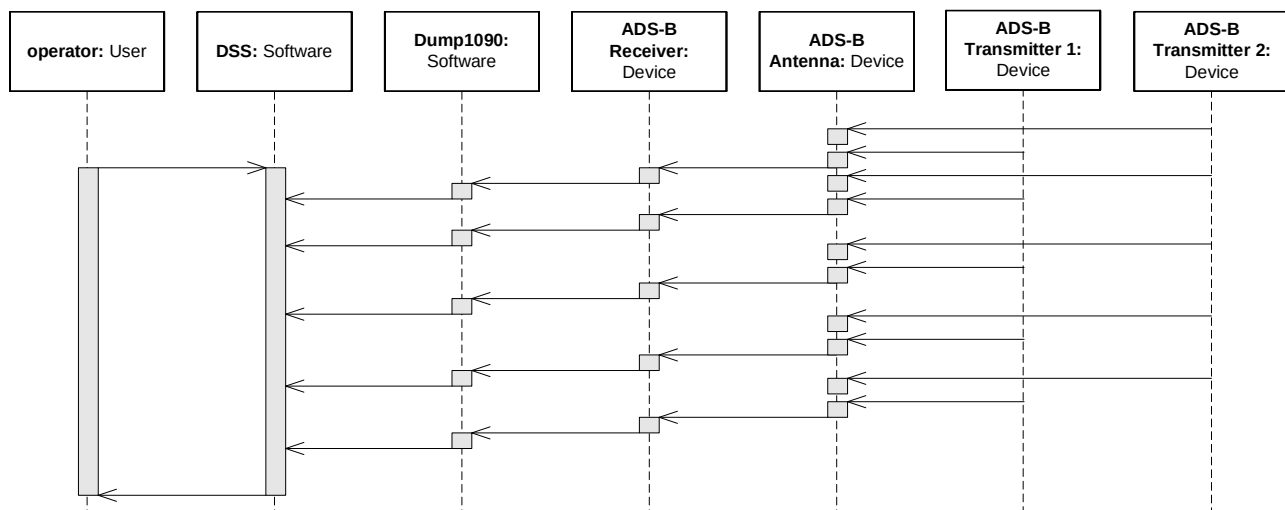


**Figure 26.** Application scenario in the garden testing trials (GTR1 and GTR2).

Table 17 presents the test cases for the office testing trial with prototype configuration B.

**Table 17.** Summary of test cases for the office testing trials (GTR1).

| Mission Phase | Use Case | Application Scenario | Prototype Configuration | Test Case                                   |
|---------------|----------|----------------------|-------------------------|---------------------------------------------|
| Pre-mission   | 1        | 1.2                  | B                       | ADS-B RF link (Table 18)                    |
|               |          |                      |                         | IP/TCP data link (Table 10)                 |
| In-Mission    | 1        | 1.2                  |                         | SAW of RWD1 with countermeasures (Table 19) |
|               |          |                      |                         | SAW of RWD1 without countermeasures         |
| Post-mission  | 1        | 1.2                  |                         | DSS information logging (Table 12)          |

### 5.2.2 Pre-Mission Phase

The purpose of the pre-mission garden testing for prototype configuration B is to check the functions of the framework prototype are correct and the right operation of it by means of two test cases as those presented in subsection 4.2.2. However, two ADS-B transmitters are used in this trial as one of them is used to simulate each drone, i.e., RWD1 and FWD1. Therefore, the test procedure for ADS-B RF link (Table 9) has extra test steps as shown in Table 18.

**Table 18.** Test procedure for checking two ADS-B RF links.

| Test Step | User Action                                                                        | Expected Results                                                                        | Observed Results                                                                 | Result Status                                                                           |
|-----------|------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|
| 1         | Run the Dump1090 application in the GOS                                            | The Dump1090 application should be up and running                                       | The Dump1090 application is up and running                                       | The Dump1090 application keeps up and running                                           |
| 2         | Switch the ADS-B transmitters on                                                   | The ADS-B transmitters should be on                                                     | The ADS-B transmitters are on                                                    | The ADS-B transmitters keep on                                                          |
| 3         | Check the ADS-B transmitters send correct data out                                 | The ADS-B transmitters should send correct data out (ADS-B light is blinking in green)  | The ADS-B transmitters send correct data out (ADS-B light is blinking in green)  | The ADS-B transmitters keep sending correct data out                                    |
| 4         | Check the Dump1090 application receives the ADS-B data from the ADS-B transmitters | The Dump1090 application should be receiving the ADS-B data from the ADS-B transmitters | The Dump1090 application is receiving the ADS-B data from the ADS-B transmitters | The DSS software application keeps receiving the ADS-B data from the ADS-B transmitters |
| 5         | Switch the ADS-B transmitters off                                                  | ADS-B transmitters should be off                                                        | ADS-B transmitters are off                                                       | ADS-B transmitters keep off                                                             |
| 6         | Stop the Dump1090 application in the GOS                                           | The Dump1090 application should be down and off                                         | The Dump1090 application is down and off                                         | The Dump1090 application keeps down and off                                             |

The test procedure for the ADS-B RF link functioning and DSS software application functioning test cases are as discussed in subsection 4.2.2.

### 5.2.3 In- Mission Phase

The purpose of the in-mission garden testing for prototype configuration B is to check the correct functioning and operation of the DSS by means of two main test cases: SAW of RWD1 (represented by an ADS-B transmitter) with countermeasures and SAW of RWD1 without countermeasures while FWD1 (represented by another ADS-B transmitter) is landing.

The test procedure for the test case on SAW of RWD1 with countermeasures requires: (1) the ADS-B transmitters are off, (2) an ADS-B transmitter is positioned on the floor (assuming RWD1 is landed), (3) another ADS-B transmitter is hold (by hand) as high as possible (assuming it is the initial FWD1's altitude for the landing), (4) the ADS-B stick is connected to the GOS computer, (5) the Dump1090 application is up and running, and (6) the DSS software application is up and running in the GOS. Table 19 shows the steps for the test case on SAW of RWD1 with countermeasures for the in-mission office testing.

**Table 19.** Test procedure for SAW of simulated RWD1 with countermeasures.

| Test Step | User Action | Expected Results | Observed Results | Result Status |
|-----------|-------------|------------------|------------------|---------------|
|-----------|-------------|------------------|------------------|---------------|

|   |                                                                                                                                                 |                                                                                                            |                                                                                                      |                                                                                                             |
|---|-------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------|
| 1 | Run the Dump1090 application in the GOS                                                                                                         | The Dump1090 application should be up and running                                                          | The Dump1090 application is up and running                                                           | The Dump1090 application keeps up and running                                                               |
| 2 | Run the DSS software application in the GOS                                                                                                     | The DSS software application should be up and running                                                      | The DSS software application is up and running                                                       | The DSS software application keeps up and running                                                           |
| 3 | Check the Dump1090 and the DSS are connected with each other using TCP/IP protocol                                                              | The Dump1090 application and the DSS software application should be TCP/IP connected with each other       | The Dump1090 application and the DSS software application are TCP/IP connected with each other       | Both applications keep connected with each other using the TCP/IP protocol                                  |
| 4 | Place an ADS-B transmitter on the ground (as if RWD1 is landed) and hold the other ADS-B transmitter (as high as possible), then switch them on | The ADS-B transmitters should be on                                                                        | The ADS-B transmitters are on                                                                        | The ADS-B transmitters keep on                                                                              |
| 5 | Check if the DSS software application displays SAW involving the two ADS-B transmitters (RWD1 and FWD1) accordingly                             | SAW of simulated RWD1 and simulated FWD1 should be displayed in the DSS software application               | SAW of simulated RWD1 and simulated FWD1 are displayed in the DSS software application               | The DSS software application keeps displaying SAW of simulated RWD1 and simulated FWD1                      |
| 6 | Check the DSS software application receives the ADS-B data from the ADS-B transmitters                                                          | DSS software application should receive the ADS-B data from the ADS-B transmitters                         | The DSS software application receives the ADS-B data from the ADS-B transmitters                     | The DSS software application keeps receiving the ADS-B data from the ADS-B transmitters                     |
| 7 | Start moving the ADS-B transmitter for simulated FWD1 as if it is landing (i.e., straight direction and losing altitude)                        | The DSS software application should provide SAW of the ADS-B transmitter (simulating FWD1)                 | The DSS software application provides SAW of the ADS-B transmitter (simulating FWD1)                 | The DSS software application keeps providing SAW of the ADS-B transmitter (simulating FWD1)                 |
| 8 | Start moving the ADS-B transmitter for simulated RWD1 as if it is flying around in locations close to simulated FWD1                            | The DSS software application should provide SAW of the ADS-B transmitter (simulating RWD1 flying around)   | The DSS software application provides SAW of the ADS-B transmitter (simulating RWD1 flying around)   | The DSS software application keeps providing SAW of the ADS-B transmitter (simulating RWD1 flying around)   |
| 9 | Try to get RWD1 in an airspace zone that is not hazardous for FWD1 taking off (while FWD1 is moving forward as it is landing)                   | The DSS software application should accordingly provide SAW of simulated RWD1 flying around simulated FWD1 | The DSS software application provides SAW of simulated RWD1 flying around simulated FWD1 accordingly | The DSS software application keeps providing SAW of simulated RWD1 flying around simulated FWD1 accordingly |

|    |                                                                                                                  |                                                                                                                   |                                                                                                             |                                                                                                             |
|----|------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------|
| 10 | Land the ADS-B transmitter for simulated RW1 and stop moving the ADS-B transmitter for simulated FWD1            | The DSS software application should accordingly keep providing SAW of simulated RWD1 flying around simulated FWD1 | The DSS software application keeps providing SAW of simulated RWD1 flying around simulated FWD1 accordingly | The DSS software application keeps providing SAW of simulated RWD1 flying around simulated FWD1 accordingly |
| 11 | Switch the two ADS-B transmitters off                                                                            | The two ADS-B transmitters should be off                                                                          | The two ADS-B transmitters is off                                                                           | The two ADS-B transmitters keep off                                                                         |
| 12 | Check if the DSS software application does not display SAW involving simulated RWD1 flying around simulated FWD1 | SAW of simulated RWD1 flying around simulated FWD1 should not be displayed by the DSS software application        | SAW of simulated RWD1 flying around simulated FWD1 is not displayed by the DSS software application         | The DSS software application keeps not displaying SAW of simulated RWD1 flying around simulated FWD1        |

The steps for the test case on SAW of RWD1 with countermeasures and without countermeasures (as introduced in Figure 5) for the in-missing park testing trial are the same than the ones presented in subsection 4.2.3. However, physical RWD1 and FWD1 are used in this test.

#### 5.2.4 Post-Mission Phase

The purpose of the post-mission park testing for prototype configuration B is to check whether the DSS can log the information broadcasted by the ADS-B transmitter. The test procedure for this test case requires: (1) assumption RWD1 and FWD1 are landed, and (2) the ADS-B transmitter assumed on board RWD1 and FWD1 are kept off.

#### 5.2.5 Experimental Results from GTR1

Figure 27 and Figure 30 present the experimental results from the GTR1 of the garden testing trials (in-mission phase). The figures also show details of areas (flight waypoints) which means hazards of potential collision between aircraft (RW1 and FWD1; both assumed). The closest distance that the aircraft can be without becoming a hazard is set at 170 units (*inDistance* = 170).

Figure 27 shows the trajectory produced by the ADS-B transmitter when simulating the RWD1 flight with the following setting: aircraft unauthorized to fly, and countermeasure (PilotContact) for possible mid-air collision. RWD1 is assumed to initially take off (green cross) ahead (on the right) of the runway (straight line in dark grey) where FWD1 is assumed to be landing with an initial position (blue cross).

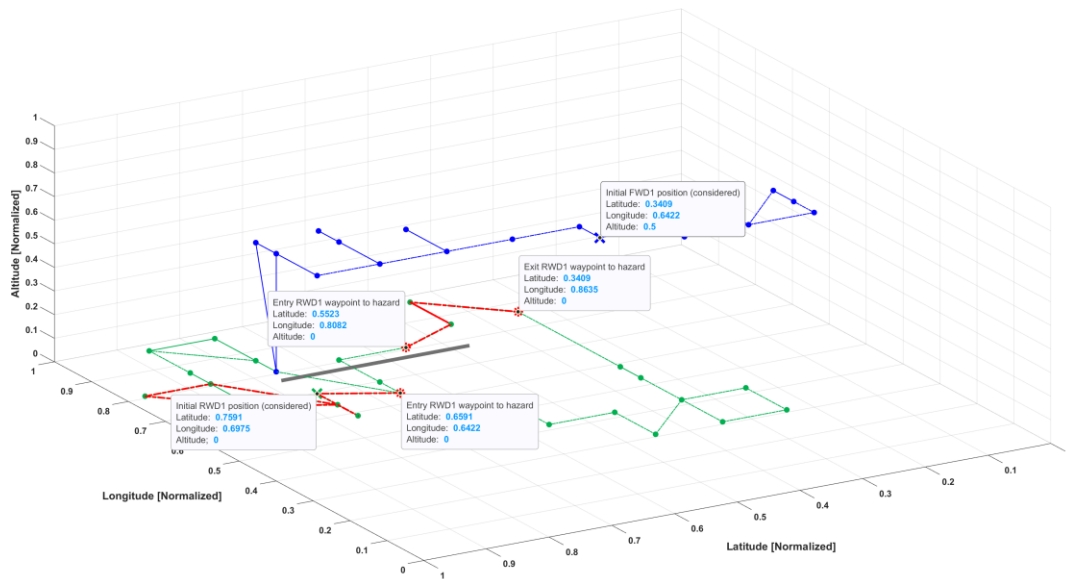


**Figure 27.** ADSB-based garden localization for SA of RWD1 with countermeasure.

RWD1 takes off from the north area of the garden (left side in Figure 27), then heads south (right side of Figure 27) by crossing over the runway (in grey color) while FWD1 is approaching the runway for landing. This situation does not mean any hazard for FWD1 as the aircraft are properly separated (the distance between them is larger than 170 units). The RWD1 trajectory in green means there is no hazard, and it is displayed in the user interface of the DDS software application as “Flight Safety” in Figure 28.

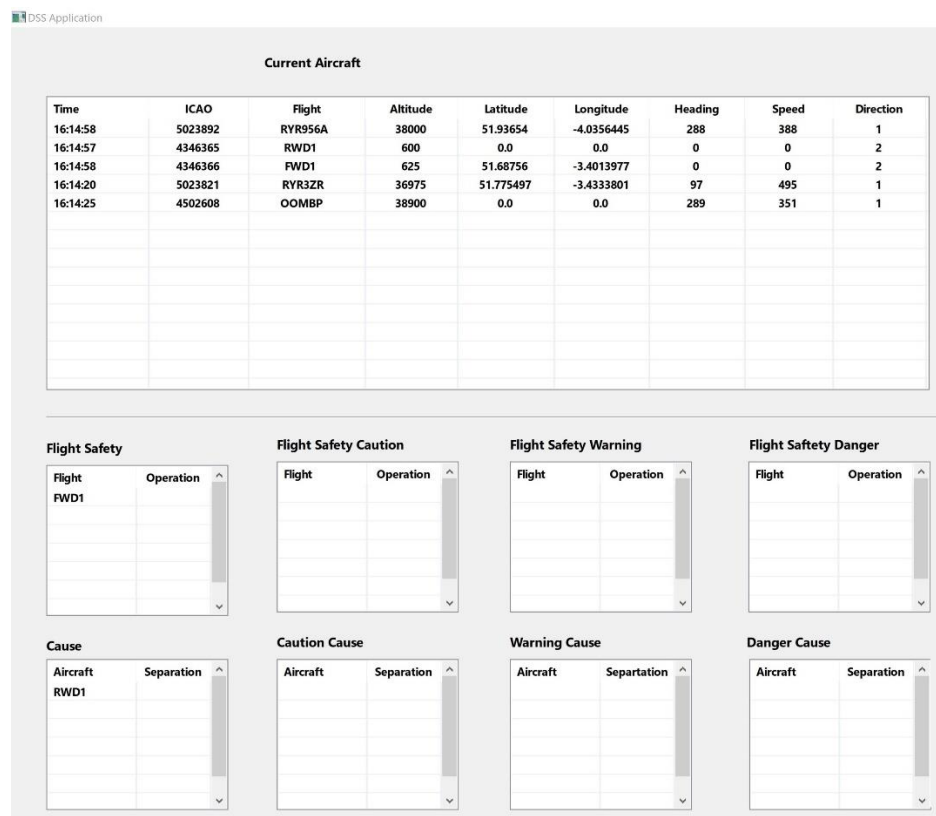


**Figure 28.** DSS user interface from the garden testing trial (SA: Flight Safety).

Then, as they are approaching each other, the air-collision hazard increases since they cross close enough to trigger a safe flight warning (red waypoints on the top of the figure). The RWD1 trajectory in red means there is hazard, and it is displayed in the user interface of the DDS software application as “Flight Safety Warning” in Figure 29. Once FWD1 is landed and about to stop, RWD1 gets close to FWD1 again as it is coming back to its earlier location (in the north). Thus, the hazard returns, and it is shown by means of the red trajectory for RWD1.

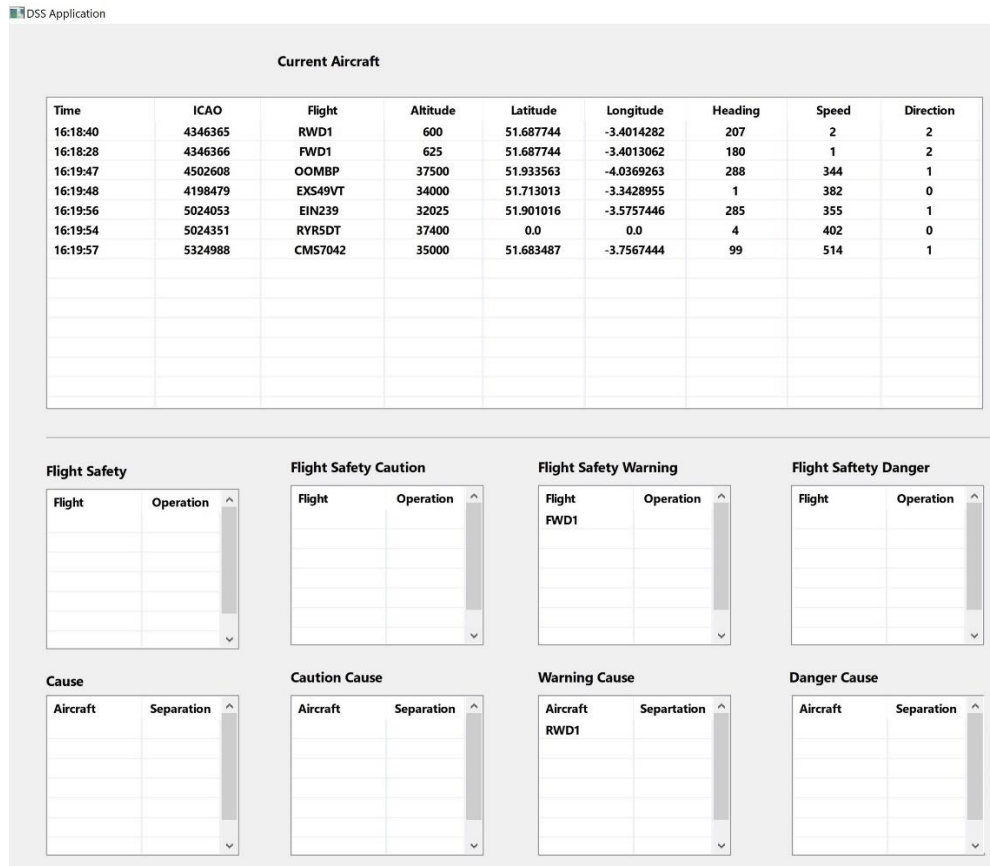


**Figure 29.** DDS user interface from the garden testing trial (SA: Flight Safety Warning).

Figure 30 shows the trajectory produced by the ADS-B transmitter in GTR2 when simulating the RWD1 flight with the following setting: aircraft unauthorized to fly, and no countermeasure (none) for possible mid-air collision. RWD1 is assumed to initially take off (green cross) on the right of the runway (straight line in dark grey) while FWD1 is landing with an initial position (blue cross).

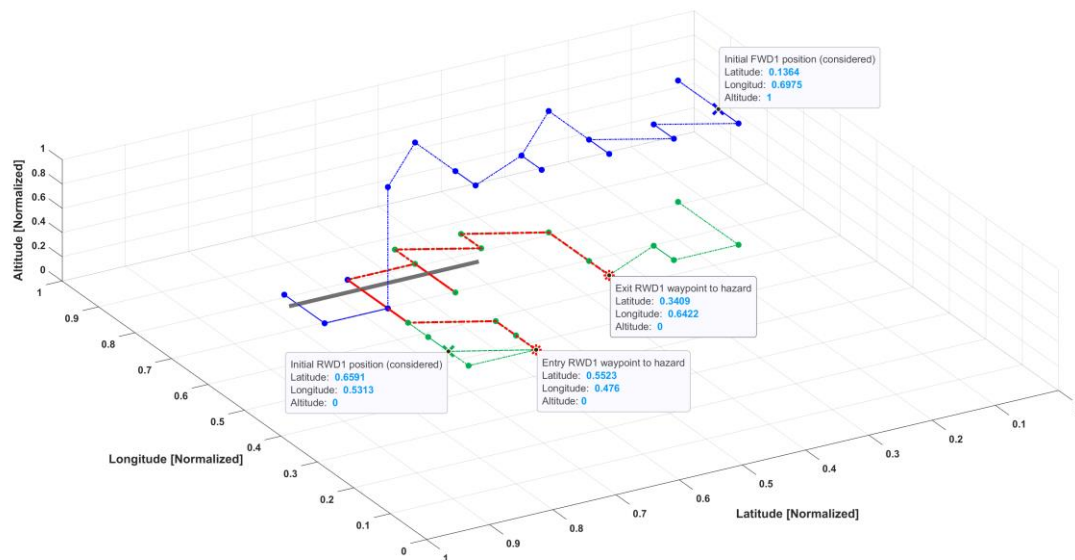


**Figure 30.** ADSB-based garden localization for SA of RWD1 without countermeasure.

RWD1 takes off from the west area of the garden (bottom of Figure 30), then heads south (right side of Figure 30) by crossing over the runway (in grey color) while FWD1 is approaching the runway for landing. This situation does not mean any hazard for FWD1 as the aircraft are properly separated (the distance between them is larger than 170 units). The RWD1 trajectory in green means there is no hazard, and it is displayed in the user interface of the DDS software application as “Flight Safety Caution” in Figure 31.

Then, as they are approaching each other, the air-collision hazard increases since they cross close enough to trigger a safe flight warning (red waypoints on the top of the figure). The RWD1 trajectory in red means there is hazard, and it is displayed in the user interface of the DDS software application as “Flight Safety Danger” in Figure 32. Once FWD1 is landed and about to stop, RWD1 is far away from FWD1 so that the hazard disappears, and it is shown by means of the green trajectory for RWD1.

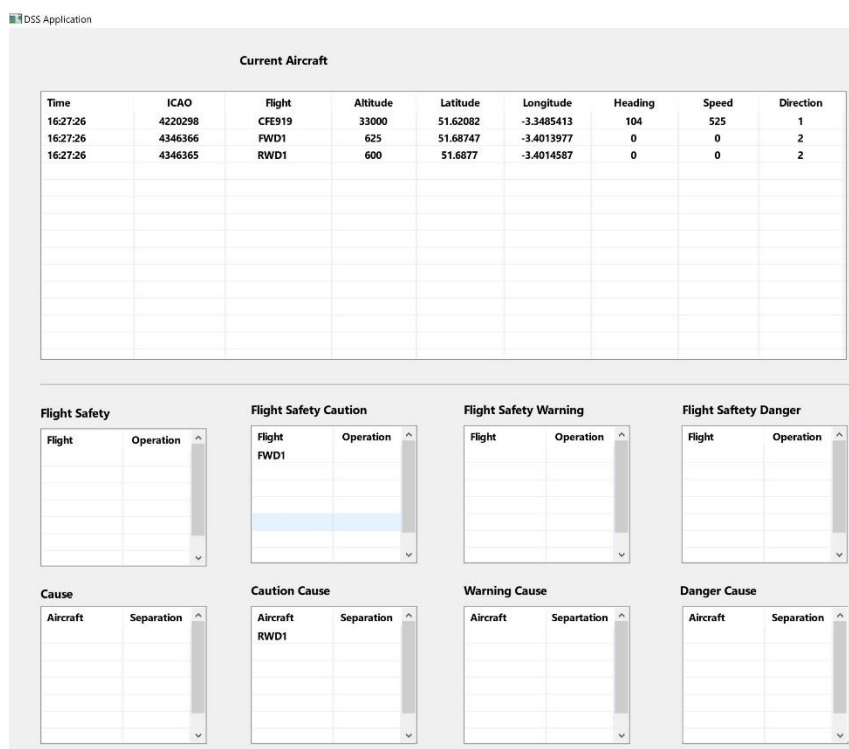


**Figure 31.** DSS user interface from the garden testing trial (SA: Flight Safety Caution).

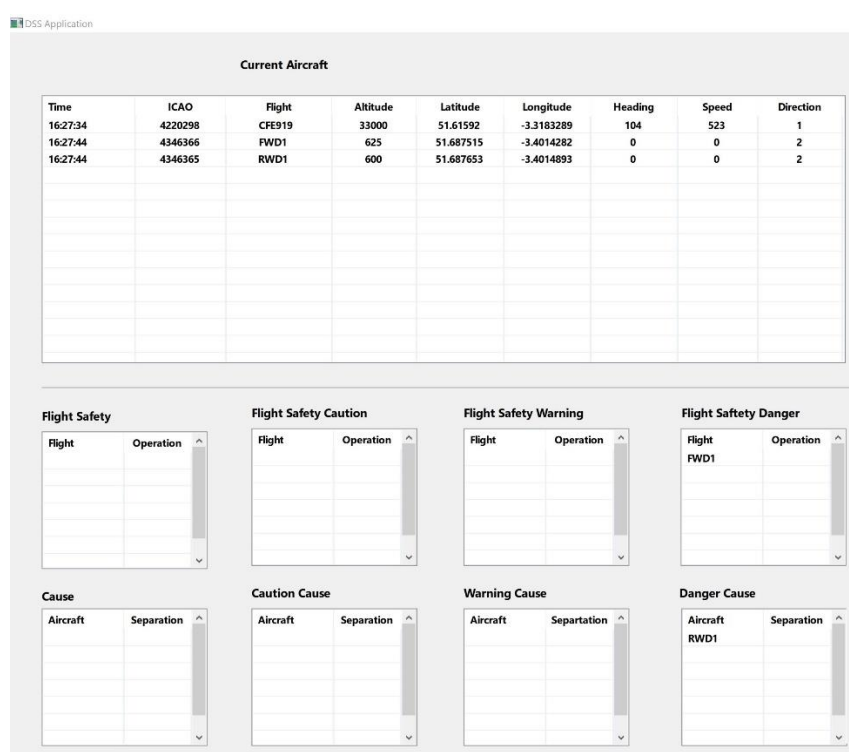


**Figure 32.** DSS user interface from the garden office testing trial (SA: Flight Safety Caution Danger).

### 5.3 Trials for Prototype Configuration C

The second garden testing trial carried out is GTR2 and it is based on configuration C of the framework prototype. The following subsection discuss details of the trial.

### 5.3.1 Technical Details of the Trails

Table 16 shows information in addition to the specifications shown in Table 20 to provide details from

**Table 20.** Additional information for office testing trial for prototype configuration C (GTR2).

|                              |                                                                                                                                                                                                                                                                                         |
|------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Date and Time</b>         | Tue, 28 Nov 2023, 11:30 - 12:00                                                                                                                                                                                                                                                         |
| <b>Weather Condition*</b>    | Partially cloudy, 5 °C, 1004.00mb, 97%, 6 km/h, 10 km                                                                                                                                                                                                                                   |
| <b>Environment Radiation</b> | <p>The following measures are with the ADS-B transmitter(s) off</p> <ul style="list-style-type: none"> <li>• (Outdoor) garden space <ul style="list-style-type: none"> <li>○ EMF: 0 - 0.1mG</li> <li>○ EF: 0 - 1 V/m</li> <li>○ RF: 0.001 – 0.2 mW/m<sup>2</sup></li> </ul> </li> </ul> |

\* Source: <https://www.foreca.com>

Figure 33 shows the context of the framework prototype for the garden testing trial with prototype configuration C for GTR2.

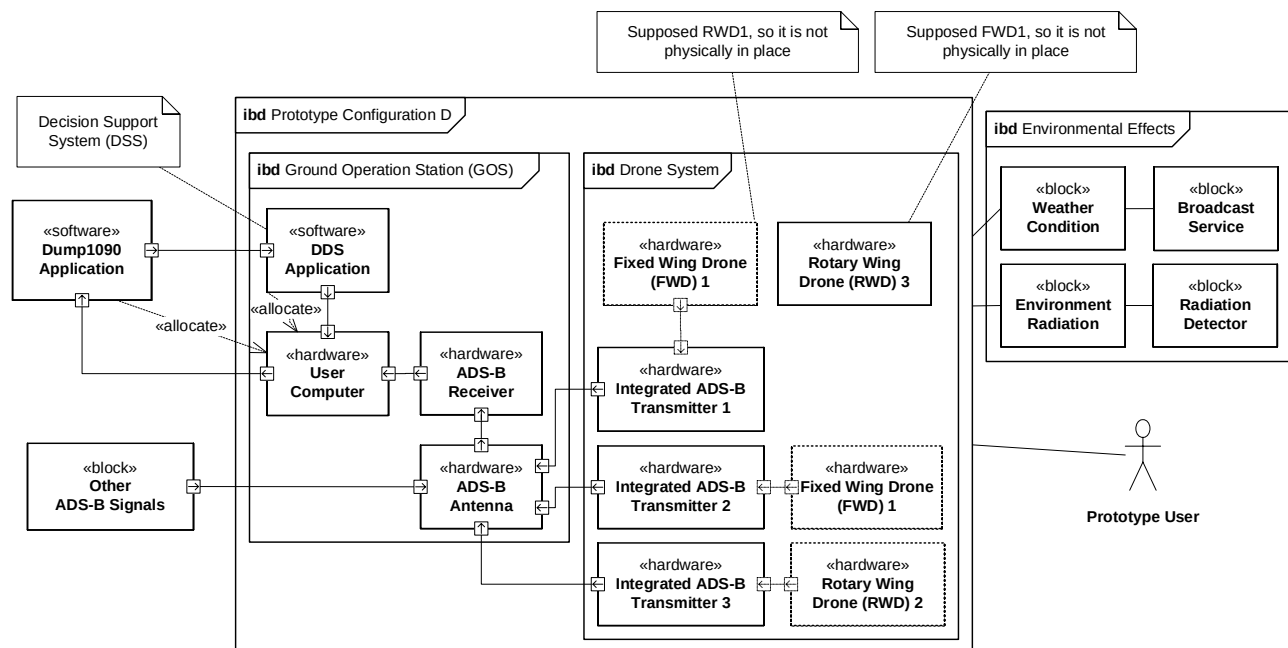
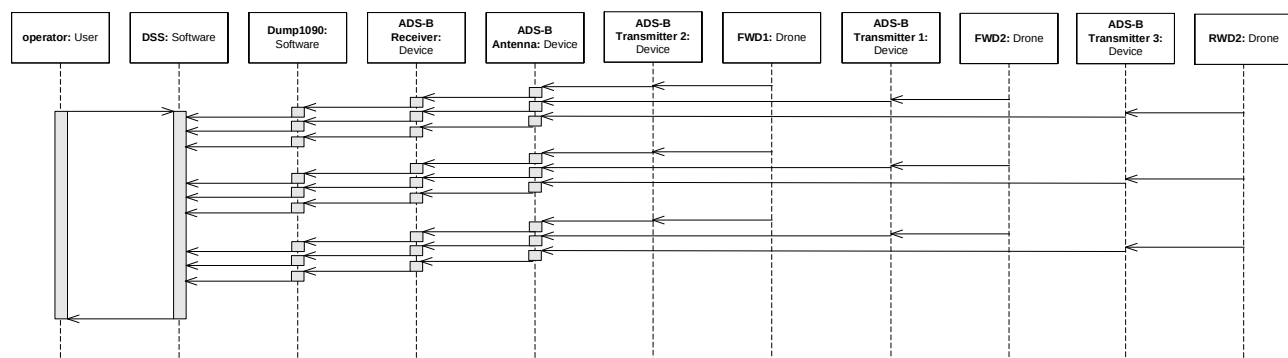
**Figure 33.** Prototype configuration C for the garden testing trial (GTR2).

Figure 34 shows details of the interaction between key elements from the application scenario of the framework prototype for the office testing trial with prototype configuration C for GTR2.

**Figure 34.** Application scenario in the garden testing trials (GTR2).

RWD3 is not involved in the ADS-B communication as it does not carry an ADS-B transmitter.

Table 25 presents the test cases for the garden testing trial with prototype configuration C for GTR2.

**Table 21.** Summary of test cases for the office testing trials (GTR2).

| Mission Phase | Use Case | Application Scenario | Prototype Configuration | Test Case                                                                                                 |
|---------------|----------|----------------------|-------------------------|-----------------------------------------------------------------------------------------------------------|
| Pre-mission   | 1        | 1.1                  | C                       | ADS-B RF link (Table 18)                                                                                  |
|               |          |                      |                         | IP/TCP data link (Table 10)                                                                               |
| In-Mission    | 1        | 1.1                  |                         | SAW of FWD2 with countermeasures, RWD2 without countermeasures, RWD3 without ADS-B transmitter (Table 19) |
| Post-mission  | 1        | 1.1                  |                         | DSS information logging (Table 12)                                                                        |

### 5.3.2 Pre-Mission Phase

The purpose of the pre-mission garden testing for prototype configuration C is to check the functions of the framework prototype are correct and the right operation of it by means of two test cases as those presented in subsection 4.2.2. However, three ADS-B transmitters are used in this trial and each of them is used to simulate each drone, i.e., RWD1, FWD2, and FWD1. RWD3 is physically present in the application scenario as it is light drone (<250 grs), and it allows to fly in the garden. Therefore, the test procedure for ADS-B RF link (Table 9) has extra test steps as shown in Table 18 along with the ones shown in Table 26.

**Table 22.** Test procedure for checking two ADS-B RF links.

| Test Step | User Action                                     | Expected Results                              | Observed Results                       | Result Status                                                |
|-----------|-------------------------------------------------|-----------------------------------------------|----------------------------------------|--------------------------------------------------------------|
| 1         | Switch the LIDAR on                             | The LIDAR should be on                        | The LIDAR is on                        | The LIDAR keeps on                                           |
| 2         | Switch RWD3 on                                  | RWD3 should be on                             | RWD3 are on                            | RWD3 keeps on                                                |
| 3         | Command basic RWD3 moves from remote controller | The RWD3 should respond according to commands | RWD3 responds according to commands    | The RWD3 provides stable flight and returns to idle properly |
| 4         | The LIDAR detects RWD3                          | The LIDAR should detect RWD3 moves            | The LIDAR is able to detect RWD3 moves | The LIDAR keep detecting RWD3                                |
| 5         | Switch RWD3 off                                 | RWD3 should be off                            | RWD3 are off                           | The RWD3 keeps off                                           |
| 6         | Switch the LIDAR off                            | The LIDAR should be off                       | The LIDAR is off                       | The LIDAR keeps off                                          |

The test procedure for the ADS-B RF link functioning and DSS software application functioning test cases are as discussed in subsection 4.2.2.

### 5.3.3 In- Mission Phase

The purpose of the in-mission garden testing for prototype configuration D (GTR2) is to check the correct functioning and operation of the DSS by means of two main test cases: SAW of RWD1, and FWD2 (represented by an ADS-B transmitter) and RWD3, with countermeasures and SAW of RWD1 without countermeasures while FWD1 (represented by another ADS-B transmitter) is landing.

The test procedure for the test case on SAW of RWD1 with countermeasures requires: (1) the ADS-B transmitters are off, (2) an ADS-B transmitter is positioned on the floor (assuming RWD1 is landed), (3) another ADS-B transmitter is hold (by hand) as high as possible (assuming it is the initial FWD1's altitude for the landing), (4) the ADS-B stick is connected to the GOS computer, (5) the Dump1090 application is up and running, and (6) the DSS software application is up and running in the GOS. Table 19 shows the steps for the test case on SAW of the drones (i.e., RWD2, RWD3, and FWD2) for the in-missing office testing.

**Table 23.** Test procedure for SAW of simulated RWD1 with countermeasures (GTR2).

| Test Step | User Action                                                                                                                  | Expected Results                                                                                             | Observed Results                                                                                       | Result Status                                                                                                 |
|-----------|------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------|
| 1         | Run the Dump1090 application in the GOS                                                                                      | The Dump1090 application should be up and running                                                            | The Dump1090 application is up and running                                                             | The Dump1090 application keeps up and running                                                                 |
| 2         | Run the DSS software application in the GOS                                                                                  | The DSS software application should be up and running                                                        | The DSS software application is up and running                                                         | The DSS software application keeps up and running                                                             |
| 3         | Check the Dump1090 and the DSS are connected with each other using TCP/IP protocol                                           | The Dump1090 application and the DSS software application should be TCP/IP connected with each other         | The Dump1090 application and the DSS software application are TCP/IP connected with each other         | Both applications keep connected with each other using the TCP/IP protocol                                    |
| 4         | Switch the LIDAR on                                                                                                          | The LIDAR should be on                                                                                       | The LIDAR is on                                                                                        | The LIDAR keeps on                                                                                            |
| 5         | Switch the ADS-B transmitters on                                                                                             | The ADS-B transmitters should be on                                                                          | The ADS-B transmitters is on                                                                           | The ADS-B transmitters keeps on                                                                               |
| 6         | Place an ADS-B transmitter on the ground (as if RWD2 and FWD2 are landed)                                                    | The ADS-B transmitters should be on                                                                          | The ADS-B transmitters are on                                                                          | The ADS-B transmitters keep on                                                                                |
| 7         | Check if the DSS software application displays SAW involving the three ADS-B transmitters (RWD2, FWD2, and FWD1) accordingly | SAW of simulated RWD2, simulated FWD2 and simulated FWD1 should be displayed in the DSS software application | SAW of simulated RWD2, simulated FWD2 and simulated FWD1 are displayed in the DSS software application | The DSS software application keeps displaying SAW of SAW of simulated RWD2, simulated FWD2 and simulated FWD1 |
| 8         | Check the DSS software application receives the ADS-B data from the ADS-B transmitters                                       | DSS software application should receive the ADS-B data from the ADS-B transmitters                           | The DSS software application receives the ADS-B data from the ADS-B transmitters                       | The DSS software application keeps receiving the ADS-B data from the ADS-B transmitters                       |
| 9         | Start moving the ADS-B transmitter for simulated FWD1 as if it is landing (i.e., straight direction and losing altitude)     | The DSS software application should provide SAW of the ADS-B transmitter (simulating FWD1)                   | The DSS software application provides SAW of the ADS-B transmitter (simulating FWD1)                   | The DSS software application keeps providing SAW of the ADS-B transmitter (simulating FWD1)                   |

|    |                                                                                                                               |                                                                                                                   |                                                                                                             |                                                                                                             |
|----|-------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------|
| 10 | Start moving the ADS-B transmitter for simulated RWD1 as if it is flying around in locations close to simulated FWD1          | The DSS software application should provide SAW of the ADS-B transmitter (simulating RWD1 flying around)          | The DSS software application provides SAW of the ADS-B transmitter (simulating RWD1 flying around)          | The DSS software application keeps providing SAW of the ADS-B transmitter (simulating RWD1 flying around)   |
| 11 | Try to get RWD1 in an airspace zone that is not hazardous for FWD1 taking off (while FWD1 is moving forward as it is landing) | The DSS software application should accordingly provide SAW of simulated RWD1 flying around simulated FWD1        | The DSS software application provides SAW of simulated RWD1 flying around simulated FWD1 accordingly        | The DSS software application keeps providing SAW of simulated RWD1 flying around simulated FWD1 accordingly |
| 12 | Land the ADS-B transmitter for simulated RW1 and stop moving the ADS-B transmitter for simulated FWD1                         | The DSS software application should accordingly keep providing SAW of simulated RWD1 flying around simulated FWD1 | The DSS software application keeps providing SAW of simulated RWD1 flying around simulated FWD1 accordingly | The DSS software application keeps providing SAW of simulated RWD1 flying around simulated FWD1 accordingly |
|    | Switch the two ADS-B transmitters off                                                                                         | The two ADS-B transmitters should be off                                                                          | The two ADS-B transmitters is off                                                                           | The two ADS-B transmitters keep off                                                                         |
|    | Switch the LIDAR off                                                                                                          | The LIDAR should be off                                                                                           | The LIDAR is off                                                                                            | The LIDAR keeps off                                                                                         |
|    | Check if the DSS software application does not display SAW involving simulated RWD1 flying around simulated FWD1              | SAW of simulated RWD1 flying around simulated FWD1 should not be displayed by the DSS software application        | SAW of simulated RWD1 flying around simulated FWD1 is not displayed by the DSS software application         | The DSS software application keeps not displaying SAW of simulated RWD1 flying around simulated FWD1        |

The steps for the test case on SAW of drones (i.e., RWD2, FWD2) with countermeasures and without countermeasures (as introduced in Figure 5) for the in-missing garden testing trial are the same than the ones presented in subsection 4.2.3. However, physical RWD3 and FWD1 are used in this test.

#### 5.3.4 Post-Mission Phase

The purpose of the post-mission park testing for prototype configuration C (GTR2) is to check whether the DSS can log the information broadcasted by the ADS-B transmitter. The test procedure for this test case requires: (1) assumption RWD2, RWD3, FWD2, and FWD1 are landed, and (2) the ADS-B transmitter assumed on board RWD2, FWD2, and FWD1 are kept off, (3) RWD3 is off.

#### 5.3.5 Experimental Results from GTR2

Figure 35 and Figure 36 present the experimental results from the GTR2 of the garden testing trials (in-mission phase) for GTR2. The figures also show details of areas (flight waypoints) which means hazards of potential collision between aircraft (RWD2, RWD3, FWD2, and FWD1; both assumed). The closest distance that the aircraft can be without becoming a hazard is set at 170 units (*inDistance* = 170).

Figure 36 shows the trajectory produced by the ADS-B transmitter when simulating FWD2 flight with the following setting: aircraft unauthorized to fly, and countermeasure (PilotContact) for possible mid-air collision. FWD2 is assumed to initially take off (pink cross) ahead of the runway (straight line in dark grey) where FWD1 is assumed to be taxied with an initial position (blue cross) and ready for take roll. The RWD2 trajectory in red means there is hazard.

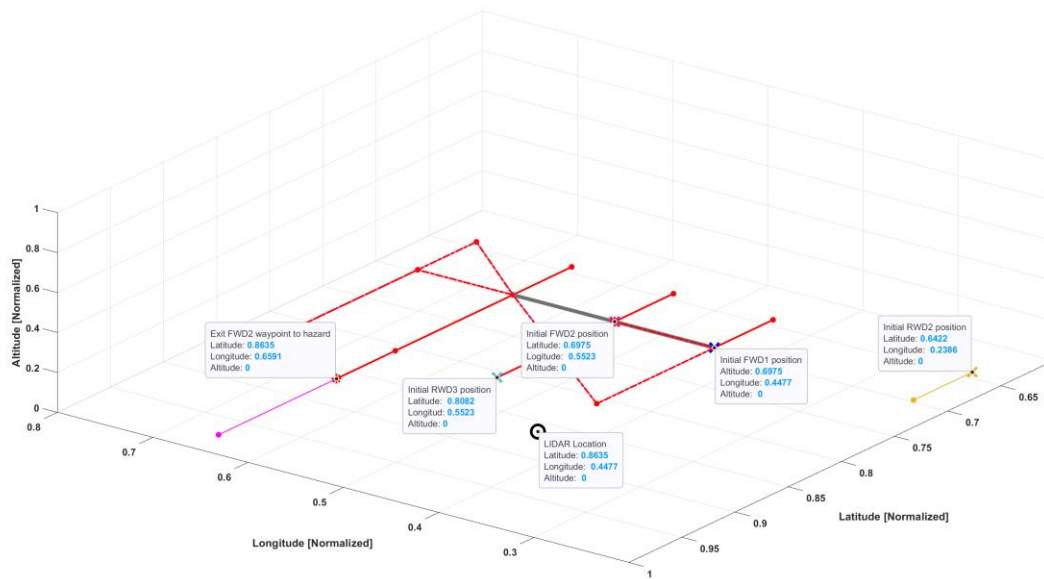


**Figure 35.** ADSB-based garden localization for SA of RWD1 with countermeasure.

Figure 36 also shows the trajectory produced by the ADS-B transmitter when simulating RWD2 flight with the following setting: aircraft unauthorized to fly, and no countermeasure (None) for possible mid-air collision. RWD2 is assumed to initially take off (yellow cross) behind FWD1 and it does not represent any hazard for the FWD1 take off.

RWD3 takes off from the left side, ahead of the runway (light blue cross in Figure 27), then it heads south flying close to FWD1. The RWD3's trajectory is not shown as it is equipped with an ADS-B transmitter. However, its flight is detected by the LIDAR (black circle) and it produces a hazardous situation for FWD1. Figure 36 shows a screenshot of the user interface of the LSC16 software application provided by the LIDAR manufacturer. The altitude of the RWD3 flight is around 1 m.

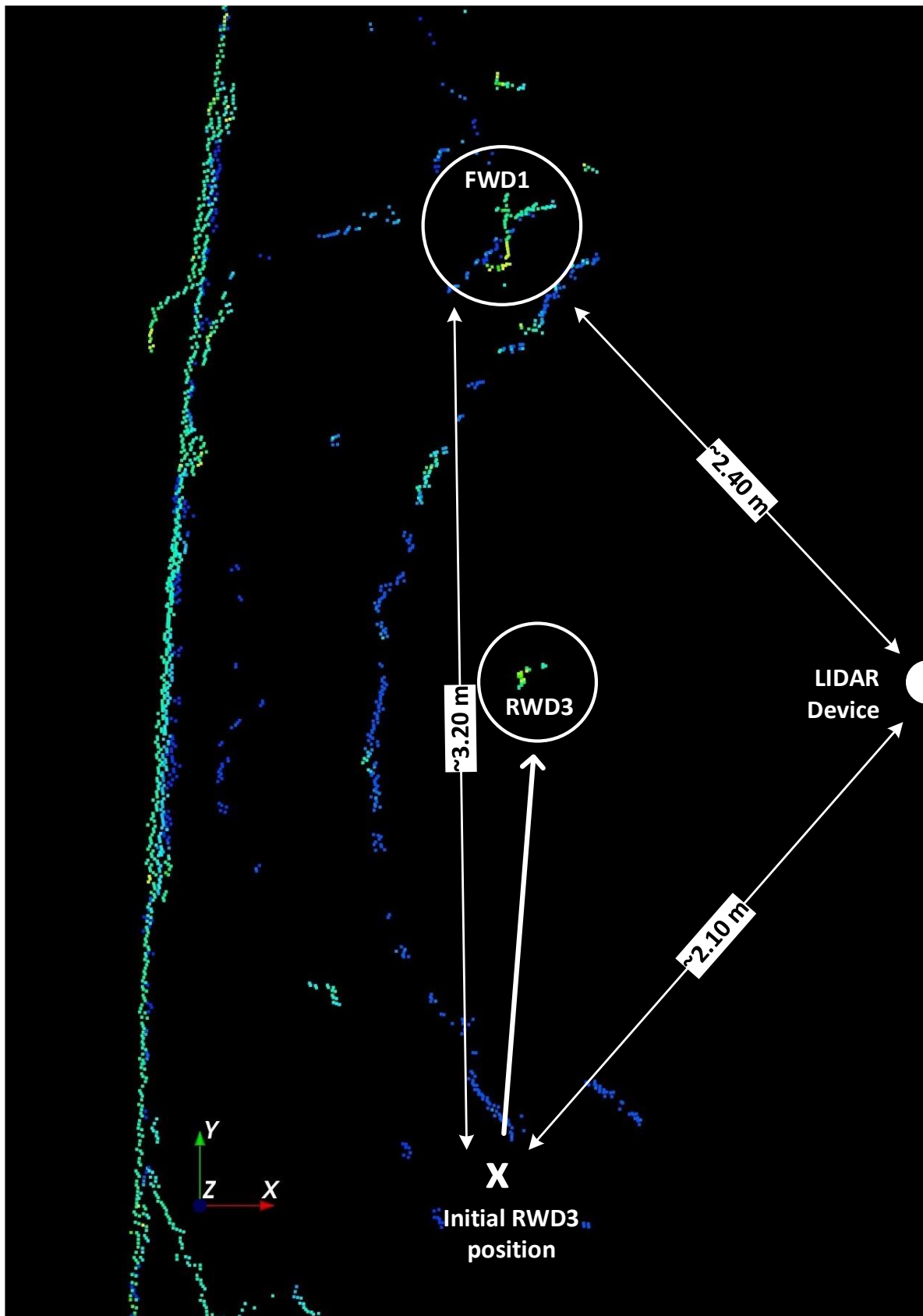


**Figure 36.** Data collected from the LIDAR device for GTR2.

At this stage, the information from the LIDAR is manually inputted in the AAO.

Figure 37 shows the results of such a feeding of information on AAO.

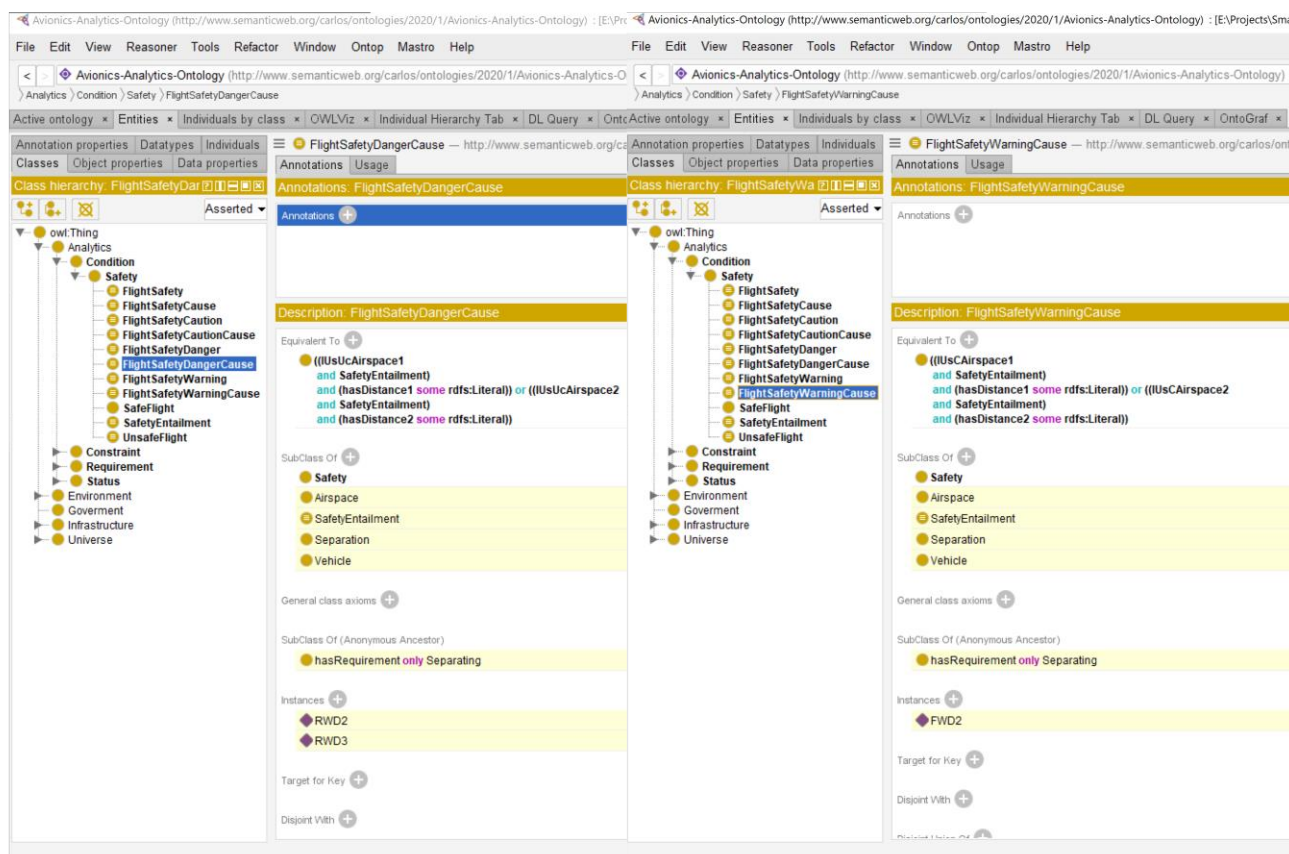


**Figure 37.** Protégé details for cause of Flight Safety Danger and Flight Safety Warning in GTR2.

Figure 39 shows the distance between FWD2 and FWD1 as well as RWD2 and FWD1 for each sampling time (every 1 second) in the DSS software application. For RWD3, only two distances are shown: that at the beginning (initial RWD3 position) and the other when it is detected by the LIDAR. There are the two light blue dots at sampling time 346 sec and 413 respectively. The distance is calculated as a vectorial difference between the ADSB-based localization of the two pairs of drones (FWD2/RWD2/RWD3 and FWD1). In the case of RWD3, the initial position is given by GPS.

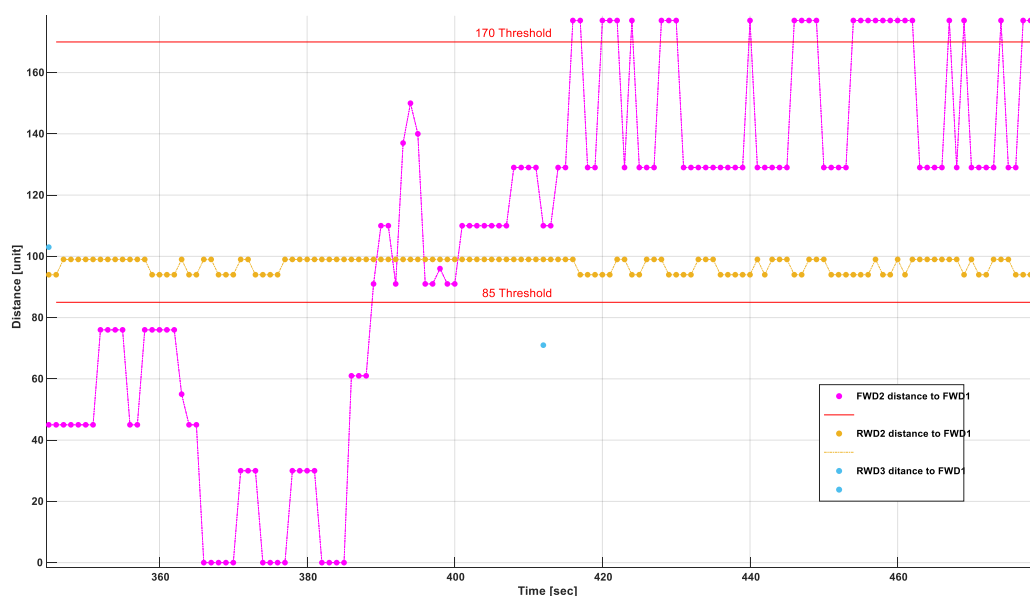


**Figure 38.** ADSB-based distance between RWD2/RWD3/FWD2 and FWD1 in GTR2.

## 5.4 Discussion on Experimental Garden Results

The office testing trials, and the garden testing trials share the same problem regarding accuracy in locations provided by the GPS embedded in the ADS-B transmitter (Figure 95) as discussed in Subsection 4.3. Both trials involve the same garden as outdoor facility. Thus, the altitude readings only change around 7 feet (a bit more than 2 meters). Like the office testing trials, 0 unit of altitude (normalized with the minimum altitude) in the experimental results does not mean RWD1 or FWD1 (simulated by moving the ADS-B transmitters with a hand) moves (flies) toughing the floor or nearly doing it. It rather means their altitude can well be in a range 0-7 feet from the floor.

Apart from being mobile, the reference point (FWD1) to check the distance to RWD1 in this trial has its location provided by a ADS-B transmitter (Figure 95) which adds an extra challenge to the problem of localization accuracy mentioned above. Thus, when checking the distance between RWD1 and FWD1 there is even less accuracy and more uncertainty to determine hazards by the DSS (ultimately, the AAO) in comparison with the office testing trials (where the location of FWD1 is fixed and manually set).

GTR2 provides the chance to run first tests of the LIDAR. While data from the LIDAR are not yet automatically processed, the manual input allows for consideration of such data by the AAO in order to come up with the relevant SAW.

## 6 Park Testing Trials

This section discusses details from the park testing trial, including technical specifications and experimental results.

### 6.1 General Aspects of the Trials

The park testing trials involve a computer (GOS) running the Dump1090 software application and the DSS software application. The trials are carried out by using two framework prototype configurations (D and E).

Two physical drones, RWD1 and FWD1 (both equipped with ADS-B transmitters), are used in trials for prototype configuration D. FWD1 plays the role of an airplane that is about to take off (e.g., a commercial airplane). RWD1 plays the role of a drone flying near the runway FWD1 takes off from. FWD1 is initially taxied to a location which is one end of the runway. Then, FWD1 starts its run on the runway (as part of the takeoff operation).

Three physical drones (RWD1, RWD2, and FWD1; all of them are equipped with ADS-B transmitters) are used in trials for prototype configuration E. FWD1 plays the role of an airplane (e.g., a commercial airplane) that is landing. FWD1 has already touched the ground and it is running in the runway on its way to stop close to one of the ends of the runway. RWD1 and RWD2 play the role of drones flying near the runway where FWD1 is landing.

Table 24 shows the details of the park testing task carried out. The specification presented in this table applies to all the park testing trials. The following subsection shows the updates and changes for the different prototype configurations of the park testing trials carried out.

**Table 24.** General information for park testing trials.

|                             |                                                                                        |
|-----------------------------|----------------------------------------------------------------------------------------|
| <b>Testing Location</b>     | Park                                                                                   |
| <b>Testing Facility</b>     | (outdoor) park space                                                                   |
| <b>System Context</b>       | Figure 39 (configuration D) & Figure 47(configuration E)                               |
| <b>Use case</b>             | Use Case 1: Take-off (Subsection 2.1) & Landing (Subsection 2.2)                       |
| <b>Application Scenario</b> | Derived from Application Scenario 1.1 (Figure 1) & Application Scenario 1.2 (Figure 2) |

| Prototype Configuration | D, E, F (Table 2)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|-------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Hardware Platform       | <ul style="list-style-type: none"> <li>• ADS-B Receiver – FlightAware Pro Stick Plus (Figure 94)</li> <li>• 3 ADS-B Transmitters – uAvionix EchoSky 2 (Figure 95)</li> <li>• GOS Computer</li> <li>• RWD1 (Figure 96)</li> <li>• RWD2 (Figure 97); only for prototype configuration E</li> <li>• FWD1 (Figure 99)</li> <li>• FWD2 (Figure 100)</li> </ul>                                                                                                                                                                                                                                                                       |
| Software Application    | <ul style="list-style-type: none"> <li>• DSS software application</li> <li>• Dump1090 application</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Testing Equipment       | Radiation Detector: GQ Electronics EMF Meter [15]                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Testing Area            | <ul style="list-style-type: none"> <li>• 70 m x 70 m = 4900 m<sup>2</sup></li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Testing Setup           | <ul style="list-style-type: none"> <li>• The ADS-B Receiver is power on as it is plugged in the GOS computer.</li> <li>• The Dump1090 application is up and running.</li> <li>• The DSS software application is up and running in the GOS.</li> <li>• The ADS-B Transmitter is power on.</li> <li>• RWD1 is initially landed and in an initial given position.</li> <li>• RWD2 is initially landed and in an initial given position (configuration E only)</li> <li>• FWD1 is taxied for take-off at one of the end of the runway (configuration D) and FWD1 is landing and running on the runway (configuration E).</li> </ul> |

Table 25 presents details of the two framework prototype configurations for the park testing trials. The runs of these trials are done for RWD1 with and without countermeasure (PilotContact) for framework prototype configuration D and E, and the same settings are applied to RWD2 for framework prototype configuration E.

**Table 25.** Prototype configuration for the park testing trial.

|              | Role          | ADS-B                  | Authorization | Countermeasure      | Traffic      | Flight            | Place      |
|--------------|---------------|------------------------|---------------|---------------------|--------------|-------------------|------------|
| <b>GOS</b>   | Operator unit | Receiver + antenna     | N/A           | N/A                 | N/A          | N/A               | Park space |
| <b>RWD1</b>  | UAV           | Integrated transmitter | No            | None / PilotContact | FWD1, RWD2 * | Landed / airborne | Park space |
| <b>RWD2*</b> | UAV           | Integrated transmitter | No            | None / PilotContact | FWD1, RWD1   | Landed / airborne | Park space |
| <b>FWD1</b>  | MAV           | Integrated transmitter | Yes           | PilotContact        | RWD1, RWD2 * | Take-off          | Park space |
| <b>FWD2</b>  | Not used      |                        |               |                     |              |                   |            |
| <b>LIDAR</b> | Not used      |                        |               |                     |              |                   |            |

\* Only used in prototype configuration E

The park-testing trials entail four runs: PTR1, PTR2, PTR3, and PTR4. PTR1 and PTR2 are for prototype configuration D, and PTR3 and PTR4 are for prototype configuration E.

## 6.2 Trials for Prototype Configuration D

The very first park testing trials carried out is based on configuration D of the framework prototype. The following subsections discuss details of the trials.

### 6.2.1 Technical Details of the Trials

Table 26 shows specific details of these trials for prototype configuration D which is in addition to the information shown in Table 24.

**Table 26.** Additional information for park testing trial for prototype configuration D.

|                              |                                                                                                                                                                                                                                                                       |
|------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Date and Time</b>         | Fri, 19 May 2023, 11:00 - 13:00                                                                                                                                                                                                                                       |
| <b>Weather Condition*</b>    | Slightly cloudy, 16 °C, 1032.00mb, 52%, 16 km/h, 10 km                                                                                                                                                                                                                |
| <b>Environment Radiation</b> | The following measures are with the ADS-B transmitter(s) on <ul style="list-style-type: none"> <li>(Outdoor) park space <ul style="list-style-type: none"> <li>EMF: 0.2 - 0.4mG</li> <li>EF: 1 V/m</li> <li>RF: 0.500 – 8.502 mW/m<sup>2</sup></li> </ul> </li> </ul> |

\* Source: <https://www.foreca.com>

Figure 39 shows the context of the framework prototype for the park testing trial with prototype configuration D.

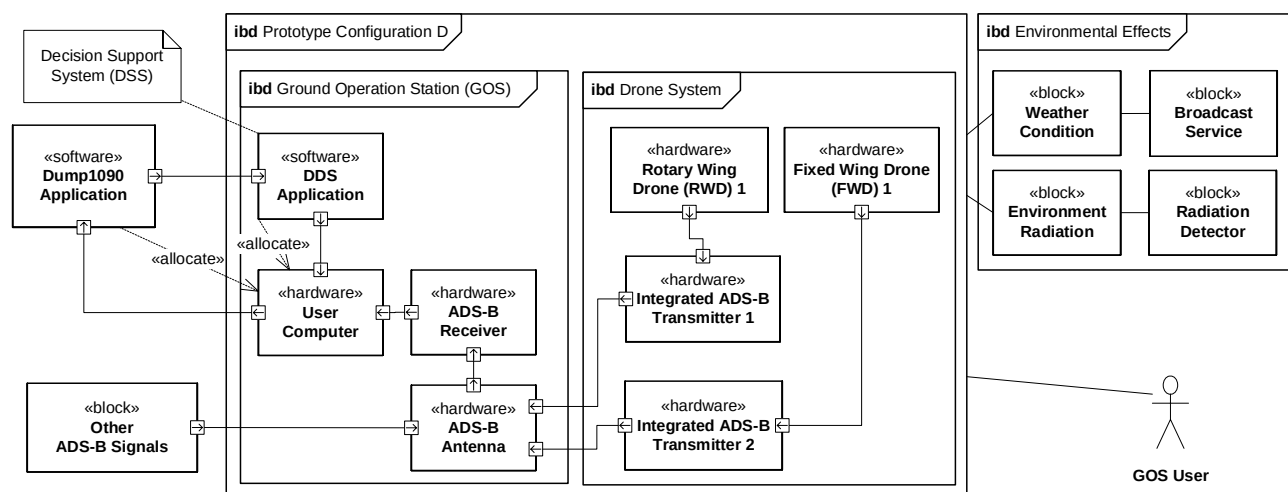


**Figure 39.** System context in the park testing trial (configuration D).

Figure 40 shows details of the interaction between key elements from the application scenario of the framework prototype for the park testing trial with prototype configuration D.

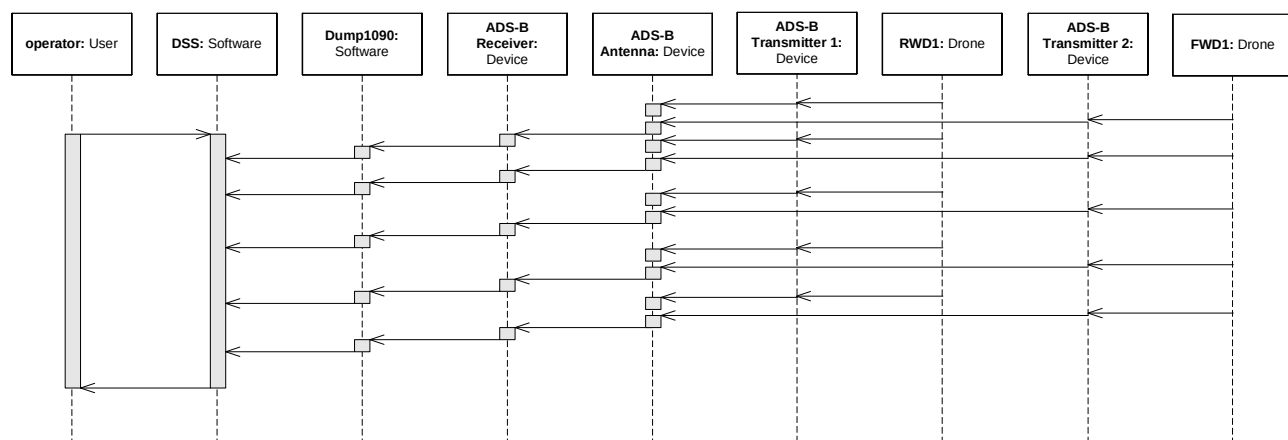


**Figure 40.** Application scenario in the park testing trial (configuration D).

Table 27 presents the test cases for the park testing trial with prototype configuration D.

**Table 27.** Summary of test cases for the park testing trials (configuration D).

| Mission Phase | Use Case | Application Scenario | Prototype Configuration | Test Case                                   |
|---------------|----------|----------------------|-------------------------|---------------------------------------------|
| Pre-mission   | 1        | 1.1                  | D                       | RWD1 and FWD1 operation (Table 28)          |
|               |          |                      |                         | ADS-B RF link (Table 9)                     |
|               |          |                      |                         | IP/TCP data link (Table 10)                 |
| In-Mission    | 1        | 1.1                  |                         | SAW of RWD1 with countermeasures (Table 11) |
|               |          |                      |                         | SAW of RWD1 without countermeasures         |
| Post-mission  | 1        | 1.1                  |                         | DSS information logging (Table 12)          |

### 6.2.2 Pre-Mission Phase

The purpose of the pre-mission park testing for prototype configuration D is to check the functions of the framework prototype are correct and the right operation of it by means of three test cases:

- RWD1 and FWD1 operation, targeting stable RWD1 flight and FWD1 manoeuvres when landed (Table 28). Both with a payload (each) which is the ADS-B transmitter.
- ADS-B RF link between the ADS-B transmitter (UAvionix EchoSky 2) device (onboard RWD1 and FWD1) and the ADS-B receiver (FlightAware Pro Stick Plus) device connected to the GOS.
- IP/TCP data link between the Dump1090 application (assumed onboard RWD1) and the DSS software application. Both applications run in the GOS. This testing is also to check if the DSS is fully operational.

The test procedure for the RWD1 and FWD1 operation test case requires: (1) the RWD1 and FWD1 structure and onboard avionics be in one piece (one ADS-B transmitter is mounted in RWD1 and another ADS-B transmitter is mounted in FWD1), (2) the RWD1 and FWD1 are initially off, and (3) the RWD1 and FWD1 are positioned on the floor.

Table 28 shows the steps for the RWD1 operation test case (as introduced in Table 1) for the pre-mission park testing.

**Table 28.** Test procedure for RWD1 and FWD1 operation test case.

| Test Step | User Action                                              | Expected Results                                       | Observed Results                                | Result Status                                                        |
|-----------|----------------------------------------------------------|--------------------------------------------------------|-------------------------------------------------|----------------------------------------------------------------------|
| 1         | Switch the RWD1 and FWD1 on                              | The RWD1 and FWD1 should be on                         | The RWD1 and FWD1 are on                        | The RWD1 and FWD1 keep on                                            |
| 2         | Command basic RWD1 and FWD1 moves from remote controller | The RWD1 and FWD1 should respond according to commands | The RWD1 and FWD1 respond according to commands | The RWD1 and FWD1 provide stable flight and returns to idle properly |
| 3         | Switch the RWD1 and FWD1 off                             | The RWD1 and FWD1 should be off                        | The RWD1 and FWD1 are off                       | The RWD1 and FWD1 keep off                                           |

The test procedure for the ADS-B RF link functioning as well as the IP/TCP data link functioning test cases are as discussed in subsection 4.2.2.

### 6.2.3 In- Mission Phase

The purpose of the in-mission park testing for prototype configuration D is to check the correct functioning and operation of the DSS by means of two main test cases: SAW of RWD1 with countermeasures and SAW of RWD1 without countermeasures.

The test procedure for the test case on SAW of RWD1 with countermeasures requires: (1) RWD1 and FWD1 are positioned on the floor, (2) RWD1 and FWD1 are off, (3) the ADS-B device on board RWD1 and FWD1 are off, (4) the ADS-B stick is connected to the GOS computer, (5) the Dump1090 application is ready for running in the GOS, and (6) the DSS software application is ready for running in the GOS. Table 29 shows the steps for the test case on SAW of RWD1 with countermeasures for the in-mission park testing.

**Table 29.** Test procedure for SAW of physical RWD1 with countermeasures.

| Test Step | User Action                                                                                                  | Expected Results                                                                                     | Observed Results                                                                               | Result Status                                                                           |
|-----------|--------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|
| 1         | Run the Dump1090 application in the GOS                                                                      | The Dump1090 application should be up and running                                                    | The Dump1090 application is up and running                                                     | The Dump1090 application keeps up and running                                           |
| 2         | Run the DSS software application in the GOS                                                                  | The DSS software application should be up and running                                                | The DSS software application is up and running                                                 | The DSS software application keeps up and running                                       |
| 3         | Check the Dump1090 and the DSS are connected with each other using TCP/IP protocol                           | The Dump1090 application and the DSS software application should be TCP/IP connected with each other | The Dump1090 application and the DSS software application are TCP/IP connected with each other | Both applications keep connected with each other using the TCP/IP protocol              |
| 4         | Place RW1 and FWD1 on the ground, then switch them on, also their ADS-B transmitters.                        | The RW1 and FWD1 along with their ADS-B transmitters should be on                                    | The RW1 and FWD1 along with their ADS-B transmitters is on                                     | The RW1 and FWD1 along with their ADS-B transmitters keeps on                           |
| 5         | Check the DSS software application receives the ADS-B data from the ADS-B transmitter                        | DSS software application should receive the ADS-B data from the ADS-B transmitter                    | The DSS software application receives the ADS-B data from the ADS-B transmitter                | The DSS software application keeps receiving the ADS-B data from the ADS-B transmitter  |
| 6         | Check if the DSS software application displays SAW involving RWD1 and FWD1 accordingly                       | SAW of RWD1 and FWD1 should be displayed in the DSS software application                             | SAW of RWD1 and FWD1 are displayed in the DSS software application                             | The DSS software application keeps displaying SAW of RWD1 and FWD1                      |
| 7         | Start flying RWD1 around in locations close to the FWD1                                                      | The DSS software application should provide SAW of RWD1 flying around FWD1                           | The DSS software application provides SAW of RWD1 flying around FWD1                           | The DSS software application keeps providing SAW of RWD1 flying around FWD1             |
| 8         | Try to get RWD1 in an airspace zone that is not hazardous for FWD1 taking off (while FWD1 is moving forward) | The DSS software application should accordingly provide SAW of RWD1 flying around FWD1               | The DSS software application provides SAW of RWD1 flying around FWD1 accordingly               | The DSS software application keeps providing SAW of RWD1 flying around FWD1 accordingly |

|    |                                                                                                          |                                                                                        |                                                                                  |                                                                                         |
|----|----------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|
| 9  | Try to get RWD1 in an airspace zone that is hazardous for FWD1 taking off (while FWD1 is moving forward) | The DSS software application should accordingly provide SAW of RWD1 flying around FWD1 | The DSS software application provides SAW of RWD1 flying around FWD1 accordingly | The DSS software application keeps providing SAW of RWD1 flying around FWD1 accordingly |
| 10 | Land RW1 and stop moving FWD1 (last FWD1 point before leaving ground)                                    | The DSS software application should accordingly keep providing SAW of RW1 and FWD1     | The DSS software application keeps providing SAW of RWD1 and FWD1 accordingly    | The DSS software application keeps providing SAW of RWD1 accordingly                    |
| 11 | Switch the two ADS-B transmitters off                                                                    | The two ADS-B transmitters should be off                                               | The two ADS-B transmitters are off                                               | The two ADS-B transmitters keep off                                                     |
| 12 | Check if the DSS software application does not display SAW involving RWD1 and FWD1                       | SAW of RWD1 and FWD1 should not be displayed by the DSS software application           | SAW of RWD1 and FWD1 is not displayed by the DSS software application            | The DSS software application keeps not displaying SAW of RWD1 and FWD1                  |

The steps for the test case on SAW of RWD1 without countermeasures for the in-missing park testing trials are the same than the ones presented for the test case on SAW of RWD1 with countermeasures (Table 29), the difference is that RWD1 is set to have no countermeasures.

The test cases for prototype configuration D extend the ones for prototype configuration A (Subsection 4.2). However, physical RWD1 and FWD1 are used in this test.

#### 6.2.4 Post-Mission Phase

The purpose of the post-mission park testing for prototype configuration D is to check whether the DSS can log the information broadcasted by the ADS-B transmitter. The test procedure for this test case requires: (1) RWD1 and FWD1 are landed, and (2) the ADS-B transmitters on board RWD1 and FWD1 keep off.

The test procedure for this test case for the post-missing park testing trial are the same than the ones presented in subsection 4.2.4 (Table 12).

#### 6.2.5 Experimental Results

In PTR1, the operation of the aircraft (RWD1 and FWD1) is meant to reproduce a (downscaled) scenario where an airplane (e.g., a commercial airliner represented by FWD1) is taking off while a AUV (represented by RWD1) flies around. FWD1 takes off from one of the ends of the runway.

This Subsection presents the experimental results from the OTR1 of the park-testing trials (in-mission phase) with real values for latitude, longitude, and altitude (not normalized as in the office and garden testing trials). The figures also show details of areas (flight waypoints) which means hazards of potential collision between aircraft (RWD1 and FWD1; both real drones used). The closest distance that the aircraft can be without becoming a hazard is set at 170 units for drones in front and in the direction of the airplane (FWD1) and 85 units for drones behind and not in the direction of the airplane (FWD1).

Figure 41 shows the trajectory produced by the ADS-B transmitter 1 mounted in RWD1 (in green) with the following setting: aircraft unauthorized to fly, and countermeasure (“PilotContact” which means the UAV has a remote contactable pilot that can be reached in case of any manoeuvre required to keep the UAV and the MAV in question properly separated) for possible mid-air collision. RWD1 is initially located (green cross) at one of the ends of the runway (straight line in dark grey) where FWD1 is taxed (blue cross) ready

to take off in the beginning of the runway, the other end of the runway. The trial's duration is 307 sec (5 min 7 sec).

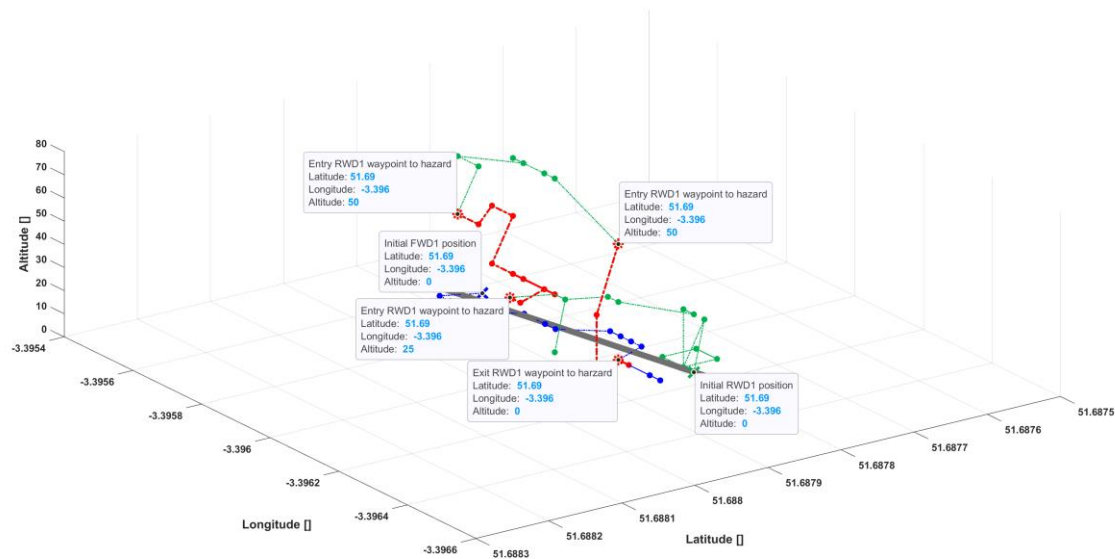


**Figure 41.** ADSB-based localization for SA of RWD1 with countermeasure.

Figure 42 shows the distance between RWD1 and FWD1 for each sampling time (every 1 second) in the DSS software application. The distance is calculated as a vectorial difference between the ADSB-based localization of the two drones (RWD1 and FWD1).

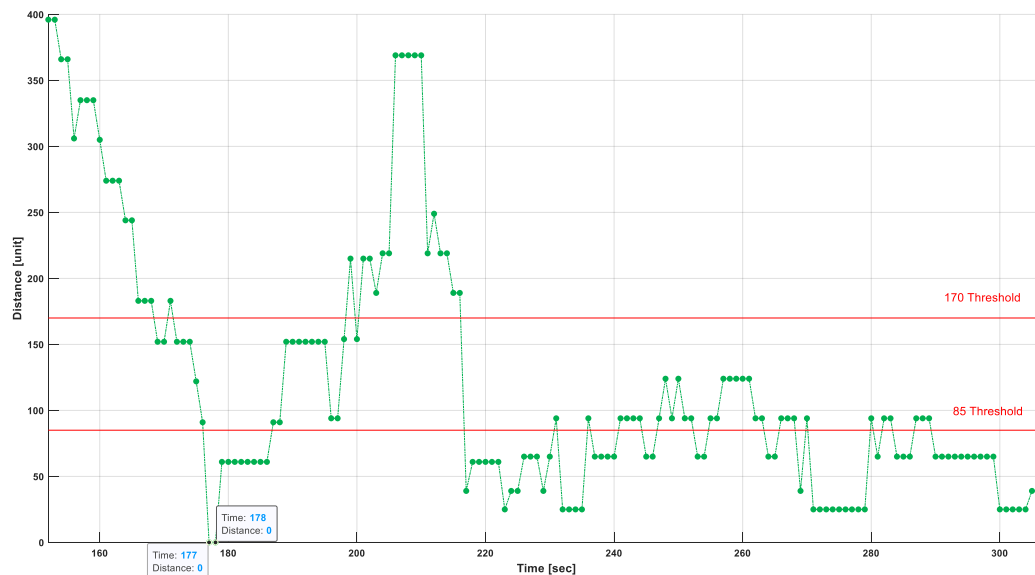


**Figure 42.** ADSB-based distance between RWD1 and FWD1 (with countermeasure).

If RWD1 is behind FWD1 (opposite to the direction of FWD1) the reference distance to determine whether RWD1 flight is a hazard for FWD1 is 85 units. If RWD1 is ahead FWD1 (in the direction of FWD1) the reference distance to determine whether RWD1 flight is a hazard for FWD1 is 170 units. Both reference distances are highlighted in Figure 42. There is a critical period when the two aircraft (RWD1 and FWD1) get very close (no collision) and for which the current distance calculated is 0 units (177 and 178 secs).

Figure 43 shows the SA provided by the DSS software application for the duration of the experiment. The possible outputs for this trial are Flight Safety (FS) where the airplane (FWD1) under consideration is not at risk of collision with the relevant AUV (RWD1) and Flight Safety Warning (FSW) where the airplane (FWD1) under consideration is at considerable risk of collision with the relevant AUV (RWD1).

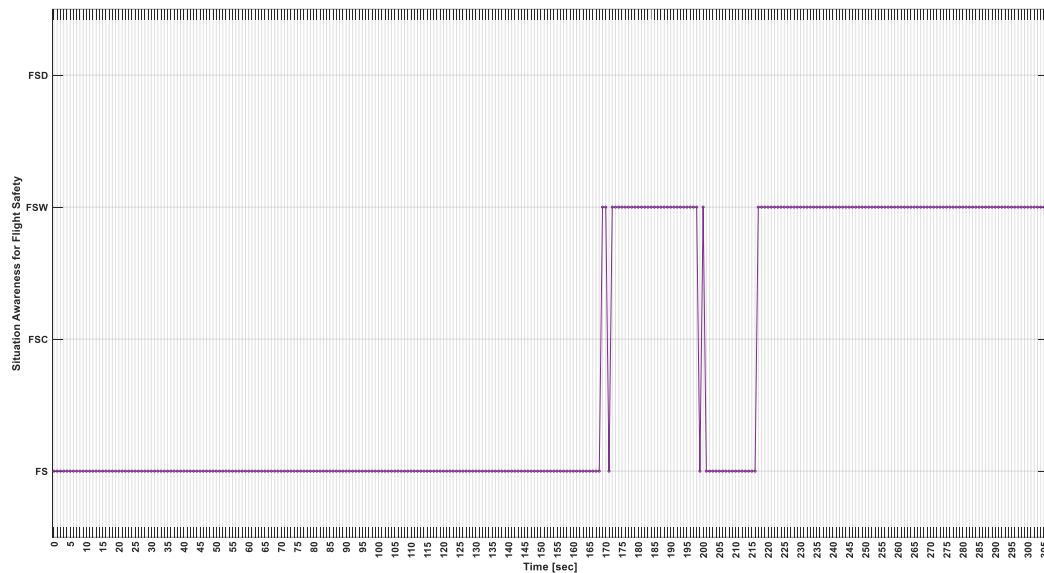


**Figure 43.** ADSB-based SA of RWD1 with countermeasure.

There are two times (171 sec and 199 sec) during the transition of the SA states in which values for the SA bounce. This is due to interim changes in the calculation of the distance between aircraft that suggests the threshold given by the limit distance is crossed and then it is not crossed for a sample period.

Figure 44 shows the trajectory produced by the ADS-B transmitter mounted in RWD1 with the following setting in PTR1: aircraft unauthorized to fly, and with no countermeasure (None) for possible mid-air collision. RWD1 is initially located at the beginning of the runway (straight line in dark grey) near FWD1 that is taxied (blue cross) ready to take off. The trial's duration is 1142 sec (19 min 2 sec).

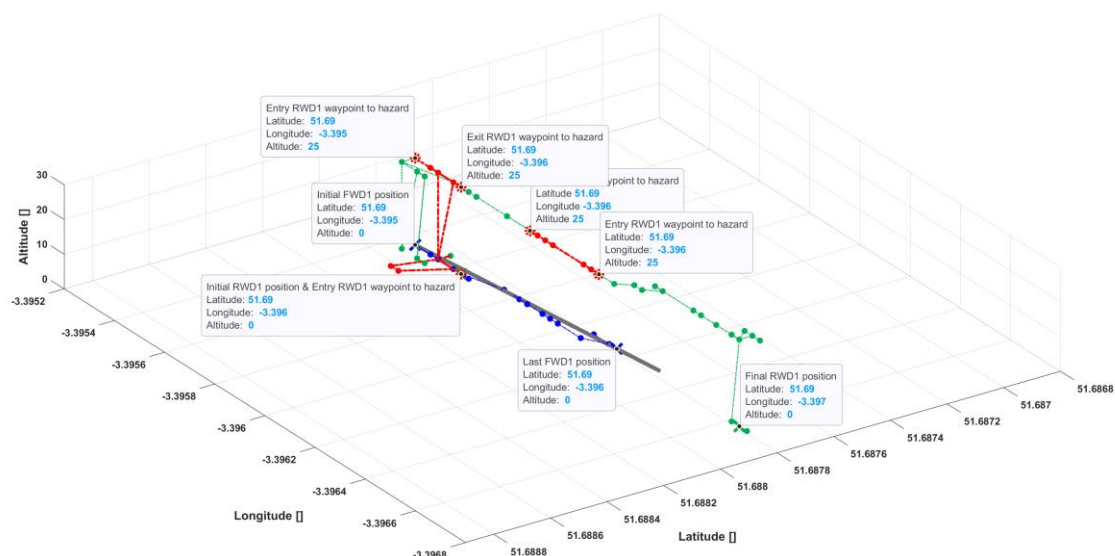


**Figure 44.** ADSB-based localization for SA of RWD1 without countermeasure in OTR1.

Figure 45 shows the distance between RWD1 and FWD1 for each sampling time (every 1 second) in the DSS software application for a duration of 342 sec. The distance is calculated as a vectorial difference between the ADSB-based localization of the two drones (RWD1 and FWD1).

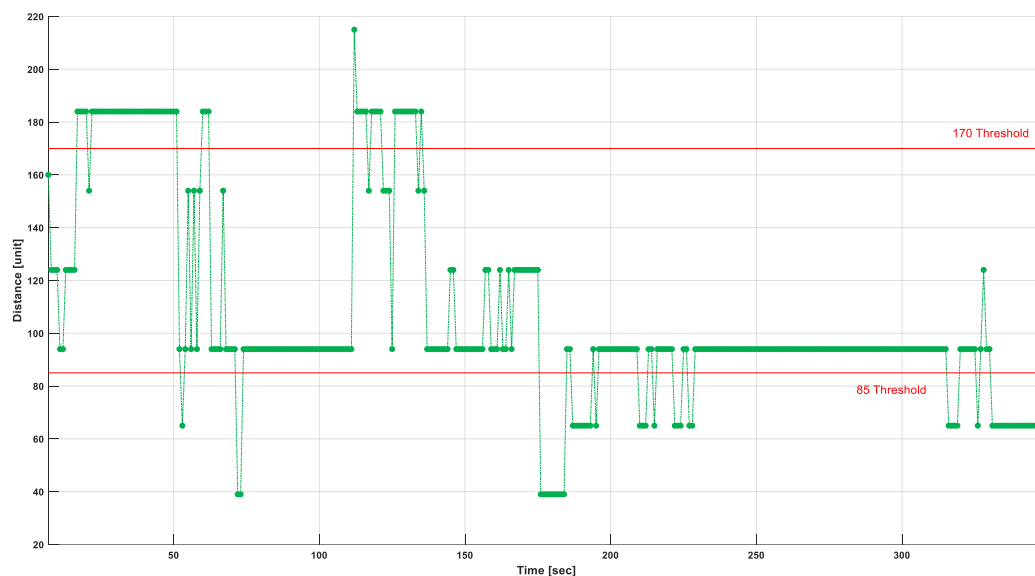


**Figure 45.** ADSB-based distance between RWD1 and FWD1 (without countermeasure).

If RWD1 is behind FWD1 (opposite to the direction of FWD1) the reference distance to determine whether RWD1 flight is a hazard for FWD1 is 85 units. If RWD1 is ahead FWD1 (in the direction of FWD1) the reference distance to determine whether RWD1 flight is a hazard for FWD1 is 170 units. Both reference distances are highlighted in Figure 45.

Figure 46 shows the SA provided by the DSS software application for the 342 sec (from the beginning) of the experiment. The possible outputs for this trial are Flight Safety Caution (FSC) where the airplane (FWD1) under consideration is at moderate risk of collision with the relevant AUV (RWD1) and Flight Safety Danger (FSD) where the airplane (FWD1) under consideration is at high risk of collision with the relevant AUV (RWD1).

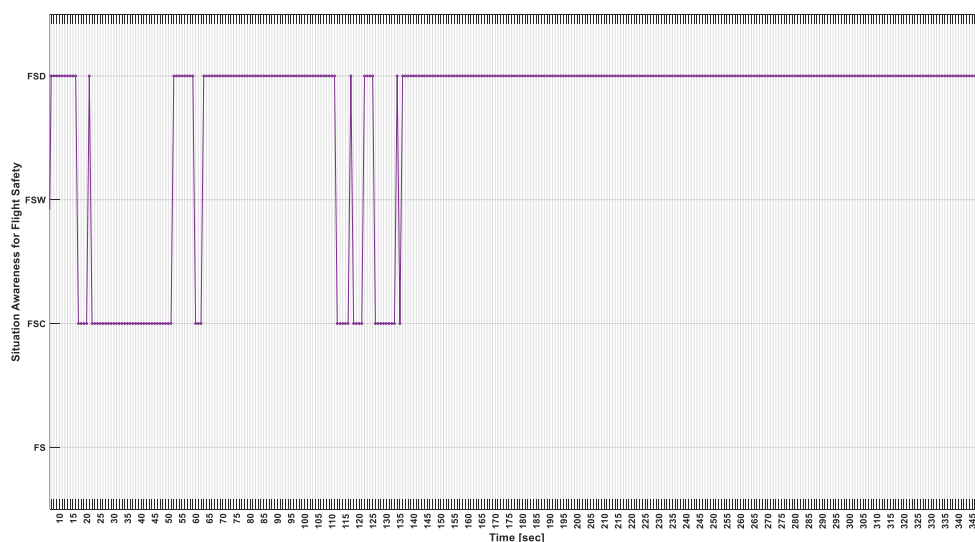


**Figure 46.** ADSB-based SA of RWD1 without countermeasure.

RWD1 is ahead FWD1 in the first 342 sec of the experimental trial. There are few times during the transition of SA states in which values for the SA switch. This is due to a calculation as discussed for Figure 43.

### 6.3 Trials for Prototype Configuration E

PTR3 and PTR4 are based on configuration E of the framework prototype. The following subsection discuss details of the trial.

#### 6.3.1 Technical Details of the Trails

Table 30 shows information in addition to the specifications shown in Table 24 to provide details from the environment of the trails using prototype configuration E.

**Table 30.** Additional information for park testing trial for prototype configuration E.

|                              |                                                                                                                                                                                                                                                                            |
|------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Date and Time</b>         | Fri, 16 Jun 2023, 12:00 - 13:30                                                                                                                                                                                                                                            |
| <b>Weather Condition*</b>    | Sunny, 24 °C, 1018.00mb, 48%, 13 km/h, 10 km                                                                                                                                                                                                                               |
| <b>Environment Radiation</b> | The following measures are with the ADS-B transmitter(s) off <ul style="list-style-type: none"> <li>• (Outdoor) park space <ul style="list-style-type: none"> <li>○ EMF: 0.2 - 0.4mG</li> <li>○ EF: 1 V/m</li> <li>○ RF: 0.1 – 0.5 mW/m<sup>2</sup></li> </ul> </li> </ul> |

\* Source: <https://www.foreca.com>

Figure 47 shows the context of the framework prototype for the park testing trial with prototype configuration E.

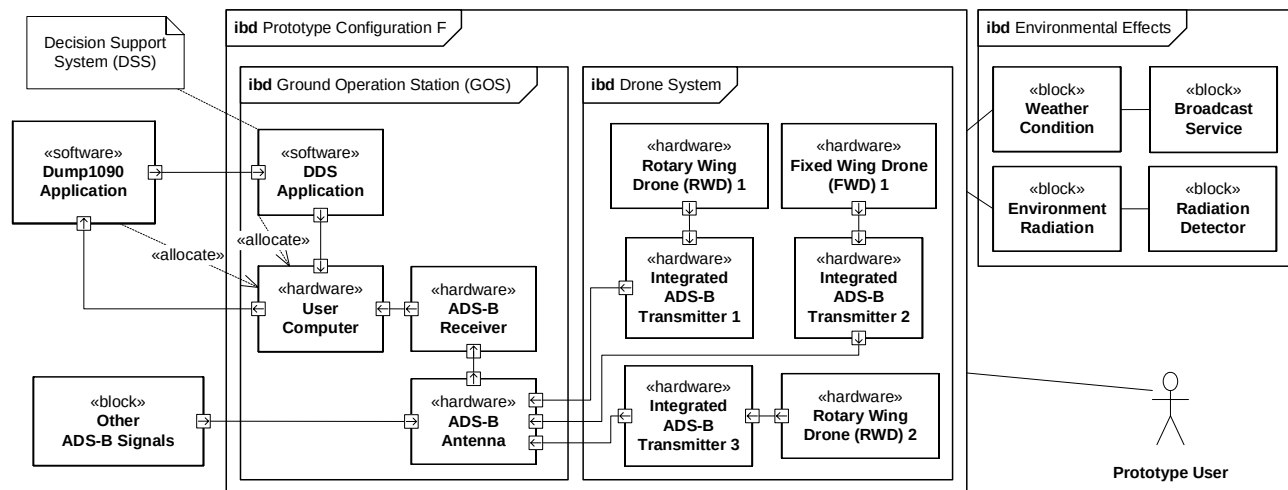


**Figure 47.** System context in the park testing trial (configuration E).

Figure 48 shows details of the interaction between key elements from the application scenario of the framework prototype for the park testing trial with prototype configuration E.

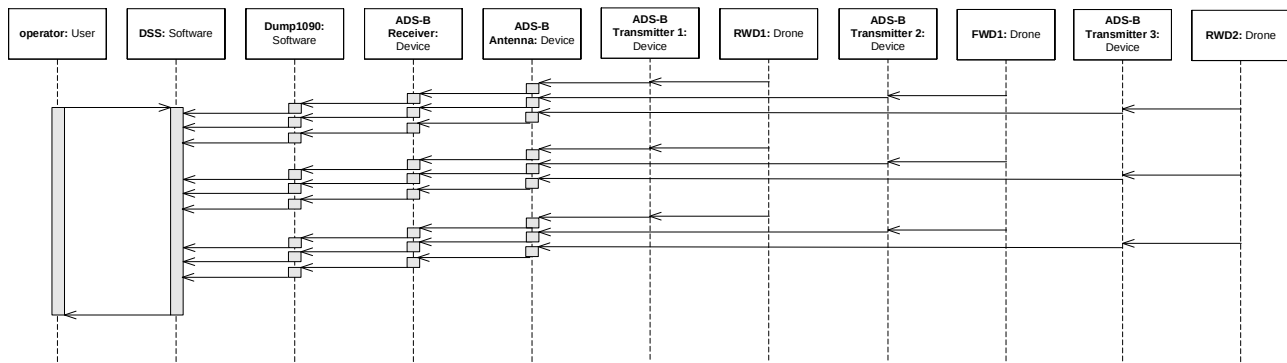


**Figure 48.** Application scenario in the park testing trial (configuration E).

Table 31 presents the test cases for the park testing trial with prototype configuration E.

**Table 31.** Summary of test cases for the park testing trials (configuration E).

| Mission Phase | Use Case | Application Scenario | Prototype Configuration | Test Case                                                                    |
|---------------|----------|----------------------|-------------------------|------------------------------------------------------------------------------|
| Pre-mission   | 1        | 1.1                  | E                       | RWD1, RWD2, and FWD1 operation (Table 32)                                    |
|               |          |                      |                         | ADS-B RF link (Table 9)                                                      |
|               |          |                      |                         | IP/TCP data link (Table 10)                                                  |
| In-Mission    | 1        | 1.1                  |                         | SAW of RWD1 without countermeasures and RWD2 with countermeasures (Table 33) |
|               |          |                      |                         | SAW of RWD1 and RWD2 with countermeasures                                    |
| Post-mission  | 1        | 1.1                  |                         | DSS information logging (Table 12)                                           |

### 6.3.2 Pre-Mission Phase

The purpose of the pre-mission park testing for prototype configuration E is to check the functions of the framework prototype are correct and the right operation of it by means of two test cases:

- RWD1, RWD2, and FWD1 operation, targeting proper RWD1 and RWD2 flight and FWD1 manoeuvres when landed.
- ADS-B RF link between the ADS-B transmitter (UAvionix EchoSky 2) device (onboard RWD1 and FWD1) and the ADS-B receiver (FlightAware Pro Stick Plus) device connected to the GOS.
- IP/TCP data link between the Dump1090 application (assumed onboard RWD1) and the DSS software application. Both applications run in the GOS. This testing is also to check if the DSS is fully operational.

The test procedure for the RWD1, RWD2, and FWD1 operation test case requires: (1) the structure of RWD1, RWD2, and FWD1 and onboard avionics be in one piece, and (2) the RWD1, RWD2, and FWD1 are initially off, and (3) the RWD1 and FWD1 are positioned on the floor. Table 32 shows the steps for the RWD operation test case (as introduced in Table 1) for the pre-missing park testing.

**Table 32.** Test procedure for RWD1, RWD2, and FWD1 operation test case.

| Test Step | User Action                                                     | Expected Results                                              | Observed Results                                       | Result Status                                                               |
|-----------|-----------------------------------------------------------------|---------------------------------------------------------------|--------------------------------------------------------|-----------------------------------------------------------------------------|
| 1         | Switch the RWD1, RWD2, and FWD1 on                              | The RWD1, RWD2, and FWD1 should be on                         | The RWD1, RWD2, and FWD1 are on                        | The RWD1, RWD2, and FWD1 keep on                                            |
| 2         | Command basic RWD1, RWD2, and FWD1 moves from remote controller | The RWD1, RWD2, and FWD1 should respond according to commands | The RWD1, RWD2, and FWD1 respond according to commands | The RWD1, RWD2, and FWD1 provide stable flight and returns to idle properly |
| 3         | Switch the RWD1, RWD2, and FWD1 off                             | The RWD1, RWD2, and FWD1 should be off                        | The RWD1, RWD2, and FWD1 are off                       | The RWD1, RWD2, and FWD1 keep off                                           |

The test procedure for the ADS-B RF link functioning and IP/TCP data link functioning test cases are as discussed in subsection 4.2.2.

### 6.3.3 In- Mission Phase

The purpose of the in-mission park testing for prototype configuration E is to check the correct functioning and operation of the DSS by means of two main test cases: (1) SAW of RWD1 without countermeasures and RWD2 with countermeasures, and (2) SAW of RWD1 and RWD2 with countermeasures.

The test procedure for the test case on SAW of RWD1 without countermeasures and RWD2 with countermeasures requires: (1) RWD1, RWD2, and FWD1 are positioned on the floor, (2) the RWD1 and RWD2 are off, (3) the ADS-B device on board the RWD1 and RWD2 are off, (4) the ADS-B stick is connected to the GOS computer, (5) the Dump1090 application is up and running, and (6) the DSS software application is up and running in the GOS. Table 33 shows the steps for the test case on SAW of RWD1 without countermeasures and RWD2 with countermeasures for the in-missing park testing.

**Table 33.** Test procedure for SAW of physical RWD1 and RWD2 with countermeasures.

| Test Step | User Action                                                                        | Expected Results                                                                                     | Observed Results                                                                               | Result Status                                                              |
|-----------|------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------|
| 1         | Run the Dump1090 application in the GOS                                            | The Dump1090 application should be up and running                                                    | The Dump1090 application is up and running                                                     | The Dump1090 application keeps up and running                              |
| 2         | Run the DSS software application in the GOS                                        | The DSS software application should be up and running                                                | The DSS software application is up and running                                                 | The DSS software application keeps up and running                          |
| 3         | Check the Dump1090 and the DSS are connected with each other using TCP/IP protocol | The Dump1090 application and the DSS software application should be TCP/IP connected with each other | The Dump1090 application and the DSS software application are TCP/IP connected with each other | Both applications keep connected with each other using the TCP/IP protocol |

|    |                                                                                                              |                                                                                                          |                                                                                                    |                                                                                                           |
|----|--------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------|
| 4  | Place RW1, RWD2, and FWD1 on the ground, then switch them along with their ADS-B transmitters on.            | The RW1, RWD2, and FWD1 along with their ADS-B transmitters should be on                                 | The RW1, RWD2, and FWD1 along with their ADS-B transmitters is on                                  | The RW1, RWD2, and FWD1 along with their ADS-B transmitters keeps on                                      |
| 5  | Check if the DSS software application displays SAW involving RWD1, RWD2, and FWD1 accordingly                | SAW of RWD1 and FWD1 should be displayed in the DSS software application                                 | SAW of RWD1 and FWD1 are displayed in the DSS software application                                 | The DSS software application keeps displaying SAW of RWD1 and FWD1                                        |
| 6  | Check the DSS software application receives the ADS-B data from the ADS-B transmitter                        | DSS software application should receive the ADS-B data from the ADS-B transmitter                        | The DSS software application receives the ADS-B data from the ADS-B transmitter                    | The DSS software application keeps receiving the ADS-B data from the ADS-B transmitter                    |
| 7  | Check SAW is according to the distance RWD1 and RWD2 are from FWD1                                           | The DSS software application should accordingly provide SAW of RWD1 and RWD2 around FWD1                 | The DSS software application provides SAW of RWD1 and RWD2 around FWD1 accordingly                 | The DSS software application keeps providing SAW of RWD1 and RWD2 around FWD1 accordingly                 |
| 8  | Start flying RWD2 around, in locations close to the FWD1                                                     | The DSS software application should provide SAW of the ADS-B transmitter (simulating RWD2 flying around) | The DSS software application provides SAW of the ADS-B transmitter (simulating RWD2 flying around) | The DSS software application keeps providing SAW of the ADS-B transmitter (simulating RWD2 flying around) |
| 9  | Try to get RWD2 in an airspace zone that is not hazardous for FWD1 taking off (while FWD1 is moving forward) | The DSS software application should accordingly provide SAW of RWD2 flying around FWD1                   | The DSS software application provides SAW of RWD2 flying around FWD1 accordingly                   | The DSS software application keeps providing SAW of RWD2 flying around FWD1 accordingly                   |
| 10 | Land RW2 and stop moving FWD1                                                                                | The DSS software application should accordingly keep providing SAW of RW2 and FWD1                       | The DSS software application keeps providing SAW of RWD2 and FWD1 accordingly                      | The DSS software application keeps providing SAW of RWD2 accordingly                                      |
| 11 | Start flying RWD1 around, in locations close to the FWD1                                                     | The DSS software application should provide SAW of the ADS-B transmitter (simulating RWD1 flying around) | The DSS software application provides SAW of the ADS-B transmitter (simulating RWD1 flying around) | The DSS software application keeps providing SAW of the ADS-B transmitter (simulating RWD1 flying around) |
| 12 | Try to get RWD1 in an airspace zone that is hazardous for FWD1 taking off (while FWD1 is moving forward)     | The DSS software application should accordingly provide SAW of RWD1 flying around FWD1                   | The DSS software application provides SAW of RWD1 flying around FWD1 accordingly                   | The DSS software application keeps providing SAW of RWD1 flying around FWD1 accordingly                   |
| 13 | Land RW1 and stop moving FWD1                                                                                | The DSS software application should accordingly keep providing SAW of RW1 and FWD1                       | The DSS software application keeps providing SAW of RWD1 and FWD1 accordingly                      | The DSS software application keeps providing SAW of RWD1 accordingly                                      |

|    |                                                                                    |                                                                              |                                                                       |                                                                        |
|----|------------------------------------------------------------------------------------|------------------------------------------------------------------------------|-----------------------------------------------------------------------|------------------------------------------------------------------------|
| 14 | Switch the two ADS-B transmitters off                                              | The two ADS-B transmitters should be off                                     | The two ADS-B transmitters is off                                     | The two ADS-B transmitters keep off                                    |
| 15 | Check if the DSS software application does not display SAW involving RWD1 and FWD1 | SAW of RWD1 and FWD1 should not be displayed by the DSS software application | SAW of RWD1 and FWD1 is not displayed by the DSS software application | The DSS software application keeps not displaying SAW of RWD1 and FWD1 |

The steps for the test case on SAW of RWD1 and RWD2, both with countermeasures countermeasures, for the in-missing park testing trial are the same than the ones presented in Table 33.

#### 6.3.4 Post-Mission Phase

The purpose of the post-mission park testing for prototype configuration E is to check whether the DSS can log the information broadcasted by the ADS-B transmitter. The test procedure for this test case requires: (1) assumption RWD1, RWD2, and FWD1 are landed, and (2) the ADS-B transmitter assumed on board RWD1 and FWD1 are kept off.

The test procedure for this test case for the post-missing park testing trial are the same than the ones presented in subsection 4.2.4 (Table 12).

#### 6.3.5 Experimental Results

In PTR3, the operation of the aircraft (RWD1, RWD2, and FWD1) is meant to reproduce a (downscaled) scenario where an airplane (e.g., a commercial airliner represented by FWD1) is landing while AUVs (represented by RWD1 and RWD2) fly around. FWD1 lands by touching down one of the ends of the runway.

This Subsection presents the experimental results from the OTR1 of the park-testing trials (in-mission phase) with real values for latitude, longitude, and altitude (not normalized as in the office and garden testing trials). The figures also show details of areas (flight waypoints) which means hazards of potential collision between aircraft (RWD1, RWD2, and FWD1; real drones used). The closest distance that the aircraft can be without becoming a hazard is set at 170 units for drones in front and in the direction of the airplane (FWD1) and 85 units for drones behind and not in the direction of the airplane (FWD1).

Figure 49 shows the trajectory produced by the ADS-B transmitter 1 mounted in RWD1 (in green) with the following setting: aircraft unauthorized to fly, and no countermeasure (“none”) for possible mid-air collision. It also shows the trajectory produced by the ADS-B transmitter 3 mounted in RWD2 (in yellow) with the following setting: aircraft unauthorized to fly, and countermeasure (“PilotContact” which means the UAV has a remote contanctable pilot that can be reached in case of any manouvre required to keep the UAV and the MAV in question properly separated ) for possible mid-air collision.

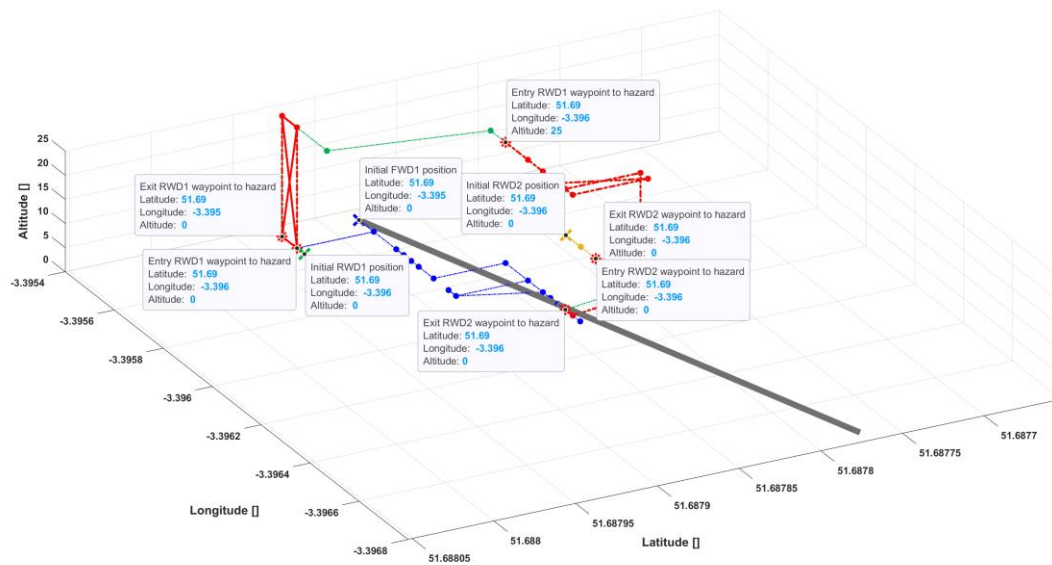


**Figure 49.** ADSB-based localization for SA of RWD1 with countermeasure.

RWD1 is initially located (green cross) at one of the ends of the runway (straight line in dark grey) where FWD1 has just touched down for landing (blue cross) and it is moving from this end of the runway to the other end of the runway. RWD2 is initially on the other side of the runway (yellow cross) and it flies not much forward. The trial's duration is 258 sec (4 min 18 sec).

Figure 50 shows the distance between RWD1 and FWD1 as well as RWD2 and FWD1 for each sampling time (every 1 second) in the DSS software application. The distance is calculated as a vectorial difference between the ADSB-based localization of the two pairs of drones (RWD1/RWD2 and FWD1).

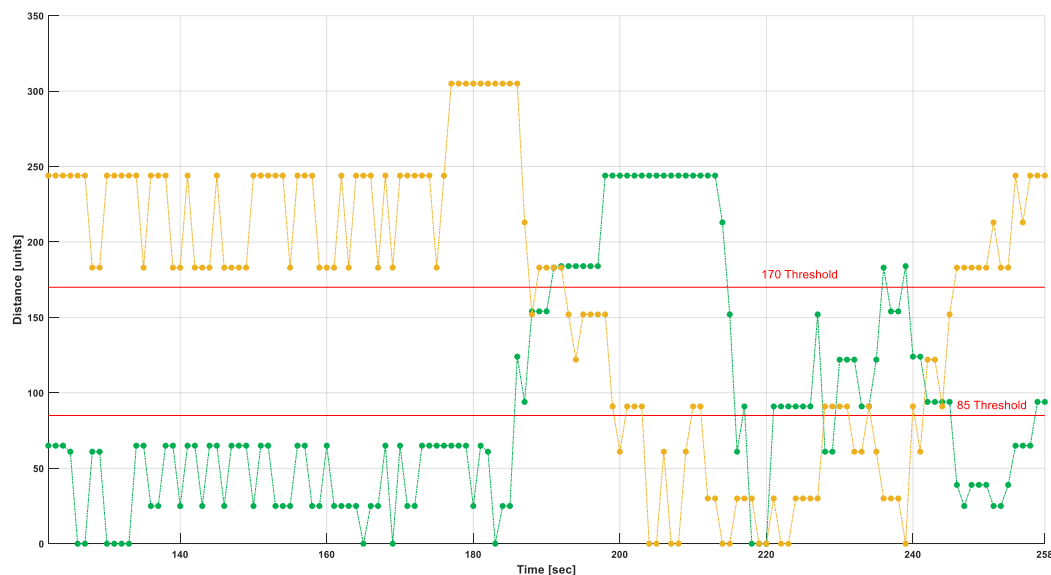


**Figure 50.** ADSB-based distance between RWD1 and FWD1 (with countermeasure).

If RWD1/RWD2 is behind FWD1 (opposite to the direction of FWD1) the reference distance to determine whether RWD1/RWD2 flight is a hazard for FWD1 is 85 units. If RWD1/RWD2 is ahead FWD1 (in the direction of FWD1) the reference distance to determine whether RWD1/RWD2 flight is a hazard for FWD1

is 170 units. Both reference distances are highlighted in Figure 42. There is a critical period when the two aircraft (RWD1/RWD2 and FWD1) get very close (no collision) and for which the current distance calculated is 0 units (177 and 178 secs).

Figure 51 shows the SA provided by the DSS software application for the time the three drones are on during the experiment. The possible outputs for this trial for RWD1 are Flight Safety (FS) where the airplane (FWD1) under consideration is not at risk of collision with one of the relevant AUV (i.e., RWD1) and Flight Safety Warning (FSW) where the airplane (FWD1) under consideration is at considerable risk of collision with RWD1. On the other hand, the possible outputs for this trial for RWD2 are Flight Safety Caution (FSC) where the airplane (FWD1) under consideration is not at risk of collision with the other relevant AUV (i.e., RWD2) and Flight Safety Danger (FSD) where the airplane (FWD1) under consideration is at considerable risk of collision with RWD2.

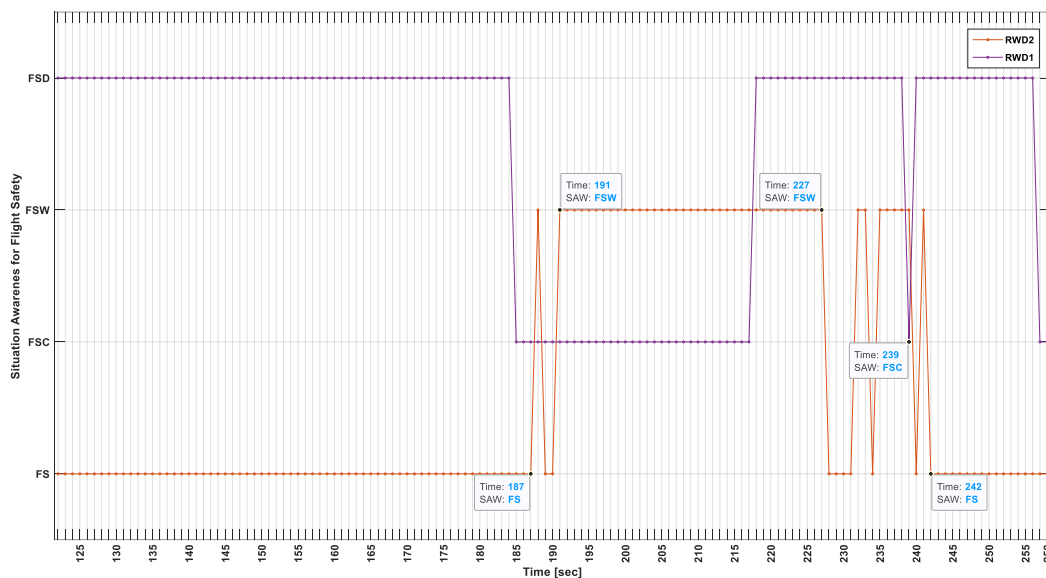


**Figure 51.** ADSB-based SA of RWD1 with countermeasure and RWD2 without it.

There are some periods of times (187-191 secs and 227-242 secs) during the transition of the SA states in which values for the SA bounce for RWD2. Likewise, there is an isolated change at 239 sec during the transition of the SA states in which values for the SA bounce for RWD1. Both situations are due to interim changes in the calculation of the distance between aircraft that suggest the threshold given by the limit distance is crossed and then it is not crossed for a sample period. In the case of RWD 1, proximity to FWD1 is affected by the readings from the GPS of its ADS-B transmitter as the distance is borderline (threshold). In the case of RWD2, RWD2 crosses multiple time the threshold distance.

Figure 52 shows the trajectory produced by the ADS-B transmitters mounted in the drones. Both AUVs (RWD1 and RWD2) are set is set to be aircraft unauthorized to fly and both have countermeasure (PilotContact) for possible mid-air collision in PTR4.

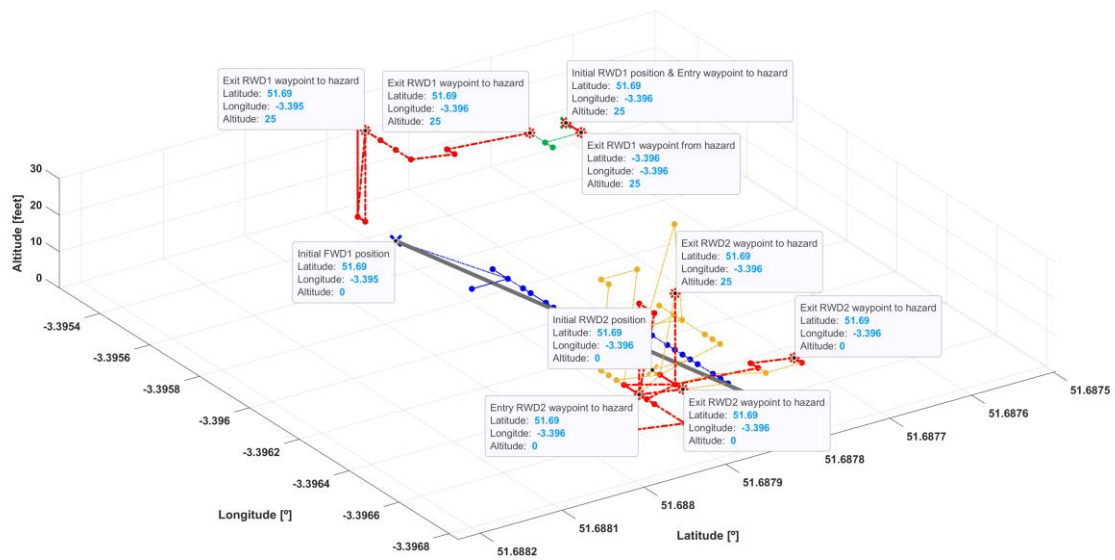


**Figure 52.** ADSB-based localization for SA of RWD1 and RWD2 with countermeasures.

RWD1 is initially located on the right of Figure 52 (on the extreme where FWD1 has just touched down for landing; blue cross). RWD2 is initially landed ahead of the runway. The trial's duration is 841 sec (14 min 1 sec).

Figure 53 shows the distance between RWD1 and FWD1 as well as RWD2 and FWD1 for each sampling time (every 1 second) in the DSS software application. The distance is calculated as a vectorial difference between the ADSB-based localization of the two pairs of drones (RWD1/RWD2 and FWD1).

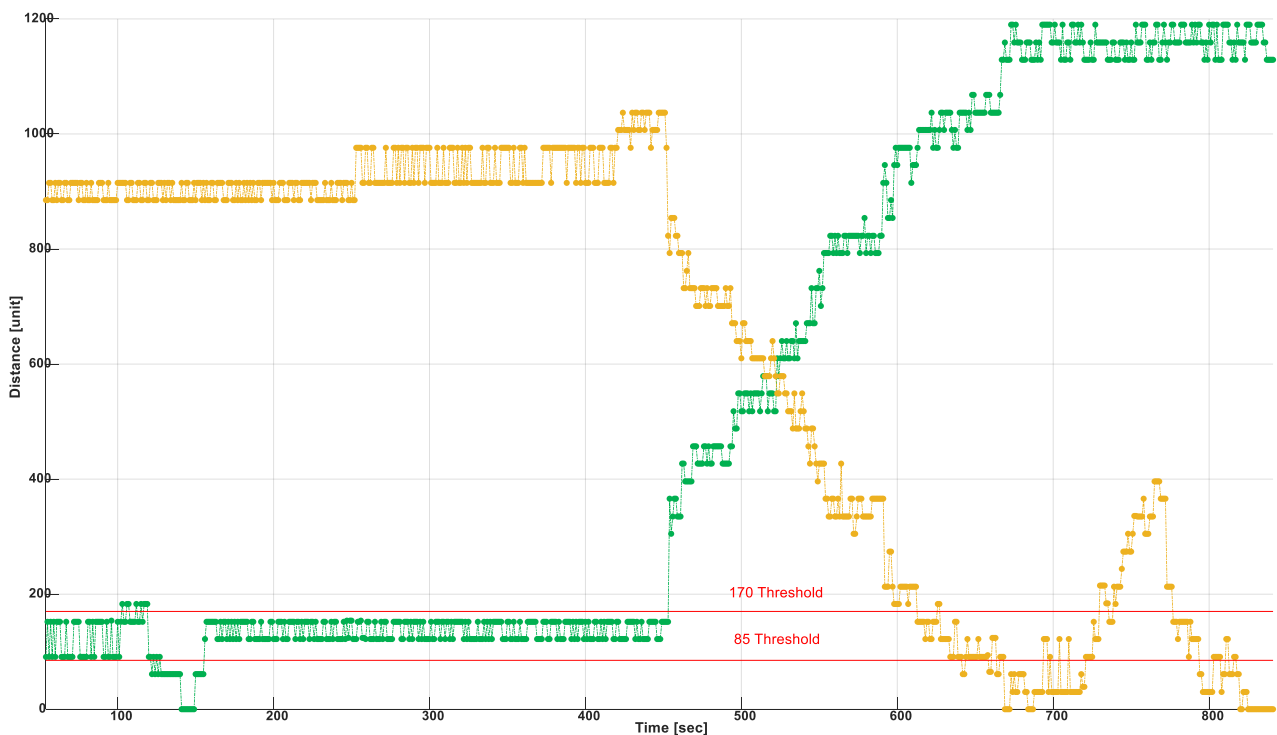


**Figure 53.** ADSB-based distance between RWD1/RWD2 and FWD1 (RWDs with countermeasures).

If RWD1/RWD2 is behind FWD1 (opposite to the direction of FWD1) the reference distance to determine whether RWD1/RWD2 flight is a hazard for FWD1 is 85 units. If RWD1/RWD2 is ahead FWD1 (in the direction of FWD1) the reference distance to determine whether RWD1/RWD2 flight is a hazard for FWD1 is 170 units. Both reference distances are highlighted in Figure 45.

Figure 46 shows the SA provided by the DSS software application for the time the experiment computes SAW for the two drones (i.e., RWD1 and RWD2). The possible outputs for this trial are Flight Safety (FS) where the airplane (FWD1) under consideration has no risk of collision with the relevant AUVs (RWD1 and RWD2) and Flight Safety Warning (FSW) where the airplane (FWD1) under consideration is at considerable risk of collision with the relevant AUVs (RWD1 and RWD2).

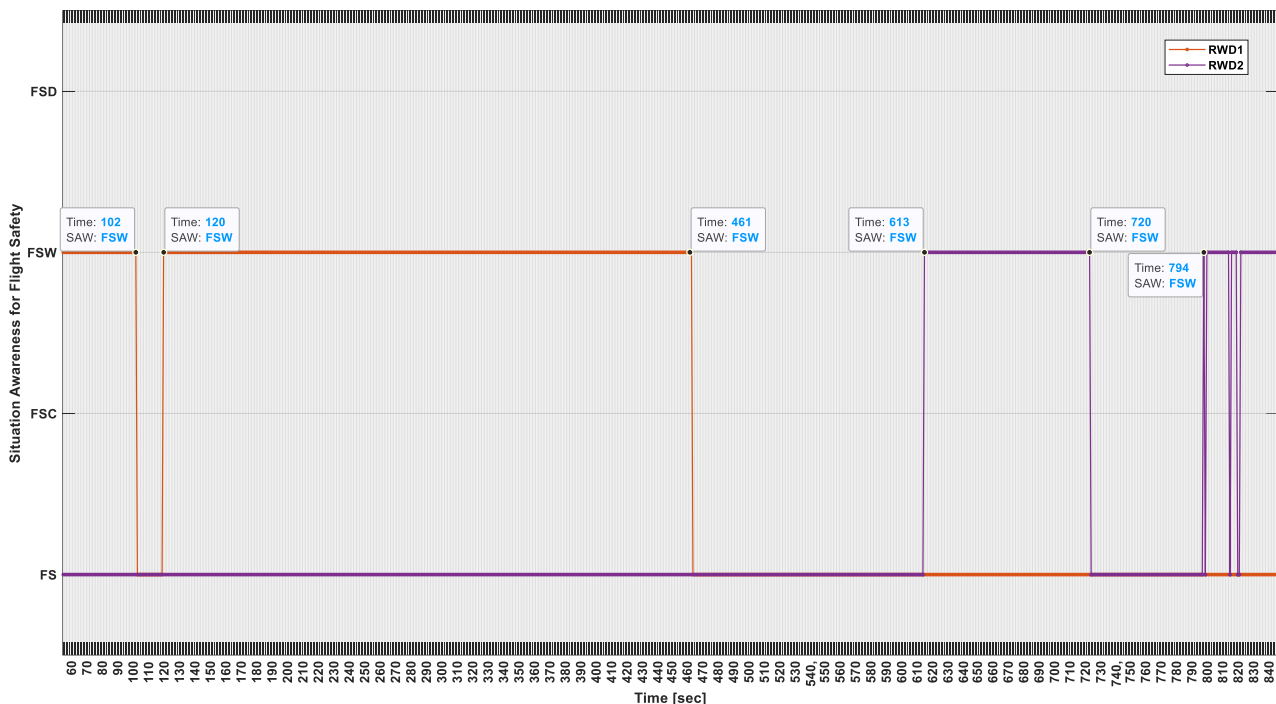


**Figure 54.** ADSB-based SA of RWD1 without countermeasure.

When FWD1 touches down the runway for landing, RWD1 is ahead it (first 102 sec of the experimental trial). Then, RWD1 is behind FWD1 so distance restrictions relax a bit (from 170 units down to 85 units). This is why RWD1 becomes not a problem (FS) from 103 secs to 119 secs. RWD1 gets closer than 85 units from 120 secs. This matches distances for RWD1 in Figure 53 that go below threshold (85 units) for the given time segment. RWD1 is no longer a threat from 462 secs for which RWD1 is further behind FWD1 as it has moved forward in the runways, slowing down its speed to finish landing.

RWD2 becomes a concern from 613 secs for which it is ahead FWD1 until 720 secs (by this time RWD2 is behind FWD1 so 85-unit distance restrictions is applied). There are few times during the transition of SAW states in which values for the SAW switch for RWD2. This is due to a calculation as discussed for Figure 43.

## 6.4 Discussion on Experimental Park Results

The experimental results from the park-testing trials confirm the effective performance of the ontology-based DSS proposed in this research. While detection and tracking of aircraft (in particular, the drones of the project) is only through ADS-B devices, the DSS software application driven by the AAO is able to classify and come up with a SAW output for different airspace situations from the application scenarios presented in Section 6.

Most importantly, when compared with the office-testing trials (Section 4) and garden-testing trials (Section 5), ADS-B transmitters are mounted on the drones (i.e., RWD1, RWD2, and FWD1) which are the

vehicles moving the devices around while flying instead the ADS-B devices move by hand as in the two previous trials. Park-testing trials are not only more realistic than the other two as drones are equipped with ADS-B technology like in real aircraft but also, because of the ADS-B onboard, the drones and their avionics are subjected to possible interferences from different sources, e.g., RF signals even if they have different frequencies or channels.

Additionally, some of the technical aspects of to be considered when using physical drones are the following:

- The battery of RWD1 (Beast RC quadcopter, Figure 96) must be 50% charged at least for the drone to take off and fly properly. This requirement is due to the payload (ADS-B transmitter) attached to it.
- The calibration of the inertial unit of RWD1 with payload (ADS-B transmitter, Figure 95) must be done slowly for the sensors (compass, accelerometer, etc.). Otherwise, the calibration is not properly done and RWD1 becomes unstable to control and fly.
- The results from the calculation of the distance between aircraft (RWD1 and FWD1) are better as there is more space to operate the drones and therefore to fly them in different locations. However, there is still a reasonable fluctuation when the separation threshold is crossed. This has an impact (similar fluctuations) on the SA provided by the DSS software application.

The experiments for the prototype configuration E provide encouraging results toward the next level of experiment to be carried out in the field (field-testing trials).

## 7 Field Testing Trials

This section discusses details from the field-testing trial, including technical specifications and experimental results.

### 7.1 General Aspects of the Trials

The field-testing trials involve a computer (GOS) running the Dump1090 software application and the DSS software application. The GOS is assumed to be next to ATCs for its use. The GOS's location does not affect SAW of the aircraft involved in this trial. The trials are carried out by using three framework prototype configurations (F, F, G, and H).

Four physical drones (RWD1, RWD2, FWD1, and FWD2) are used in the trials for prototype configuration F. All the drones involved in the trial are equipped with ADS-B transmitters. RWD1 and RWD2 play the role of an AUV flying near airplanes; role played by FWD1 (and FWD2 in configuration H). configuration F, F, G, and H include the two use cases with four application scenarios.

Table 34 shows the details of the field-testing tasks carried out. The specification presented in this table applies to all the field-testing trials. The following subsections show the updates and changes for the different prototype configurations used for the field-testing trials.

**Table 34.** General information for field testing trials.

|                             |                                                                                                      |
|-----------------------------|------------------------------------------------------------------------------------------------------|
| <b>Testing Location</b>     | Field                                                                                                |
| <b>Testing Facility</b>     | (outdoor) SWRCS facility and Commons                                                                 |
| <b>System Context</b>       | Figure 55                                                                                            |
| <b>Use case</b>             | Use Case 1: Take-off and Landing (Section 2)<br>Use Case 2: climbing and descending (Section 2)      |
| <b>Application Scenario</b> | Derived from Application Scenario 1.2 (Figure 1)<br>Derived from Application Scenario 1.2 (Figure 2) |

|                                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|--------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                | Derived from Application Scenario 2.1 (Figure 3)<br>Derived from Application Scenario 2.2 (Figure 4)                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| <b>Prototype Configuration</b> | F, F, G, H (Table 2)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| <b>Hardware Platform</b>       | <ul style="list-style-type: none"> <li>• ADS-B Receiver – FlightAware Pro Stick Plus (Figure 94)</li> <li>• 3 ADS-B Transmitters – uAvionix EchoSky 2 (Figure 95)</li> <li>• GOS Computer</li> <li>• RWD1 (Figure 96)</li> <li>• RWD2 (Figure 97)</li> <li>• FWD1 (Figure 99)</li> <li>• FWD2 (Figure 100)</li> </ul>                                                                                                                                                                                                                                                            |
| <b>Software Application</b>    | <ul style="list-style-type: none"> <li>• DSS software application</li> <li>• Dump1090 application</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <b>Testing Equipment</b>       | Radiation Detector: GQ Electronics EMF Meter [15]                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| <b>Testing Area</b>            | <ul style="list-style-type: none"> <li>• 500 m x 500 m = 250000 m<sup>2</sup> (SWRCS facility)</li> <li>• 100 m x 100 m = 10000 m<sup>2</sup> (Commons)</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                               |
| <b>Testing Setup</b>           | <ul style="list-style-type: none"> <li>• DSS software application is up and running in the GOS.</li> <li>• ADS-B Receiver is power on as it is plugged in the GOS computer.</li> <li>• ADS-B Transmitter is power on.</li> <li>• RWD1 is assumed to be initially landed and in an initial given position.</li> <li>• RWD2 is assumed to be initially landed and in an initial given position.</li> <li>• FWD1 is assumed to be initially landed and in an initial given position.</li> <li>• FWD2 is assumed to be initially landed and in an initial given position.</li> </ul> |

Table 35 presents details of the framework prototype configuration for the field-testing trial. The run of this trial is done for RWD1 with and without countermeasure (PilotContact).

**Table 35.** Prototype configurations for the field-testing trials.

|             | Role          | ADS-B                  | Authorization | Countermeasure      | Traffic            | Flight                                       | Place           |
|-------------|---------------|------------------------|---------------|---------------------|--------------------|----------------------------------------------|-----------------|
| <b>GOS</b>  | Operator unit | Receiver + antenna     | N/A           | N/A                 | N/A                | N/A                                          | SWRCS / Commons |
| <b>RWD1</b> | UAV           | Integrated transmitter | No            | None / PilotContact | FWD1 / FWD2        | Landed / airborne                            |                 |
| <b>RWD2</b> | UAV           | Integrated transmitter | No            | None / PilotContact | FWD1 / FWD2        | Landed / airborne                            |                 |
| <b>FWD1</b> | MAV           | Integrated transmitter | Yes           | PilotContact        | RWD1 & RWD2        | Taking off / climbing / Descending / Landing |                 |
| <b>FWD2</b> | UAV/MAV       |                        | No/Yes        | None / PilotContact | FWD1 / RWD1 & RWD2 |                                              |                 |

|              |          |  |
|--------------|----------|--|
| <b>LIDAR</b> | Not used |  |
|--------------|----------|--|

The field-testing trials entail seven runs: FTR1, FTR2, FTR3, FTR4, FTR5, FTR6, and FTR7. FTR1 is for prototype configuration F, FTR2 and FTR3 are for configuration prototype F, FTR4 is for configuration prototype G, and FTR5, FTR6, and FTR7 are for configuration prototype H.

## 7.2 Trials for Prototype Configuration F

The very first field testing trial carried out is based on configuration F of the framework prototype. The following subsection discuss details of the trial.

### 7.2.1 Technical Details of the Trials

Table 36 shows information in addition to the specifications shown in Table 34 to provide details from the environment of the trials using prototype configuration F.

**Table 36.** Additional information for field testing trial for prototype configuration F.

|                              |                                                                                                                                                                                                                             |
|------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Date and Time</b>         | Fri, 22 Sep 2023, 10:30 - 12:00                                                                                                                                                                                             |
| <b>Weather Condition*</b>    | Partly cloudy, 14 °C, 1002.00mb, 88%, 21 km/h, 25 km                                                                                                                                                                        |
| <b>Environment Radiation</b> | ADS-B Device off <ul style="list-style-type: none"> <li>Outdoor             <ul style="list-style-type: none"> <li>EMF: 0 - 0.1mG</li> <li>EF: 0 - 2 V/m</li> <li>RF: 0.001 – 0.006 mW/m<sup>2</sup></li> </ul> </li> </ul> |

\* Source: <https://www.foreca.com>

Figure 55 shows the context of the framework prototype for the field-testing trial with prototype configuration F.

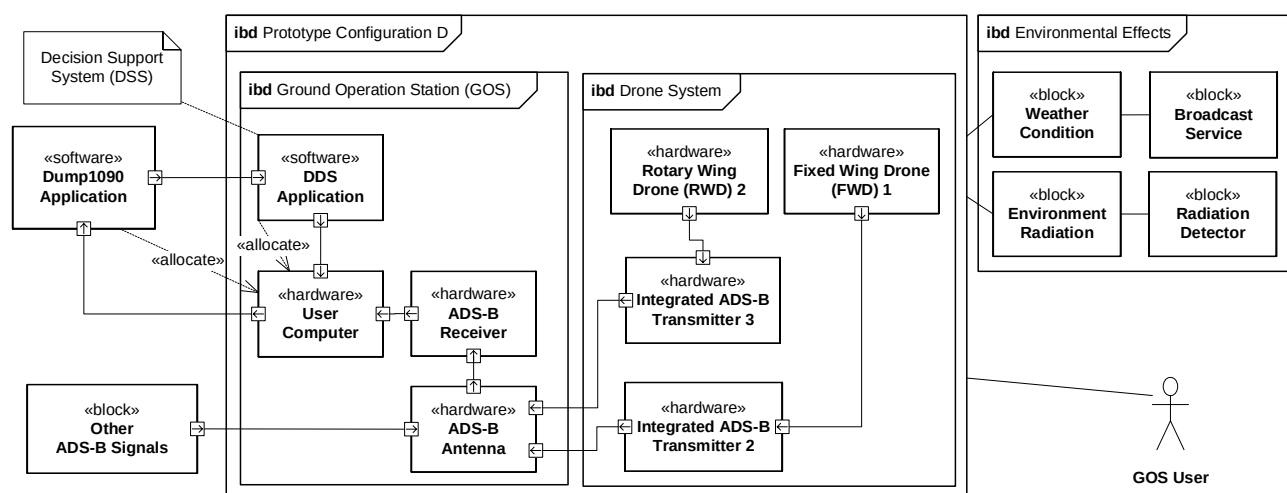


**Figure 55.** Prototype configuration F for the field-testing trial.

Figure 56 shows details of the interaction between key elements from the application scenario of the framework prototype for the field-testing trial with prototype configuration F.

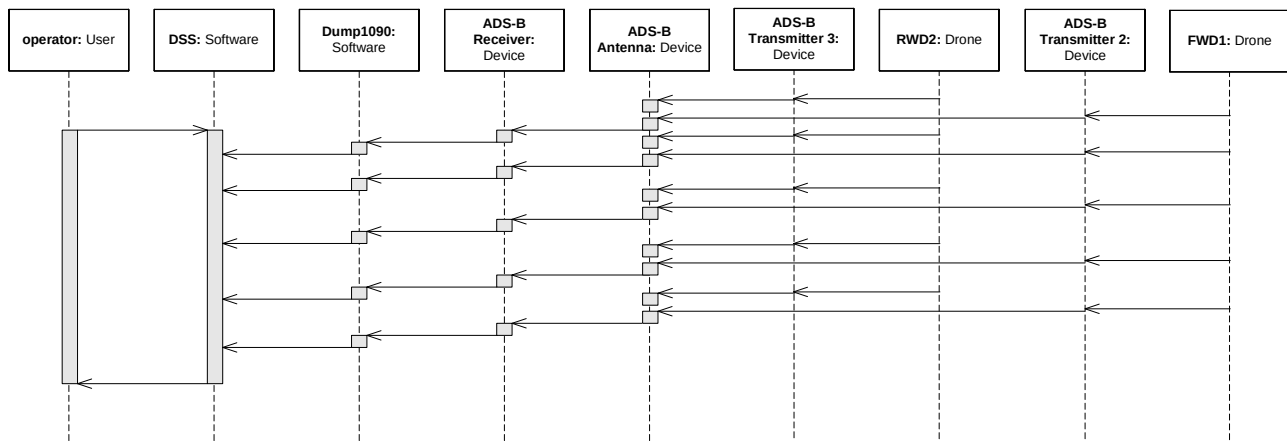


**Figure 56.** Application scenario in the field-testing trial for prototype configuration F.

Table 37 presents the test cases for the field-testing trial with prototype configuration F.

**Table 37.** Summary of test cases for the field-testing trials.

| Mission Phase | Use Case | Application Scenario | Prototype Configuration | Test Case                                   |
|---------------|----------|----------------------|-------------------------|---------------------------------------------|
| Pre-mission   | 1        | 1.2                  | F                       | RWD2 and FWD1 operation (Table 38)          |
|               |          |                      |                         | ADS-B RF link (Table 18)                    |
|               |          |                      |                         | IP/TCP data link (Table 10)                 |
|               | 2        | 2.1                  |                         | RWD1 and FWD1 operation (Table 28)          |
|               |          |                      |                         | ADS-B RF link (Table 18)                    |
|               |          |                      |                         | IP/TCP data link (Table 10)                 |
| In-Mission    | 1        | 1.2                  | F                       | SAW of RWD1 with countermeasures (Table 19) |
|               |          |                      |                         | SAW of RWD1 without countermeasures         |
|               | 2        | 2.1                  |                         | SAW of RWD1 with countermeasures (Table 19) |
|               |          |                      |                         | SAW of RWD1 without countermeasures         |
| Post-mission  | 1        | 1.2                  | F                       | DSS information logging (Table 12)          |
|               | 2        | 2.1                  |                         | DSS information logging (Table 12)          |

### 7.2.2 Pre-Mission Phase

The purpose of the pre-mission field testing for prototype configuration F is to check the functions of the framework prototype are correct and the right operation of it by means of three test cases:

- RWD2 and FWD1 operation, targeting stable RWD2 flight and FWD1 manoeuvres when landed (Table 38). Both with a payload (each) which is the ADS-B transmitter.
- ADS-B RF link between the ADS-B transmitter (UAvionix EchoSky 2) device (onboard RWD2 and FWD1) and the ADS-B receiver (FlightAware Pro Stick Plus) device connected to the GOS.
- IP/TCP data link between the Dump1090 application (assumed onboard RWD2) and the DSS software application. Both applications run in the GOS. This testing is also to check if the DSS is fully operational.

The test procedure for the RWD2 and FWD1 operation test case requires: (1) the RWD2 and FWD1 structure and onboard avionics be in one piece (one ADS-B transmitter is mounted in RWD2 and another ADS-B transmitter is mounted in FWD1), (2) the RWD2 and FWD1 are initially off, and (3) the RWD2 and FWD1 are positioned on the floor.

Table 38 shows the steps for the RWD2 operation test case (as introduced in Table 1) for the pre-missing park testing.

**Table 38.** Test procedure for RWD2 and FWD1 operation test case.

| Test Step | User Action                                              | Expected Results                                       | Observed Results                                | Result Status                                                        |
|-----------|----------------------------------------------------------|--------------------------------------------------------|-------------------------------------------------|----------------------------------------------------------------------|
| 1         | Switch the RWD2 and FWD1 on                              | The RWD2 and FWD1 should be on                         | The RWD2 and FWD1 are on                        | The RWD2 and FWD1 keep on                                            |
| 2         | Command basic RWD2 and FWD1 moves from remote controller | The RWD2 and FWD1 should respond according to commands | The RWD2 and FWD1 respond according to commands | The RWD2 and FWD1 provide stable flight and returns to idle properly |
| 3         | Switch the RWD2 and FWD1 off                             | The RWD2 and FWD1 should be off                        | The RWD2 and FWD1 are off                       | The RWD2 and FWD1 keep off                                           |

The test procedure for the ADS-B RF link functioning and DSS software application functioning test cases are as discussed in subsection 4.2.2.

### 7.2.3 In- Mission Phase

The purpose of the in-mission field testing for prototype configuration F is to check the correct functioning and operation of the DSS by means of a test case: SAW of RWD2 with countermeasures while FWD1 is taking off.

The test procedure for the test case on SAW of RWD2 with countermeasures requires: (1) RWD2 and FWD1 are positioned on the floor, (2) RWD2 and FWD1 are off, (3) the ADS-B device on board RWD2 and FWD1 are off, (4) the ADS-B stick is connected to the GOS computer, (5) the Dump1090 application is ready for running in the GOS, and (6) the DSS software application is ready for running in the GOS. Table 39 shows the steps for the test case on SAW of RWD2 with countermeasures for the in-mission field testing.

**Table 39.** Test procedure for SAW of simulated RWD2 with countermeasures.

| Test Step | User Action                                                                            | Expected Results                                                                                     | Observed Results                                                                               | Result Status                                                              |
|-----------|----------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------|
| 1         | Run the Dump1090 application in the GOS                                                | The Dump1090 application should be up and running                                                    | The Dump1090 application is up and running                                                     | The Dump1090 application keeps up and running                              |
| 2         | Run the DSS software application in the GOS                                            | The DSS software application should be up and running                                                | The DSS software application is up and running                                                 | The DSS software application keeps up and running                          |
| 3         | Check the Dump1090 and the DSS are connected with each other using TCP/IP protocol     | The Dump1090 application and the DSS software application should be TCP/IP connected with each other | The Dump1090 application and the DSS software application are TCP/IP connected with each other | Both applications keep connected with each other using the TCP/IP protocol |
| 4         | Place RWD2 and FWD1 on the ground, then switch them on, also their ADS-B transmitters. | The RW2 and FWD1 along with their ADS-B transmitters should be on                                    | The RW2 and FWD1 along with their ADS-B transmitters is on                                     | The RW2 and FWD1 along with their ADS-B transmitters keeps on              |

|    |                                                                                                                                     |                                                                                                          |                                                                                                    |                                                                                                           |
|----|-------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------|
| 5  | Check the DSS software application receives the ADS-B data from the ADS-B transmitter                                               | DSS software application should receive the ADS-B data from the ADS-B transmitter                        | The DSS software application receives the ADS-B data from the ADS-B transmitter                    | The DSS software application keeps receiving the ADS-B data from the ADS-B transmitter                    |
| 6  | Check if the DSS software application displays SAW involving RWD2 and FWD1 accordingly                                              | SAW of RWD2 and FWD1 should be displayed in the DSS software application                                 | SAW of RWD2 and FWD1 are displayed in the DSS software application                                 | The DSS software application keeps displaying SAW of RWD2 and FWD1                                        |
| 7  | Start flying RWD2 around in locations close to the FWD1                                                                             | The DSS software application should provide SAW of the ADS-B transmitter (simulating RWD2 flying around) | The DSS software application provides SAW of the ADS-B transmitter (simulating RWD2 flying around) | The DSS software application keeps providing SAW of the ADS-B transmitter (simulating RWD2 flying around) |
| 8  | Try to get RWD2 in an airspace zone that is not hazardous for FWD1 taking off (while FWD1 is taking off; takeoff roll and lift-off) | The DSS software application should accordingly provide SAW of RWD2 flying around FWD1                   | The DSS software application provides SAW of RWD2 flying around FWD1 accordingly                   | The DSS software application keeps providing SAW of RWD2 flying around FWD1 accordingly                   |
| 9  | Try to get RWD2 in an airspace zone that is hazardous for FWD1 taking off (while FWD1 is taking off; takeoff roll and lift-off)     | The DSS software application should accordingly provide SAW of RWD2 flying around FWD1                   | The DSS software application provides SAW of RWD2 flying around FWD1 accordingly                   | The DSS software application keeps providing SAW of RWD2 flying around FWD1 accordingly                   |
| 10 | Land RWD2 and FWD1                                                                                                                  | The DSS software application should accordingly keep providing SAW of RWD2 and FWD1                      | The DSS software application keeps providing SAW of RWD2 and FWD1 accordingly                      | The DSS software application keeps providing SAW of RWD2 accordingly                                      |
| 11 | Switch the two ADS-B transmitters and drones off                                                                                    | The two ADS-B transmitters and drones should be off                                                      | The two ADS-B transmitters and drones are off                                                      | The two ADS-B transmitters and drones keep off                                                            |
| 12 | Check if the DSS software application does not display SAW involving RWD2 and FWD1                                                  | SAW of RWD2 and FWD1 should not be displayed by the DSS software application                             | SAW of RWD2 and FWD1 is not displayed by the DSS software application                              | The DSS software application keeps not displaying SAW of RWD2 and FWD1                                    |

#### 7.2.4 Post-Mission Phase

The purpose of the post-mission field testing for prototype configuration F is to check whether the DSS can log the information broadcasted by the ADS-B transmitters placed in RWD2 and FWD1. The test procedure for this test case requires: (1) RWD2 and FWD1 are landed, and (2) the ADS-B transmitters on board RWD2 and FWD1 keep off. It is the same than the one presented in subsection 4.2.4 (Table 12).

### 7.2.5 Experimental Results

In FTR1, the operation of the drones (RWD2 and FWD1) is meant to reproduce a (downscaled) scenario where an airplane (e.g., a commercial airliner represented by FWD1) is taking off while an AUV (represented by RWD2) flies around. FWD1 takes off from one of the ends of the runway.

This Subsection presents the experimental results from the OTR1 of the field-testing trials (in-mission phase) with real values for latitude, longitude, and altitude (not normalized as in the office and garden testing trials). The figures also show details of areas (flight waypoints) which means hazards of potential collision between aircraft (RWD2 and FWD1; both real drones used). The closest distance that the aircraft can be without becoming a hazard is set at 170 units for drones in front and in the direction of the airplane (FWD1) and 85 units for drones behind and not in the direction of the airplane (FWD1).

Figure 57 shows the trajectory produced by the ADS-B transmitter 3 mounted in RWD2 (in green) with the following setting: aircraft unauthorized to fly, and countermeasure (“PilotContact” which means the UAV has a remote contactable pilot that can be reached in case of any manoeuvre required to keep the UAV and the MAV in question properly separated) for possible mid-air collision. RWD2 is initially located (yellow cross) on the left near one of the ends of the runway (straight line in dark grey) where FWD1 is taxied (blue cross) ready to take off in the beginning of the runway, the other end of the runway. The trial’s duration is 237 sec (3 min 57 sec).

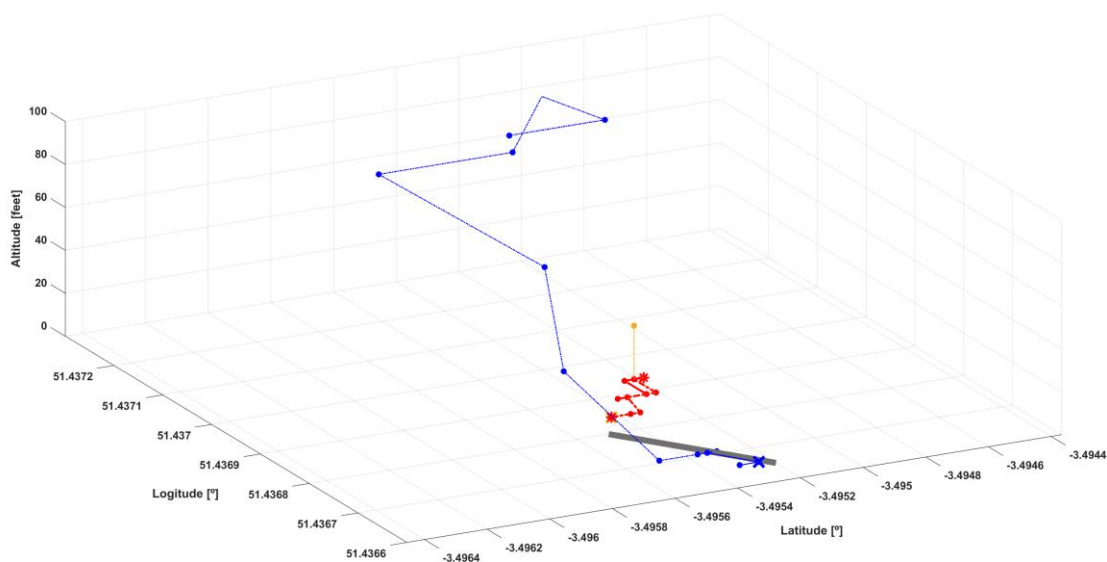


**Figure 57.** ADSB-based localization for SA of RWD2 with countermeasure.

Figure 58 shows the distance between RWD2 and FWD1 for each sampling time (every 1 second) in the DSS software application. The distance is calculated as a vectorial difference between the ADSB-based localization of the two pairs of drones (RWD2 and FWD1).

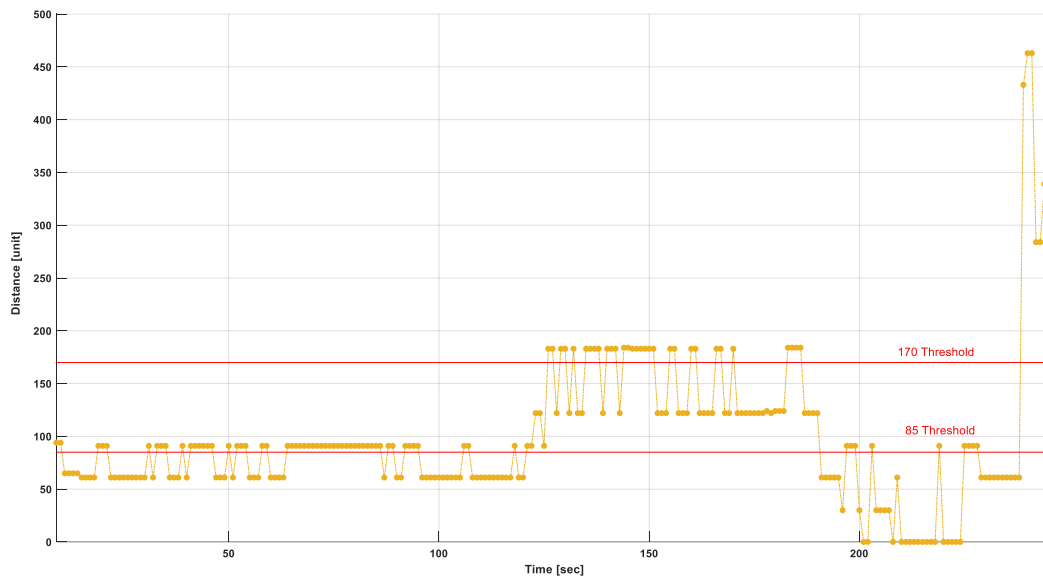


**Figure 58.** ADSB-based distance between RWD2 and FWD1 (with countermeasure).

If RWD2 is behind FWD1 (opposite to the direction of FWD1) the reference distance to determine whether RWD2 flight is a hazard for FWD1 is 85 units. If RWD2 is ahead FWD1 (in the direction of FWD1) the reference distance to determine whether RWD2 flight is a hazard for FWD1 is 170 units. Both reference distances are highlighted in Figure 58. There is a critical period when the two aircraft (RWD2 and FWD1) get very close (however, there is no collision) and for which the current distance calculated is 0 units (202 and 225 secs).

Figure 59 shows the SA provided by the DSS software application for the time the two drones are on during the experiment. The possible outputs for this trial for RWD2 are Flight Safety (FS) where the airplane (FWD1) under consideration is not at risk of collision with one of the relevant AUV (i.e., RWD2) and Flight Safety Warning (FSW) where the airplane (FWD1) under consideration is at considerable risk of collision with RWD2.

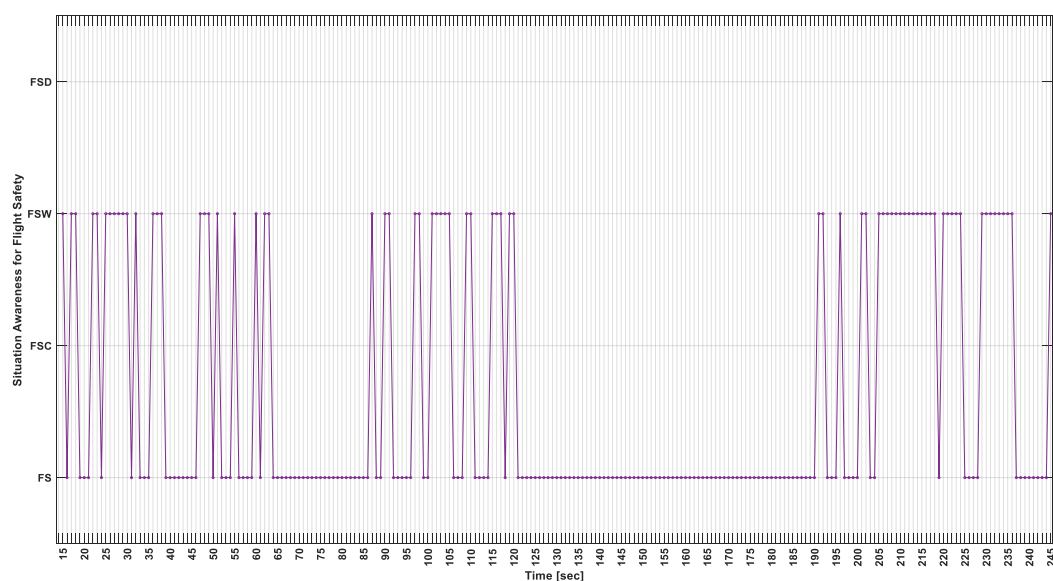


**Figure 59.** ADSB-based SA of RWD2 with countermeasure.

There are some periods of times (187-191 secs and 227-242 secs) during the transition of the SA states in which values for the SA bounce for RWD2. This situation is due to interim changes in the calculation of the distance between aircraft that suggest the threshold given by the limit distance is crossed and then it is not crossed for a sample period.

### 7.3 Trials for Prototype Configuration F

The second field testing trial carried out is based on configuration F of the framework prototype. The following subsection discuss details of the trial.

#### 7.3.1 Setting Details of the Trials

Table 40 shows information in addition to the specifications shown in Table 34 to provide details from the environment of the trails using prototype configuration F.

**Table 40.** Additional information for field testing trial for prototype configuration F.

|                              |                                                                                                                                                                                                                            |
|------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Date and Time</b>         | Sat, 23 Sep 2023, 12:00 - 13:00                                                                                                                                                                                            |
| <b>Weather Condition*</b>    | Mostly sunny, 12 °C, 1016.00mb, 64%, 15 km/h, 30 km (24.7min)                                                                                                                                                              |
| <b>Environment Radiation</b> | ADS-B Device off <ul style="list-style-type: none"> <li>• Outdoor             <ul style="list-style-type: none"> <li>○ EMF: 0 mG</li> <li>○ EF: 1 V/m</li> <li>○ RF: 0.003 – 0.624 mW/m<sup>2</sup></li> </ul> </li> </ul> |

\* Source: <https://www.foreca.com>

Figure 60 shows the context of the framework prototype for the field-testing trial with prototype configuration F.

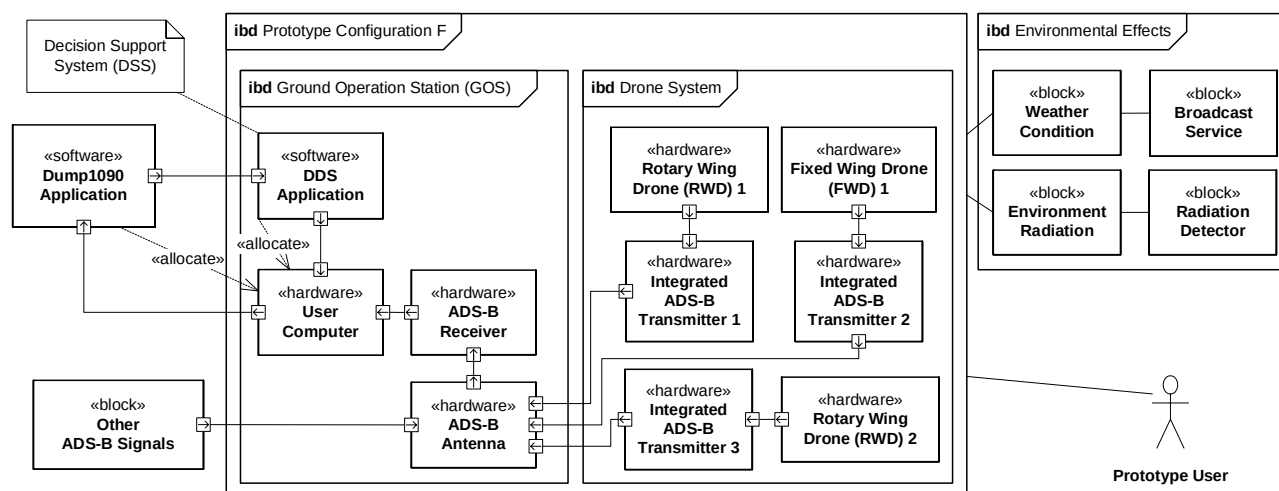


**Figure 60.** Prototype configuration F for the field-testing trial.

Figure 61 shows details of the interaction between key elements from the application scenario of the framework prototype for the field-testing trial with prototype configuration F.

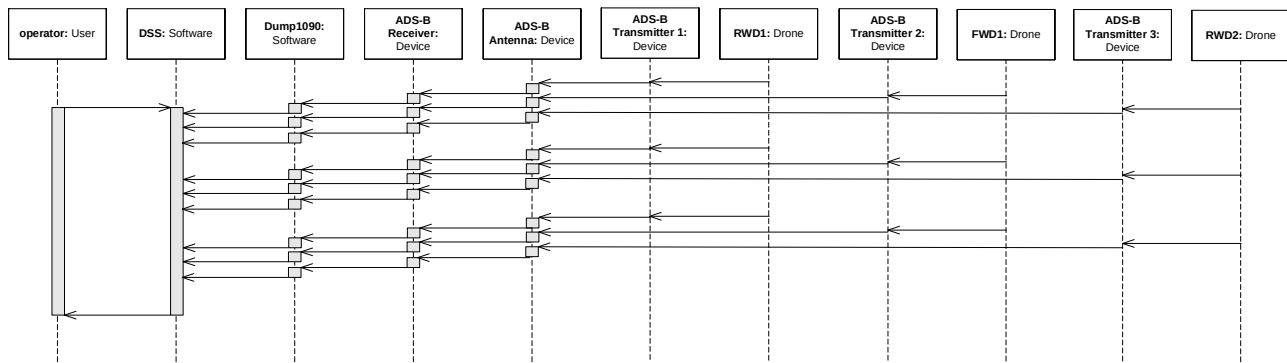


**Figure 61.** Application scenario in the field-testing trial for prototype configuration F.

Table 41 presents the test cases for the field-testing trial with prototype configuration F.

**Table 41.** Summary of test cases for the field-testing trials.

| Mission Phase | Use Case | Application Scenario | Prototype Configuration | Test Case                                                            |
|---------------|----------|----------------------|-------------------------|----------------------------------------------------------------------|
| Pre-mission   | 1        | 1.2                  | F                       | RWD2 and FWD1 operation (Table 38Error! Reference source not found.) |
|               |          |                      |                         | ADS-B RF link (Table 18)                                             |
|               |          |                      |                         | IP/TCP data link (Table 10)                                          |
|               | 2        | 2.1                  |                         | RWD1 and FWD1 operation (Table 28)                                   |
|               |          |                      |                         | ADS-B RF link (Table 18)                                             |
|               |          |                      |                         | IP/TCP data link (Table 10)                                          |
| In-Mission    | 1        | 1.2                  | F                       | SAW of RWD1 with countermeasures (Table 19)                          |
|               |          |                      |                         | SAW of RWD1 without countermeasures                                  |
|               | 2        | 2.1                  |                         | SAW of RWD1 with countermeasures (Table 19)                          |
|               |          |                      |                         | SAW of RWD1 without countermeasures                                  |
| Post-mission  | 1        | 1.2                  | F                       | DSS information logging (Table 12)                                   |
|               | 2        | 2.1                  |                         | DSS information logging (Table 12)                                   |

### 7.3.2 Experimental Results

In FTR2, the operation of the aircraft (RWD1, RWD2, and FWD1) is meant to reproduce a (downscaled) scenario where an airplane (e.g., a commercial airliner represented by FWD1) is taking off, climbing, descending, and landing while AUVs (represented by RWD1 and RWD2) fly around. FWD1 lands by touching the runway and then they take off again, so they keep a non-stop flight cycle of two takeoff-landings.

This Subsection presents the experimental results from the field-testing trials (in-mission phase) carried out in the SWRCS facility with real values for latitude, longitude, and altitude (not normalized as in the office and garden testing trials). The figures also show details of areas (flight waypoints) which means hazards of potential collision between aircraft (RWD1, RWD2, and FWD1; real drones used). The closest distance that the aircraft can be without becoming a hazard is set at 170 units for drones in front and in the direction of the airplane (FWD1) and 85 units for drones behind and not in the direction of the airplane (FWD1).

Figure 62 shows the trajectory produced by the ADS-B transmitter 1 mounted in RWD1 (in green) with the following setting: aircraft unauthorized to fly, and countermeasure (“PilotContact” which means the UAV has a remote contactable pilot that can be reached in case of any manoeuvre required to keep the UAV and the MAV in question properly separated) for possible mid-air collision. It also shows the trajectory

produced by the ADS-B transmitter 3 mounted in RWD2 (in yellow) with the following setting: aircraft unauthorized to fly, and countermeasure (“PilotContact” which means the UAV has a remote contactable pilot that can be reached in case of any manoeuvre required to keep the UAV and the MAV in question properly separated ) for possible mid-air collision. The trajectory of FWD1 is shown in blue.

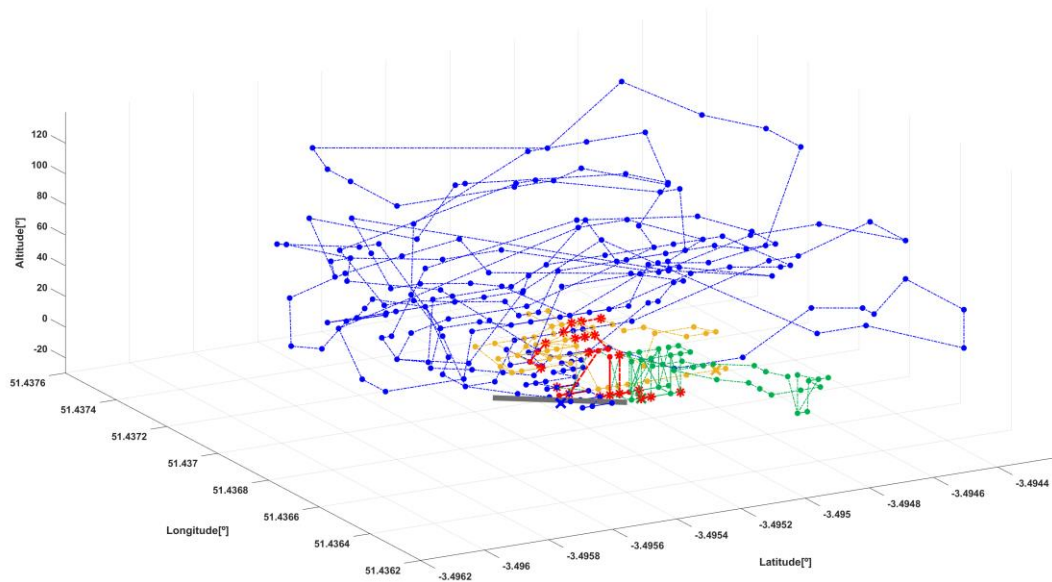


**Figure 62.** ADSB-based localization for SA of RWD1 and RWD2 (both with countermeasure).

RWD1 is initially located (green cross) at one of the ends of the runway (straight line in dark grey), behind FWD1 which is taxied ready for take-off (blue cross) in that end of the runway. RWD2 is initially on the other side of the runway and more to the right of the runway (yellow cross). The trial's duration is 873 sec (14 min 55 sec).

Figure 63 shows the distance between RWD1 and FWD1 as well as RWD2 and FWD1 for each sampling time (every 1 second) in the DSS software application. The distance is calculated as a vectorial difference between the ADSB-based localization of the two pairs of drones (RWD1/RWD2 and FWD1). Vertical lines are to show the period in which each flight phase is assessed.

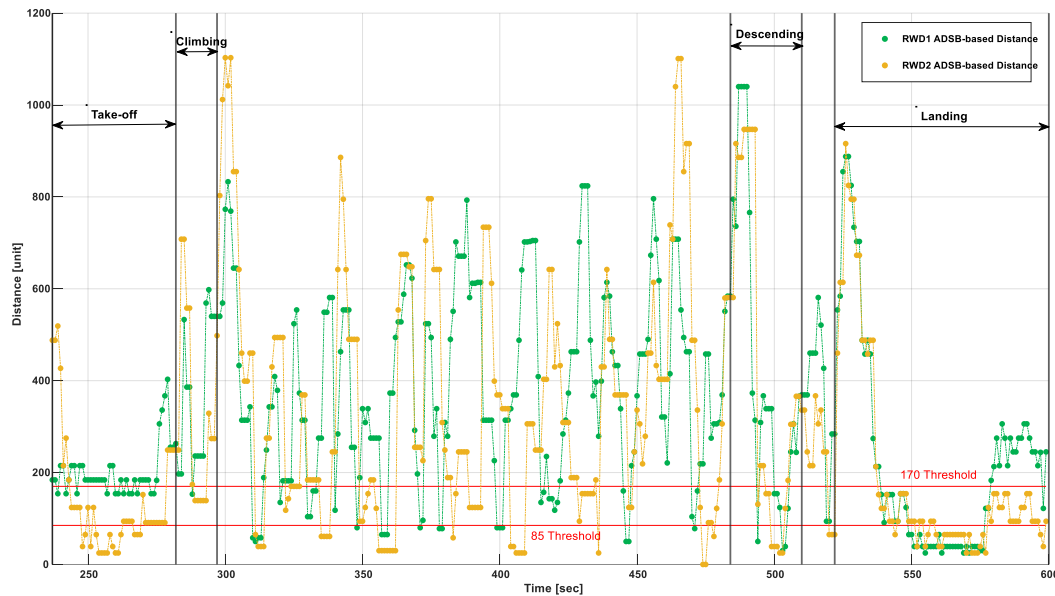


**Figure 63.** ADSB-based distance between RWD1/RWD2 (both with countermeasure) and FWD1.

If RWD1/RWD2 is behind FWD1 (opposite to the direction of FWD1) the reference distance to determine whether RWD1/RWD2 flight is a hazard for FWD1 is 85 units. If RWD1/RWD2 is ahead FWD1 (in the direction of FWD1) the reference distance to determine whether RWD1/RWD2 flight is a hazard for FWD1 is 170 units. Both reference distances are highlighted in Figure 42. There is a critical period when the two aircraft (RWD1/RWD2 and FWD1) get very close (no collision) and for which the current distance calculated is 0 units (177 and 178 secs).

Figure 64 shows the SA provided by the DSS software application for the time the three drones are operating during the experiment. The possible outputs for this trial for RWD1 and RWD2 are Flight Safety (FS) where the airplane (FWD1) under consideration is not at risk of collision with one of the AUVs (i.e., RWD1 or RWD2) and Flight Safety Warning (FSW) where the airplane (FWD1) under consideration is at considerable risk of collision with RWD1 or RWD2.

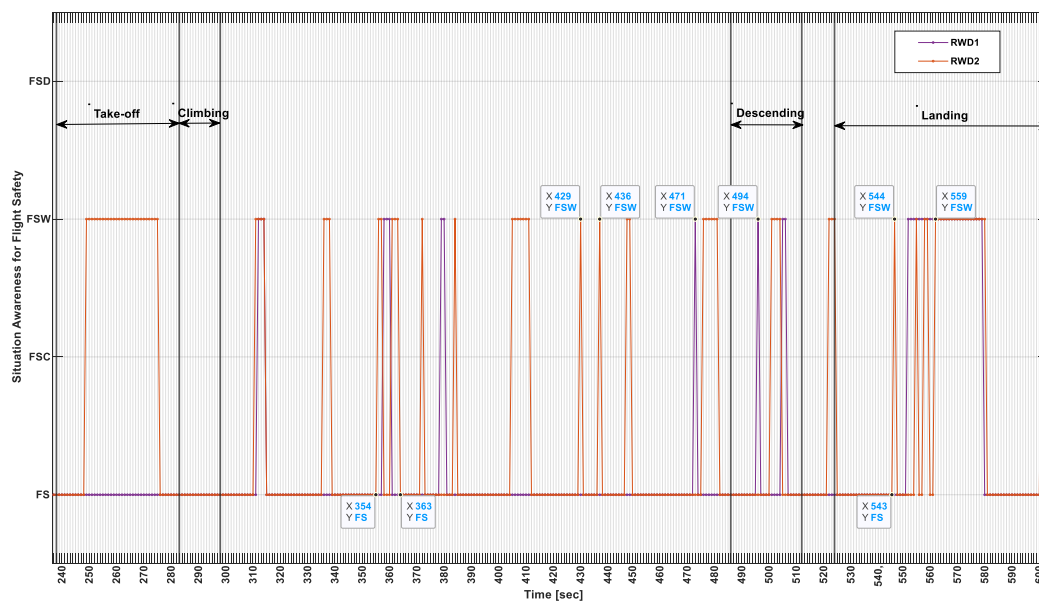


**Figure 64.** ADSB-based SA of RWD1 and RWD2 (both with countermeasure).

There are some periods of times (e.g., 354-363 secs and 543-559 secs) during the transition of the SA states in which values for the SA bounce for RWD2. Likewise, there are isolated changes during the transition of the SA states in which values for the SA bounce for RWD1 (e.g., 471 and 494 secs) and RWD2 (e.g., 429, 436, and 544 secs). These situations are due to interim changes in the calculation of the distance between aircraft that suggest the threshold given by the limit distance is crossed and then it is not crossed for a sample period. In the case of RWD 1, proximity to FWD1 is affected by the readings from the GPS of its ADS-B transmitter as the distance is borderline (threshold). In the case of RWD2, RWD2 crosses multiple time the threshold distance.

FTR3 has the same application scenarios as FTR2 but the settings for the drones playing the role of UAVs is as follows: RWD1 has “PilotContact” and RWD2 has “none” as countermeasures. The other difference is that FTR3 is carried out in the DVC instead of the SWRCS site like FTR2.

Table 40 shows information in addition to the specifications shown in Table 34 to provide details from the environment of the trails using prototype configuration F for FTR3.

**Table 42.** Additional information for field testing trial for prototype configuration F for FTR3.

|                              |                                                                                                                                                                                                                              |
|------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Date and Time</b>         | Sat, 23 Sep 2023, 12:00 - 13:00                                                                                                                                                                                              |
| <b>Weather Condition*</b>    | Mostly sunny, 12 °C, 1016.00mb, 64%, 15 km/h, 30 km (24.7 miles)                                                                                                                                                             |
| <b>Environment Radiation</b> | ADS-B Device off <ul style="list-style-type: none"> <li>• Outdoor               <ul style="list-style-type: none"> <li>○ EMF: 0 mG</li> <li>○ EF: 1 V/m</li> <li>○ RF: 0.003 – 0.624 mW/m<sup>2</sup></li> </ul> </li> </ul> |

\* Source: <https://www.foreca.com>

Figure 62 shows the trajectory produced by the ADS-B transmitter 1 mounted in RWD1 (in green) with the following setting in FTR3: aircraft unauthorized to fly, and countermeasure (“PilotContact” which means the UAV has a remote contactable pilot that can be reached in case of any manoeuvre required to keep the UAV and the MAV in question properly separated) for possible mid-air collision. It also shows the trajectory produced by the ADS-B transmitter 3 mounted in RWD2 (in yellow) with the following setting: aircraft unauthorized to fly, and countermeasure (“none” which means the UAV has no remote contactable pilot that can be reached in case of any manoeuvre required to keep the UAV and the MAV in question properly separated ) for possible mid-air collision. The trajectory of FWD1 is shown in blue.

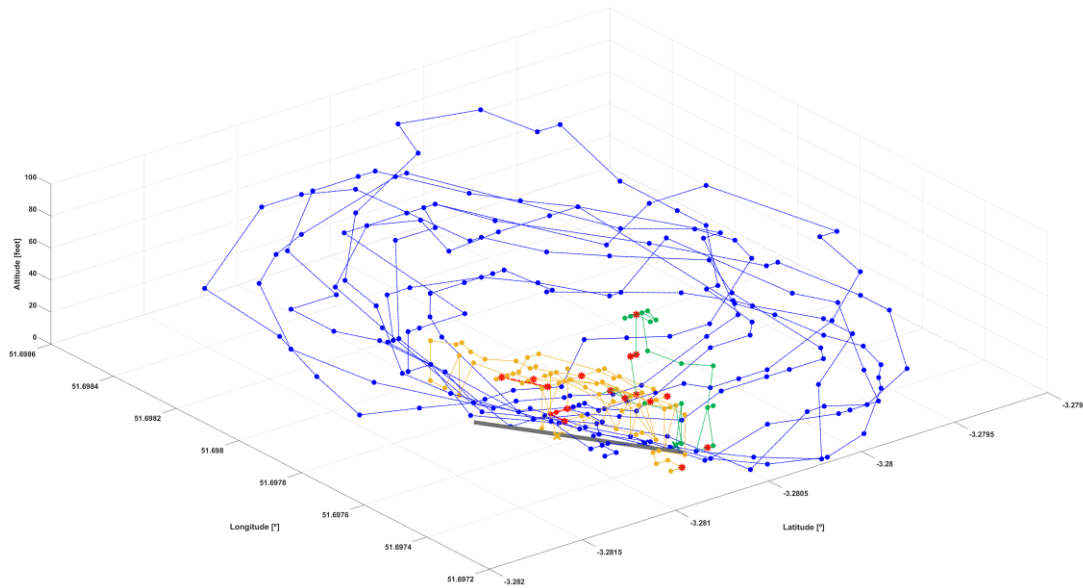


**Figure 65.** ADSB-based localization for SA of RWD1 and RWD2 (with and without countermeasure resp).

RWD1 is initially located (green cross) at one of the ends of the runway (straight line in dark grey), behind FWD1 which is taxied ready for take-off (blue cross) in that end of the runway. RWD2 is initially on the other side of the runway, slightly to the left of the runway (yellow cross). The trial's duration is 337 sec (5 min 37 sec approximately).

Figure 63 shows the distance between RWD1 and FWD1 as well as RWD2 and FWD1 for each sampling time (every 1 second) in the DSS software application. The distance is calculated as a vectorial difference between the ADSB-based localization of the two pairs of drones (RWD1/RWD2 and FWD1). Vertical lines are to show the period in which each flight phase is assessed.

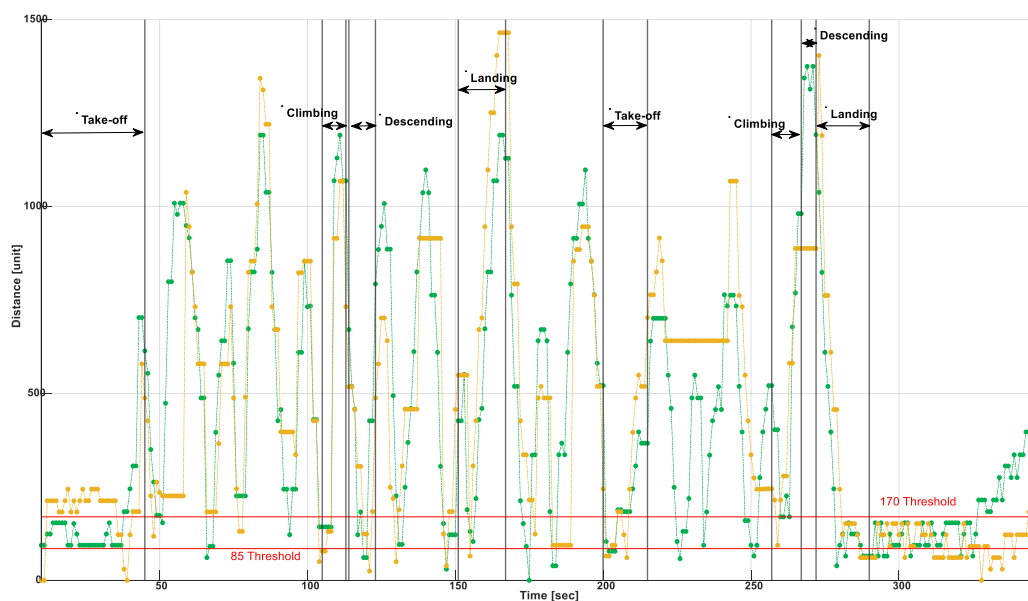


**Figure 66.** ADSB-based distance between RWD1/RWD2 (with/without countermeasure) and FWD1.

If RWD1/RWD2 is behind FWD1 (opposite to the direction of FWD1) the reference distance to determine whether RWD1/RWD2 flight is a hazard for FWD1 is 85 units. If RWD1/RWD2 is ahead FWD1 (in the direction of FWD1) the reference distance to determine whether RWD1/RWD2 flight is a hazard for FWD1 is 170 units. Both reference distances are highlighted in Figure 42. There are critical periods when the two aircraft (RWD1/RWD2 and FWD1) get very close (no collision) and for which the current distance calculated is 0 units (10, 11, 39, and 328 secs).

Figure 64 shows the SA provided by the DSS software application for the time the three drones are operating during the experiment. The possible outputs for this trial for RWD1 are Flight Safety (FS) where the airplane (FWD1) under consideration is not at risk of collision with one of the relevant AUV (i.e., RWD1) and Flight Safety Warning (FSW) where the airplane (FWD1) under consideration is at considerable risk of collision with RWD1. On the other hand, the possible outputs for this trial for RWD2 are Flight Safety Caution (FSC) where the airplane (FWD1) under consideration is not at risk of collision with the other relevant AUV (i.e., RWD2) and Flight Safety Danger (FSD) where the airplane (FWD1) under consideration is at considerable risk of collision with RWD2.

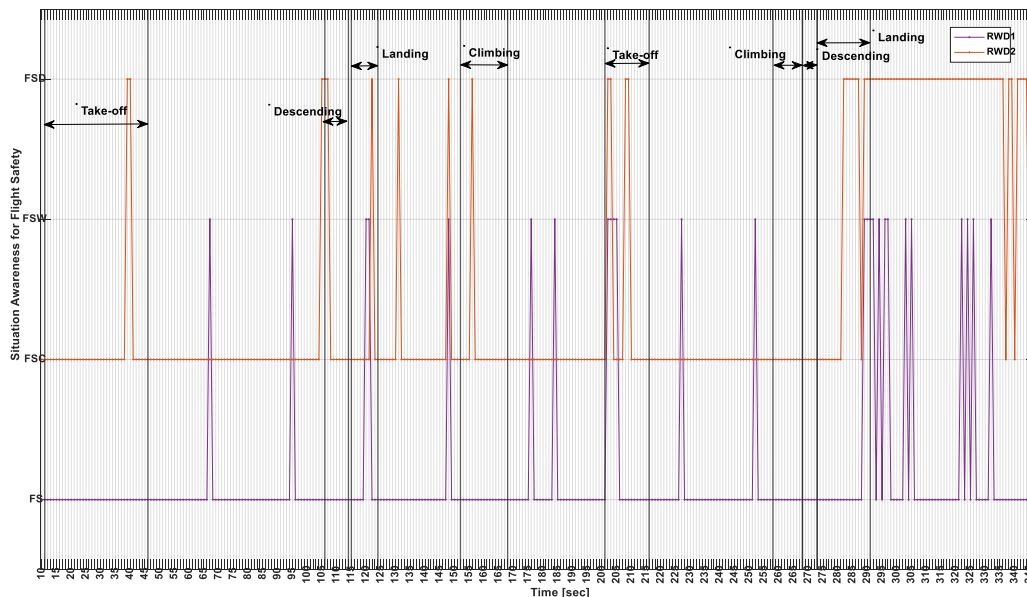


**Figure 67.** ADSB-based SA of RWD1 and RWD2 (RWD1 with, RWD2 without countermeasure).

There are some periods of times (e.g., 290-350 secs and 320-332 secs) during the transition of the SA states in which values for the SA bounce for RWD1 (when all the drones are landed). Likewise, there are isolated changes during the transition of the SA states in which values for the SA bounce for RWD2 (e.g., during the second FWD1 take-off, 200 and 215 secs) and RWD1 (e.g., by the end of the second descending, 286 and 288 secs). These situations are due to interim changes in the calculation of the distance between aircraft that suggest the threshold given by the limit distance is crossed and then it is not crossed for a sample period. In the case of RWD 1, proximity to FWD1 is affected by the readings from the GPS of its ADS-B transmitter as the distance is borderline (threshold). In the case of RWD2, RWD2 crosses multiple time the threshold distance.

Figure 68 shows details of RWD1 (Types: Quadcopter) in the AAO during FTR3 of the field-testing trial with SAW advising “Flight Safety”. This is a screenshot of sample 277 and it is when the distance between RWD1 and FWD1 is 397 units (*hasDistance* 397) during the second landing. The ICAO address of RWD1 in decimal (*hasICAOAddress* 4346365 or 4251FD in hexadecimal) as well as that RWD1 is not authorized to fly nearby FWD1 (*isAuthorized* false) are also displayed as data property assertions. RWD1 is set to have

countermeasure (*hasCountermeasure* PilotContact), and the fact that RWD1 is part of the FWD1 air traffic is set as soon as RWD1 is reported around (*isAirTrafficOf* FWD1). RWD1 is behind FWD1 when the latter has landed (*isInDirection* 4). All these parameters are displayed as object proper assertions.

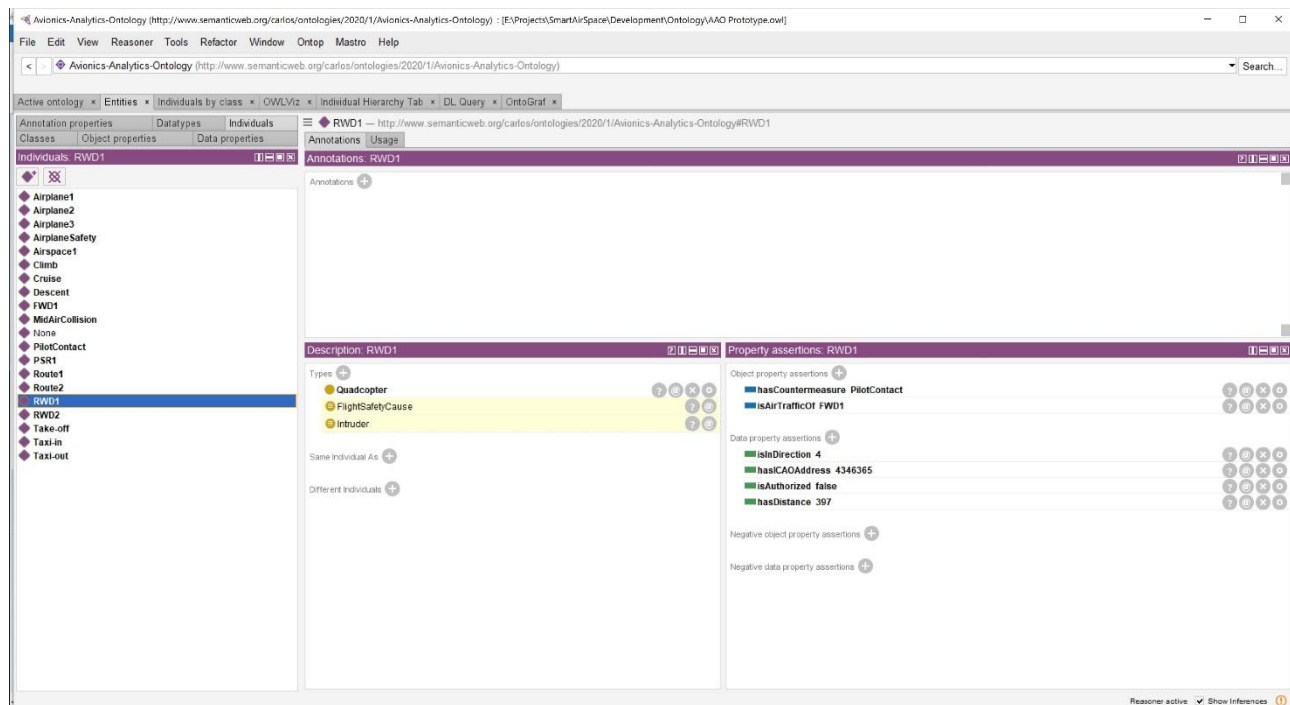


**Figure 68.** RWD1 details in Protégé for FTR3 of the field-testing trial.

Figure 69 shows details of RWD2 (Types: Quadcopter) in the AAO during FTR3 of the field-testing trial with SAW advising “Flight Safety Caution”. This is a screenshot of sample 22 and it is when the distance between RWD1 and FWD1 is 183 units (*hasDistance* 183) during the second landing. The ICAO address of RWD1 in decimal (*hasCAOAddress* 4346416 or 425230 in hexadecimal) as well as that RWDE is not authorized to fly nearby FWD1 (*isAuthorized* false) are also displayed as data property assertions. RWDE is set to have no countermeasure (*hasCountermeasure* None), and the fact that RWD2 is part of the FWD1 air traffic is set as soon as RWD2 is reported around (*isAirTrafficOf* FWD1). RWD2 is ahead FWD1 when the latter has landed (*isInDirection* 6). All these parameters are displayed as object proper assertions.

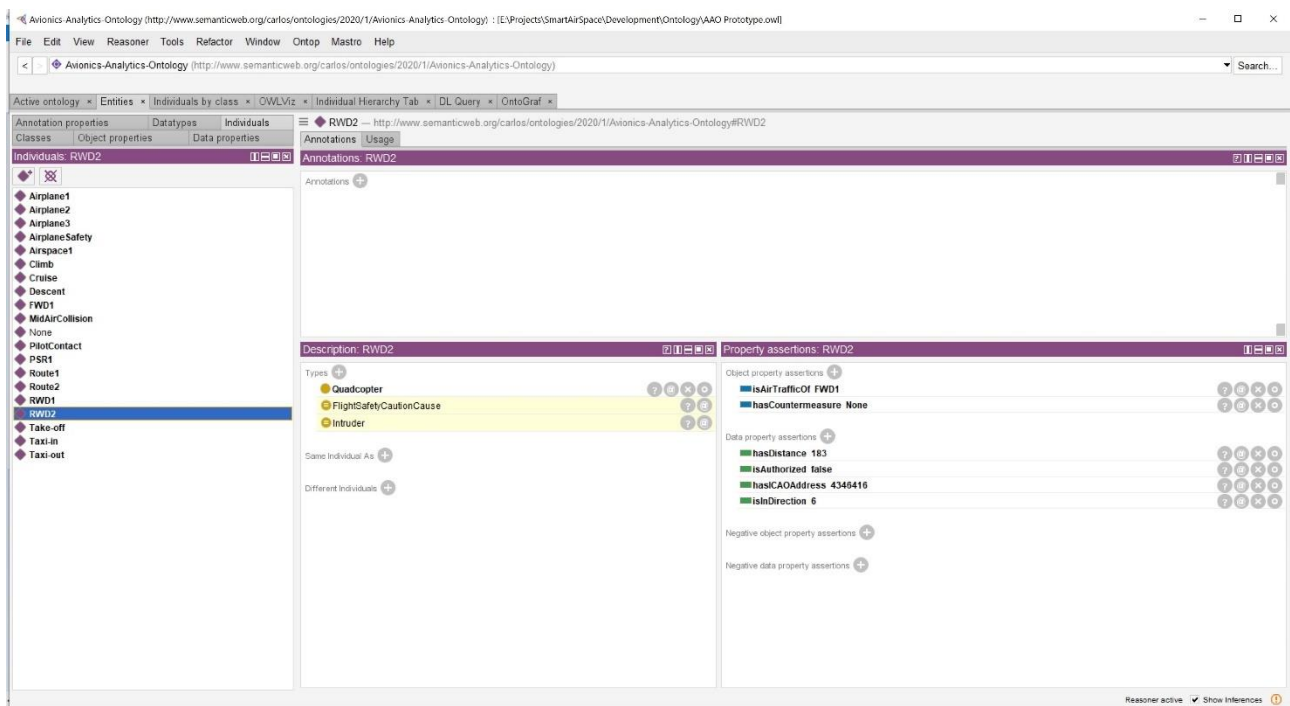


**Figure 69.** RWD2 details in Protégé for FTR3 of the field-testing trial.

Figure 70 shows details of FWD1 (Types: Airplane) in the AAO during FTR3 of the field-testing trial with SAW advising “Flight Safety” for RWD1 and “Flight Safety Caution” for RWD2. This is a screenshot of sample 69. The ICAO address of FWD1 in decimal (*hasICAOAddress* 4346366 or 4251FE in hexadecimal) as well as that RWDE is not authorized to fly nearby FWD1 (*isAuthorized* false) are also displayed as data property assertions. RWD1 and RWD2 are reported around (*hasAirTraffic* RWD1 and *hasAirTraffic* RWD2).

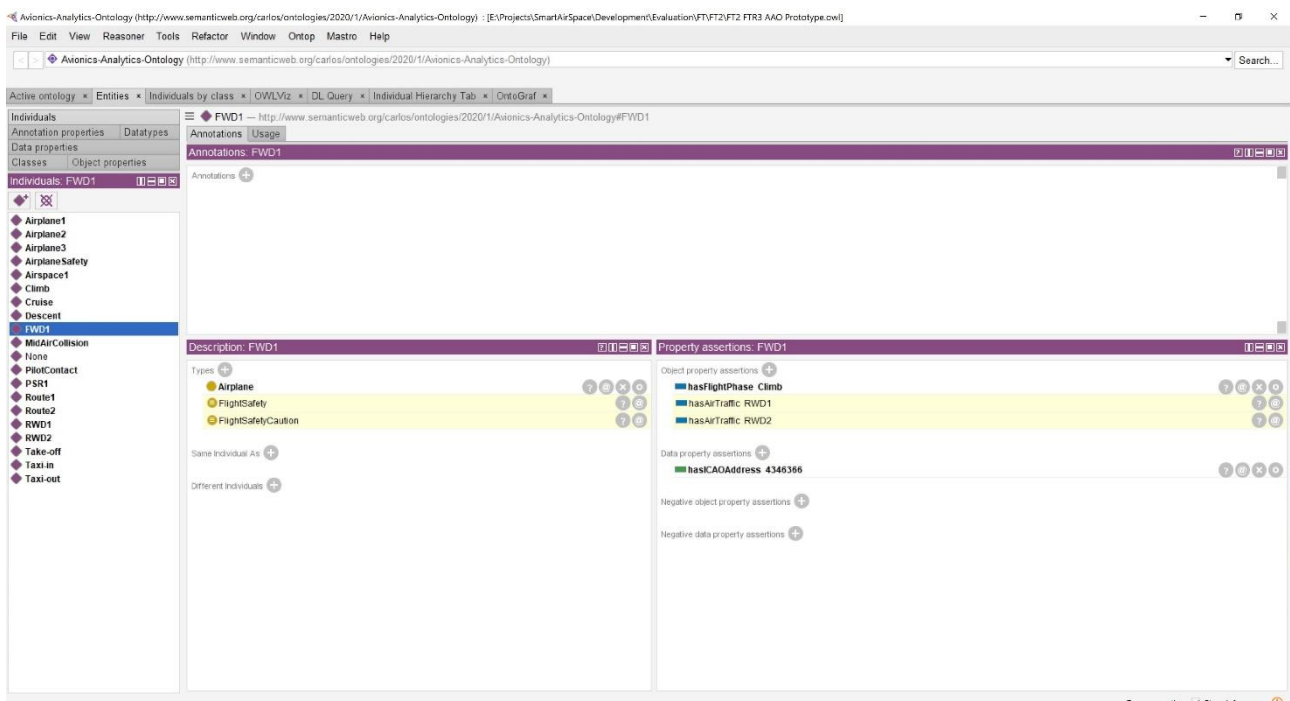


**Figure 70.** FWD1 details in Protégé for FTR3 of the field-testing trial.

Figure 71 shows details of the class “FlightSafety” in the AAO during FTR3 of the field-testing trial. The class is to define when a flight (target aircraft, represented by a drone: FWD1 in a role of MAV) is safe. It involves FWD1 which has air traffic defined by drones (with countermeasures) playing the role of UAVs flying

around FWD1 (equivalent to *hasAirTraffic* some (ISCAirspace and SafetyEntailment)). ISCAirspace is a class that involves AUVs (RWD1 and RWD2) that are not authorized to fly, have proper separation, and have countermeasures to avoid mid-air collisions. SafetyEntailment is a class that involves MAV with safety requirements.

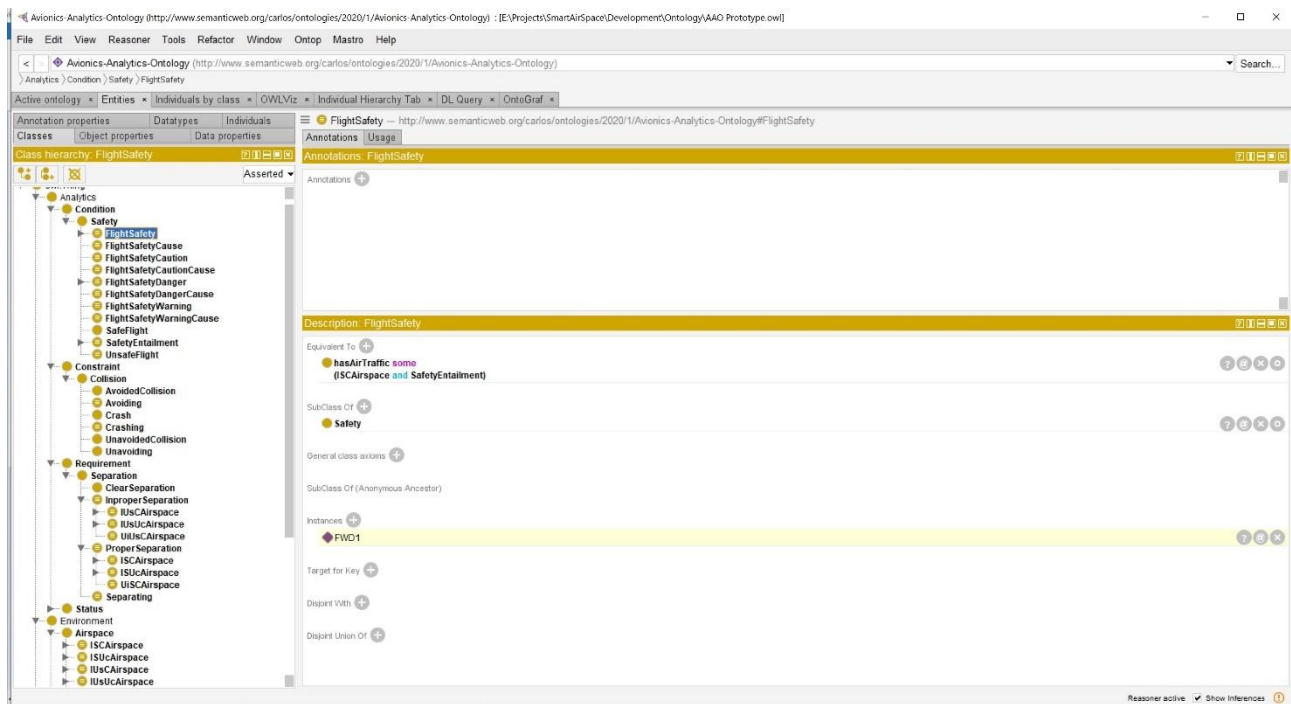


Figure 71. FlightSafety details in Protégé for FTR3 of the field-testing trial.

Figure 72 shows details of the class “FlightSafetyCause” in the AAO during FTR3 of the field-testing trial. The class is to define what drones (with countermeasures) playing the role of UAVs flying around FWD1 (equivalent to ISCAirspace and SafetyEntailment) make a flight (target aircraft, represented by a drone: FWD1 in a role of MAV) safe. It involves RWD1 which is air traffic of FWD1 defined by ISCAirspace.

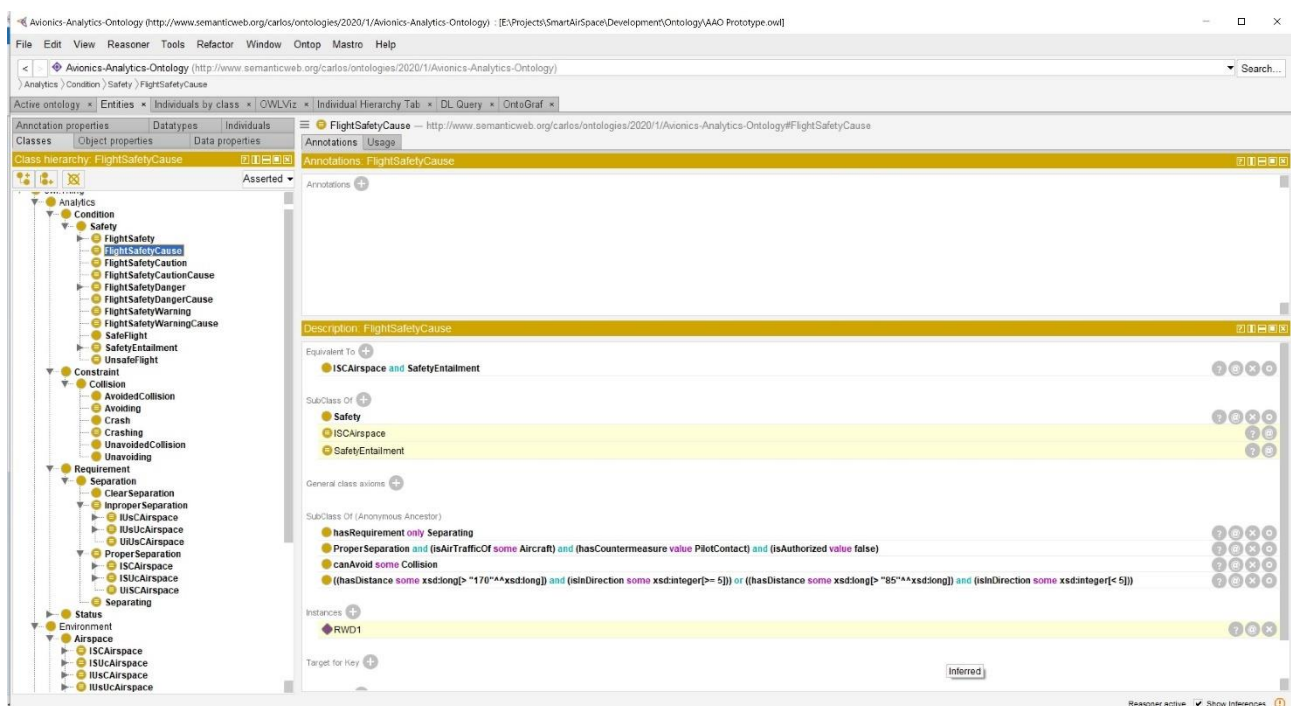


Figure 72. FlightSafetyCause details in Protégé for FTR3 of the field-testing trial.

Figure 73 shows details of the class “FlightSafetyCaution” in the AAO during FTR3 of the field-testing trial. The class is to define when a flight (target aircraft, represented by a drone: FWD1 in a role of MAV) is safe. It involves FWD1 which has air traffic defined by drones (without countermeasures) playing the role of UAVs flying around FWD1 (equivalent to ISUCAirspace and SafetyEntailment). ISUCAirspace is a class that involves AUVs (RWD1 and RWD2) that are not authorized to fly, have proper separation, and have no countermeasures to avoid mid-air collisions. SafetyEntailment is a class that involves MAV with safety requirements.

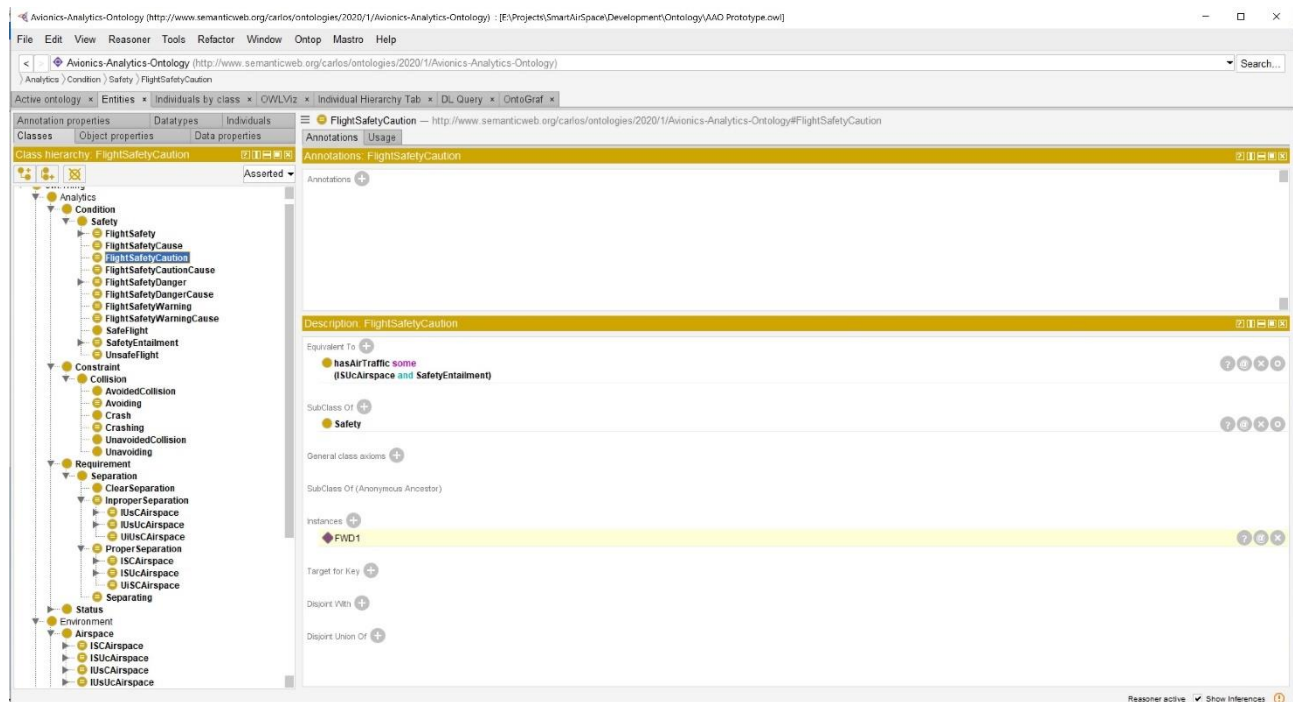


**Figure 73.** FlightSafetyCaution details in Protégé for FTR3 of the office testing trial.

Figure 74 shows details of the class “FlightSafetyCautionCause” in the AAO during FTR3 of the field-testing trial. The class is to define what drones (without countermeasures) playing the role of UAVs flying around FWD1 (equivalent to ISUCAirspace and SafetyEntailment) make a flight (target aircraft, represented by a drone: FWD1 in a role of MAV) safe. It involves RWD2 which is air traffic of FWD1 defined by ISUCAirspace.

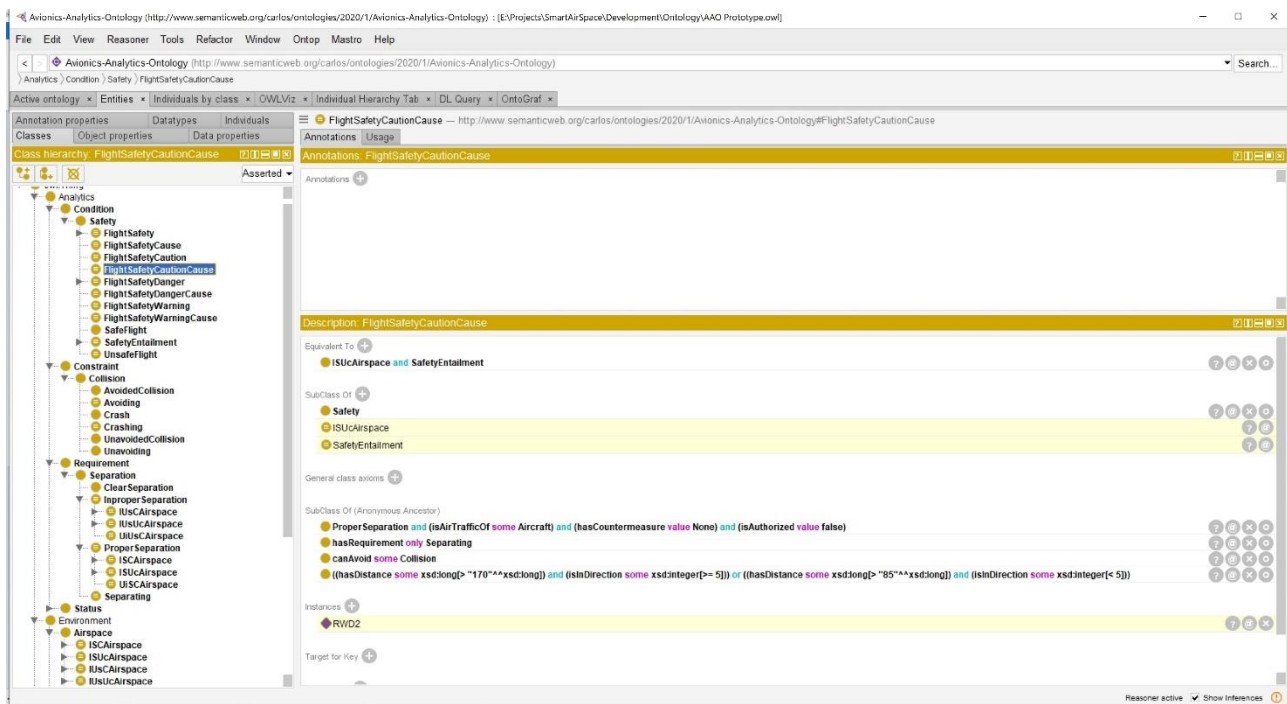


Figure 74. FlightSafetyCautionCause details in Protégé for FTR3 of the office testing trial.

## 7.4 Trials for Prototype Configuration G

The very first field testing trial carried out is based on configuration G of the framework prototype. The following subsection discuss details of the trial.

### 7.4.1 Setting Details of the Trials

Table 43 shows information in addition to the specifications shown in Table 34 to provide details from

Table 43. Additional information for field testing trial for prototype configuration F.

|                              |                                                                                                                                                                                                                               |
|------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Date and Time</b>         | Sat, 30 Sep 2023, 11:00 - 12:00                                                                                                                                                                                               |
| <b>Weather Condition*</b>    | Slight cloudy, 11 °C, 1019.00mb, 80%, 6 km/h, 10 km                                                                                                                                                                           |
| <b>Environment Radiation</b> | ADS-B Device off <ul style="list-style-type: none"> <li>Outdoor               <ul style="list-style-type: none"> <li>EMF: 0 - 0.1mG</li> <li>EF: 0 - 1 V/m</li> <li>RF: 0.001 – 0.231 mW/m<sup>2</sup></li> </ul> </li> </ul> |

\* Source: <https://www.foreca.com>

Figure 75 shows the context of the framework prototype for the field-testing trial with prototype configuration G. The FWDs swap the ADS-B transmitters in framework prototype G.

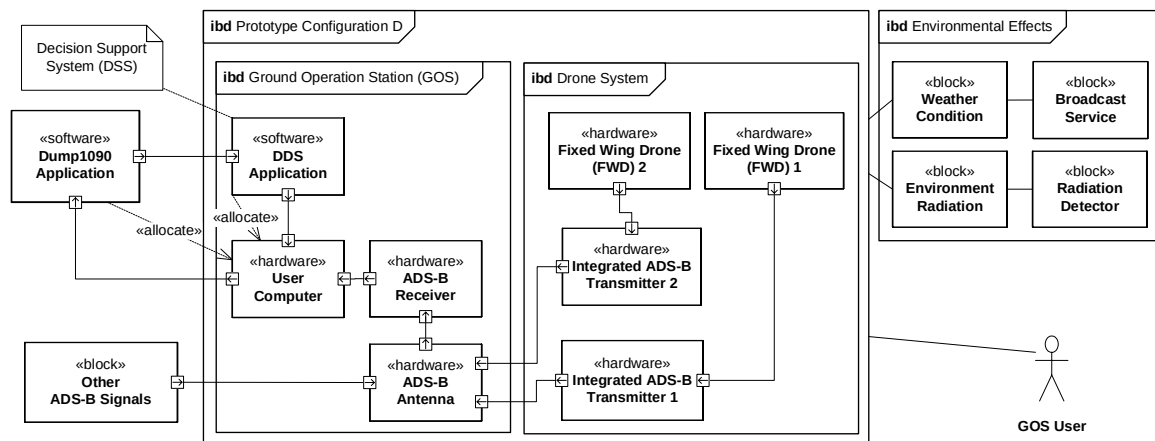


**Figure 75.** System context in the field-testing trial (configuration G).

Figure 76 shows details of the interaction between key elements from the application scenario of the framework prototype for the field-testing trial with prototype configuration G.

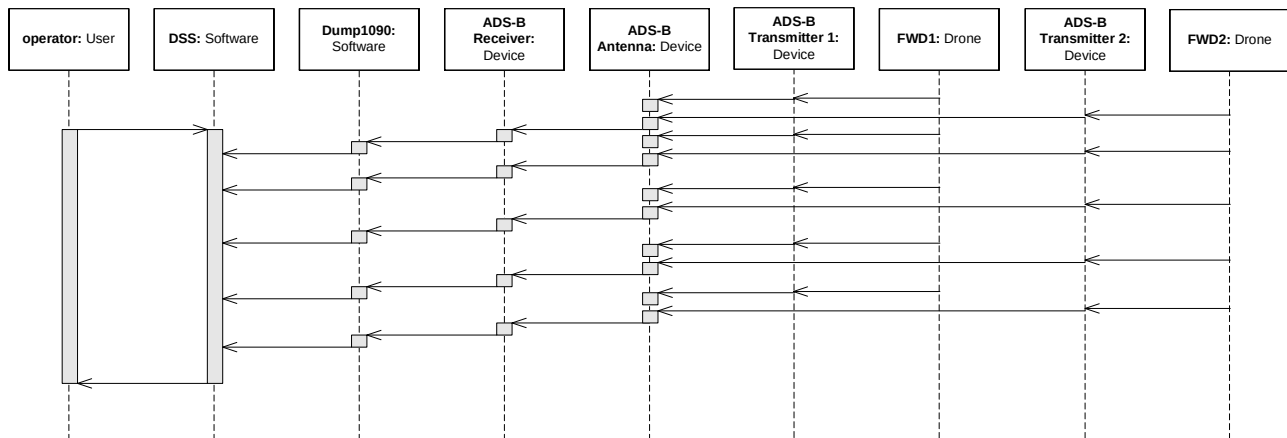


**Figure 76.** Application scenario in the park testing trial (configuration G).

Table 44 presents the test cases for the field-testing trial with prototype configuration G.

**Table 44.** Summary of test cases for the field-testing trials (configuration G).

| Mission Phase | Use Case | Application Scenario | Prototype Configuration | Test Case                           |
|---------------|----------|----------------------|-------------------------|-------------------------------------|
| Pre-mission   | 1        | 1.1                  | G                       | FWD1 and FWD2 operation (Table 45)  |
|               |          |                      |                         | ADS-B RF link (Table 9)             |
|               |          |                      |                         | IP/TCP data link (Table 10)         |
| In-Mission    | 1        | 1.1                  |                         | SAW of FWD2 without countermeasures |
| Post-mission  | 1        | 1.1                  |                         | DSS information logging (Table 12)  |

#### 7.4.2 Pre-Mission Phase

The purpose of the pre-mission field testing for prototype configuration G is to check the functions of the framework prototype are correct and the right operation of it by means of three test cases:

- FWD1 and FWD2 operation, targeting stable RWD1 flight and FWD1 manoeuvres when landed (Table 45). Both with a payload (each) which is an ADS-B transmitter.

- ADS-B RF link between the ADS-B transmitter (UAvionix EchoSky 2) device (onboard FWD1 and FWD2) and the ADS-B receiver (FlightAware Pro Stick Plus) device connected to the GOS.
- IP/TCP data link between the Dump1090 application (assumed onboard FWD2) and the DSS software application. Both applications run in the GOS. This testing is also to check if the DSS is fully operational.

The test procedure for the FWD1 and FWD2 operation test case requires: (1) the FWD1 and FWD2 structure and onboard avionics be in one piece (one ADS-B transmitter is mounted in FWD1 and another ADS-B transmitter is mounted in FWD2), (2) the FWD1 and FWD2 are initially off, and (3) the FWD1 and FWD2 are positioned on the floor.

Table 45 shows the steps for the FWD1 and FWD2 operation test case (as introduced in Table 1) for the pre-missing field testing.

**Table 45.** Test procedure for FWD1 and FWD2 operation test case.

| Test Step | User Action                                              | Expected Results                                       | Observed Results                                | Result Status                                                        |
|-----------|----------------------------------------------------------|--------------------------------------------------------|-------------------------------------------------|----------------------------------------------------------------------|
| 1         | Switch the FWD1 and FWD2 on                              | The FWD1 and FWD2 should be on                         | The FWD1 and FWD2 are on                        | The FWD1 and FWD2 keep on                                            |
| 2         | Command basic FWD1 and FWD2 moves from remote controller | The FWD1 and FWD2 should respond according to commands | The FWD1 and FWD2 respond according to commands | The FWD1 and FWD2 provide stable flight and returns to idle properly |
| 3         | Switch the FWD1 and FWD2 off                             | The FWD1 and FWD2 should be off                        | The FWD1 and FWD2 are off                       | The FWD1 and FWD2 keep off                                           |

The test procedure for the ADS-B RF link functioning as well as the IP/TCP data link functioning test cases are as discussed in subsection 4.2.2.

### 7.4.3 In- Mission Phase

The purpose of the in-mission park testing for prototype configuration G is to check the correct functioning and operation of the DSS by means of two main test cases: SAW of FWD2 without countermeasures.

The test procedure for the test case on SAW of FWD2 without countermeasures requires: (1) FWD1 and FWD2 are positioned on the floor, (2) FWD1 and FWD2 are off, (3) the ADS-B device on board FWD1 and FWD2 are off, (4) the ADS-B stick is connected to the GOS computer, (5) the Dump1090 application is ready for running in the GOS, and (6) the DSS software application is ready for running in the GOS. Table 46 shows the steps for the test case on SAW of FWD1 without countermeasures for the in-mission park testing.

**Table 46.** Test procedure for SAW of physical FWD1 without countermeasures.

| Test Step | User Action                                 | Expected Results                                      | Observed Results                               | Result Status                                     |
|-----------|---------------------------------------------|-------------------------------------------------------|------------------------------------------------|---------------------------------------------------|
| 1         | Run the Dump1090 application in the GOS     | The Dump1090 application should be up and running     | The Dump1090 application is up and running     | The Dump1090 application keeps up and running     |
| 2         | Run the DSS software application in the GOS | The DSS software application should be up and running | The DSS software application is up and running | The DSS software application keeps up and running |

|    |                                                                                                              |                                                                                                      |                                                                                                |                                                                                         |
|----|--------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|
| 3  | Check the Dump1090 and the DSS are connected with each other using TCP/IP protocol                           | The Dump1090 application and the DSS software application should be TCP/IP connected with each other | The Dump1090 application and the DSS software application are TCP/IP connected with each other | Both applications keep connected with each other using the TCP/IP protocol              |
| 4  | Place FWD1 and FWD2 on the ground, then switch them on, also their ADS-B transmitters.                       | The FWD1 and FWD2 along with their ADS-B transmitters should be on                                   | The FWD1 and FWD2 along with their ADS-B transmitters is on                                    | The FWD1 and FWD2 along with their ADS-B transmitters keeps on                          |
| 5  | Check the DSS software application receives the ADS-B data from the ADS-B transmitter                        | DSS software application should receive the ADS-B data from the ADS-B transmitter                    | The DSS software application receives the ADS-B data from the ADS-B transmitter                | The DSS software application keeps receiving the ADS-B data from the ADS-B transmitter  |
| 6  | Check if the DSS software application displays SAW involving FWD1 and FWD2 accordingly                       | SAW of FWD1 and FWD2 should be displayed in the DSS software application                             | SAW of FWD1 and FWD2 are displayed in the DSS software application                             | The DSS software application keeps displaying SAW of FWD1 and FWD2                      |
| 7  | Start flying FWD2 around in locations close to the FWD1                                                      | The DSS software application should provide SAW of FWD2 flying around FWD1                           | The DSS software application provides SAW of RWD2 flying around FWD1                           | The DSS software application keeps providing SAW of FWD2 flying around FWD1             |
| 8  | Try to get FWD2 in an airspace zone that is not hazardous for FWD1 taking off (while FWD1 is moving forward) | The DSS software application should accordingly provide SAW of FWD2 flying around FWD1               | The DSS software application provides SAW of FWD2 flying around FWD1 accordingly               | The DSS software application keeps providing SAW of FWD2 flying around FWD1 accordingly |
| 9  | Try to get FWD2 in an airspace zone that is hazardous for FWD1 taking off (while FWD1 is moving forward)     | The DSS software application should accordingly provide SAW of FWD2 flying around FWD1               | The DSS software application provides SAW of FWD2 flying around FWD1 accordingly               | The DSS software application keeps providing SAW of FWD2 flying around FWD1 accordingly |
| 10 | Land FWD2 and stop moving FWD1 (last FWD1 point before leaving ground)                                       | The DSS software application should accordingly keep providing SAW of FWD2 and FWD1                  | The DSS software application keeps providing SAW of FWD2 and FWD1 accordingly                  | The DSS software application keeps providing SAW of FWD2 accordingly                    |
| 11 | Switch the two ADS-B transmitters off                                                                        | The two ADS-B transmitters should be off                                                             | The two ADS-B transmitters are off                                                             | The two ADS-B transmitters keep off                                                     |
| 12 | Check if the DSS software application does not display SAW involving FWD2 and FWD1                           | SAW of FWD2 and FWD1 should not be displayed by the DSS software application                         | SAW of FWD2 and FWD1 is not displayed by the DSS software application                          | The DSS software application keeps not displaying SAW of FWD1 and FWD2                  |

The steps for the test case on SAW of RWD1 without countermeasures for the in-missing park testing trials are the same than the ones presented for the test case on SAW of RWD1 with countermeasures (Table 29), the difference is that RWD1 is set to have no countermeasures.

#### 7.4.4 Post-Mission Phase

The purpose of the post-mission park testing for prototype configuration D is to check whether the DSS can log the information broadcasted by the ADS-B transmitter. The test procedure for this test case requires: (1) FWD1 and FWD2 are landed, and (2) the ADS-B transmitters on board FWD1 and FWD2 keep off.

The test procedure for this test case for the post-missing park testing trial are the same than the ones presented in subsection 4.2.4 (Table 12).

#### 7.4.5 Experimental Results

In FTR4, the operation of the aircraft (FWD1 and FWD2) is meant to reproduce a (downscaled) scenario where an airplane (e.g., a commercial airliner represented by FWD1) is taking off while a AUV (represented by FWD2) flies around. FWD1 takes off from one of the ends of the runway.

This Subsection presents the experimental results from FTR4 of the field-testing trials (in-mission phase) with real values for latitude, longitude, and altitude (not normalized as in the office and garden testing trials). The figures also show details of areas (flight waypoints) which means hazards of potential collision between aircraft (FWD1 and FWD2; both real drones used). The closest distance that the aircraft can be without becoming a hazard is set at 170 units for drones in front and in the direction of the airplane (FWD1) and 85 units for drones behind and not in the direction of the airplane (FWD1).

Figure 77 shows the trajectory produced by the ADS-B transmitter 2 mounted in FWD2 (in pink) with the following setting: aircraft unauthorized to fly, and no countermeasure (“None” which means the UAV do not have a remote contactable pilot that can be reached in case of any manoeuvre required to keep the UAV and the MAV in question properly separated) for possible mid-air collision. FWD2 is initially located flying (pink cross) near a runway (straight line in dark grey) where FWD1 is taxied (blue cross) in preparation for take-off. The time of trial considered is 53 sec.

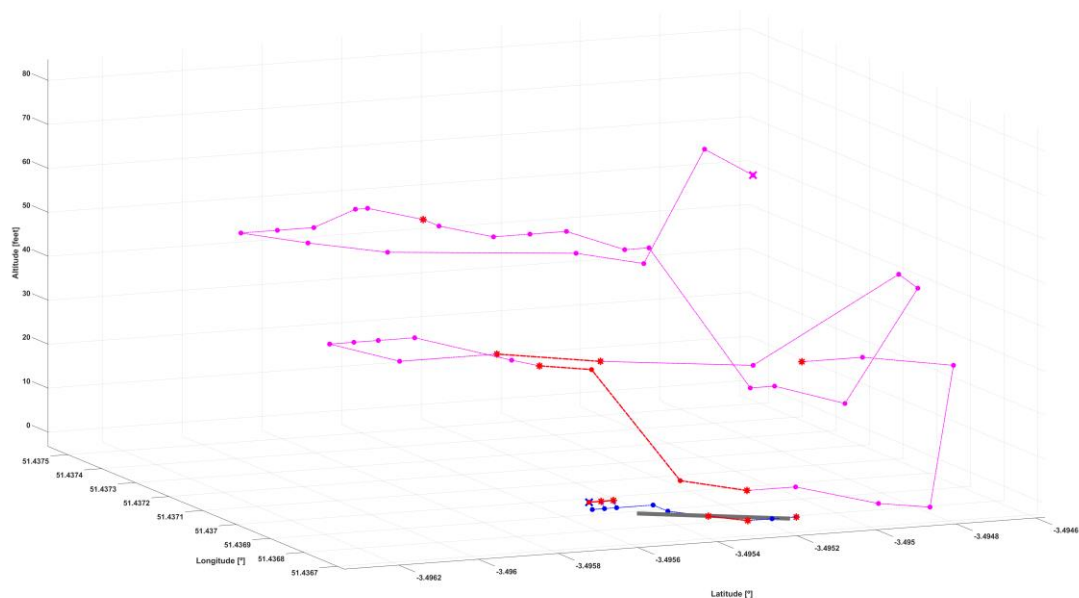


**Figure 77.** ADSB-based localization for SA of FWD2 without countermeasure.

Figure 78 shows the distance between FWD1 and FWD2 for each sampling time (every 1 second) in the DSS software application. The distance is calculated as a vectorial difference between the ADSB-based localization of the two drones (FWD1 and FWD2).

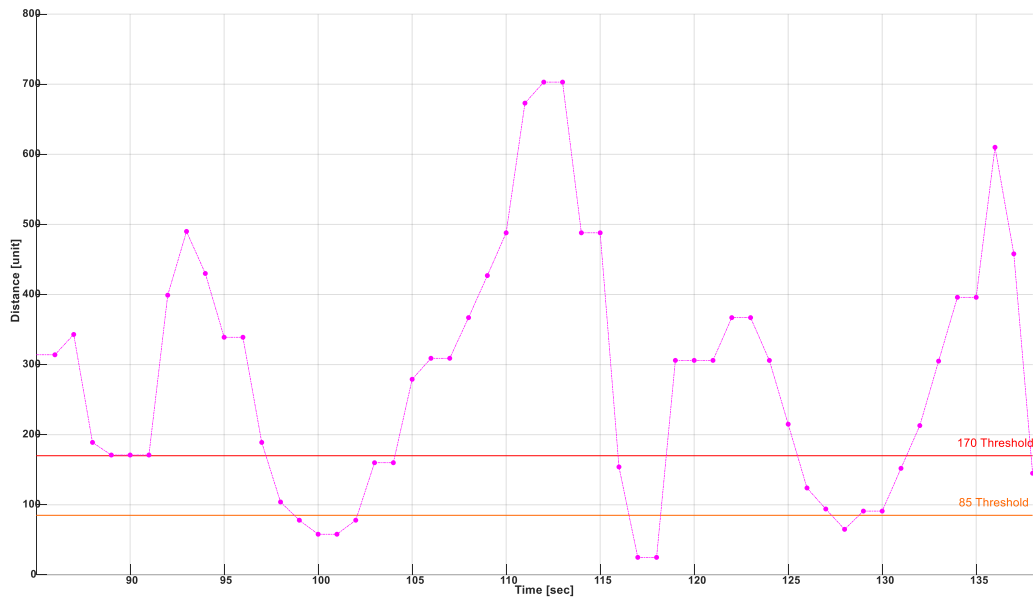


**Figure 78.** ADSB-based distance between FWD1 and FWD2 (without countermeasure).

If FWD2 is behind FWD1 (opposite to the direction of FWD1) the reference distance to determine whether FWD2 flight is a hazard for FWD1 is 85 units. If FWD2 is ahead of FWD1 (in the direction of FWD1) the reference distance to determine whether FWD2 flight is a hazard for FWD1 is 170 units. Both reference distances are highlighted in Figure 78. FWD2 is behind FWD1 during 89-91 secs. So, there is no trigger of SA such as FSD. . FWD2 is behind FWD1 during 99-102 secs. So, this triggers FSD.

Figure 79 shows the SA provided by the DSS software application for the duration of the experiment. The possible outputs for this trial are Flight Safety Caution (FSC) where the airplane (FWD1) under consideration is not at risk of collision with the relevant AUV (FWD2) and Flight Safety Danger (FSD) where the airplane (FWD1) under consideration is at considerable risk of collision with the relevant AUV (FWD2).

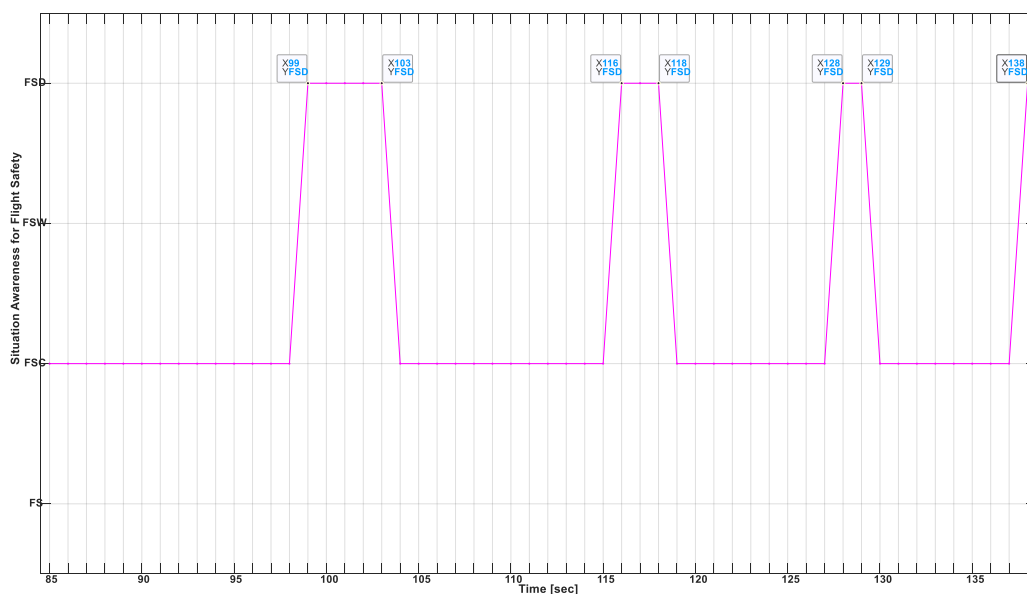


**Figure 79.** ADSB-based SA of FWD2 without countermeasure.

## 7.5 Trials for Prototype Configuration H

The third field testing trial carried out is based on configuration H of the framework prototype. The following subsection discuss details of the trial.

### 7.5.1 Setting Details of the Trials

Table 47 shows information in addition to the specifications shown in Table 34 to provide details from the environment of the trails using prototype configuration H.

**Table 47.** Additional information for field testing trial for prototype configuration F.

|                              |                                                                                                                                                                                                                               |
|------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Date and Time</b>         | Sun, 8 Oct 2023, 11:00 - 12:30                                                                                                                                                                                                |
| <b>Weather Condition*</b>    | Slight cloudy, 6 °C, 1022.00mb, 90%, 2 km/h, 10 km                                                                                                                                                                            |
| <b>Environment Radiation</b> | ADS-B Device off <ul style="list-style-type: none"> <li>Outdoor               <ul style="list-style-type: none"> <li>EMF: 0 - 0.1mG</li> <li>EF: 0 - 1 V/m</li> <li>RF: 0.001 – 0.181 mW/m<sup>2</sup></li> </ul> </li> </ul> |

\* Source: <https://www.foreca.com>

Figure 55 shows the context of the framework prototype for the field-testing trial with prototype configuration H. The drone system includes two FWDs and one RWD instead of two RWDs and one FWD like in prototype configuration F.

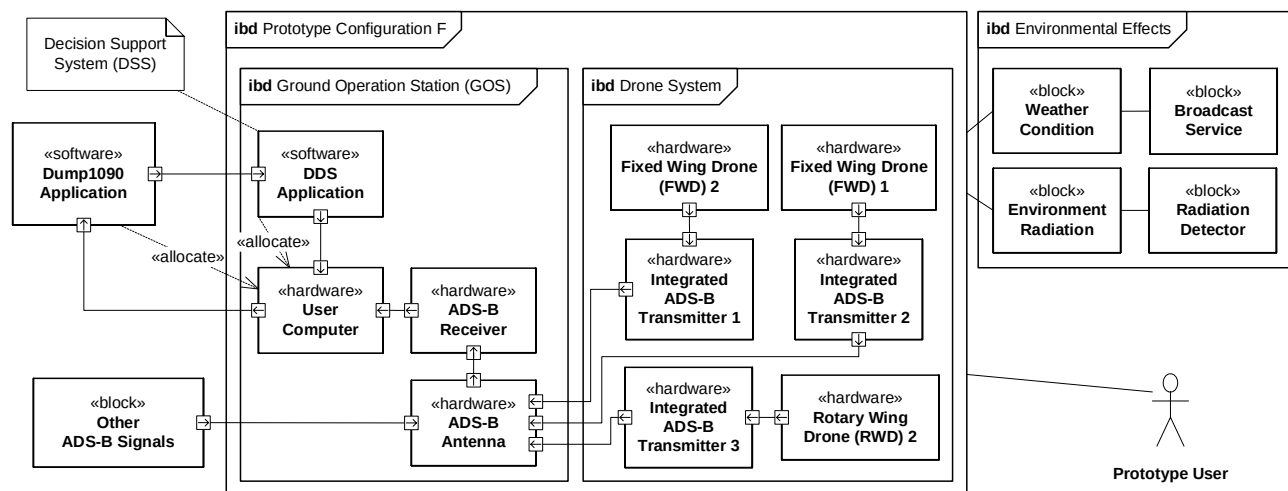


**Figure 80.** Prototype configuration H for the field-testing trial.

Figure 81 shows details of the interaction between key elements from the application scenario of the framework prototype for the field-testing trial with prototype configuration H.

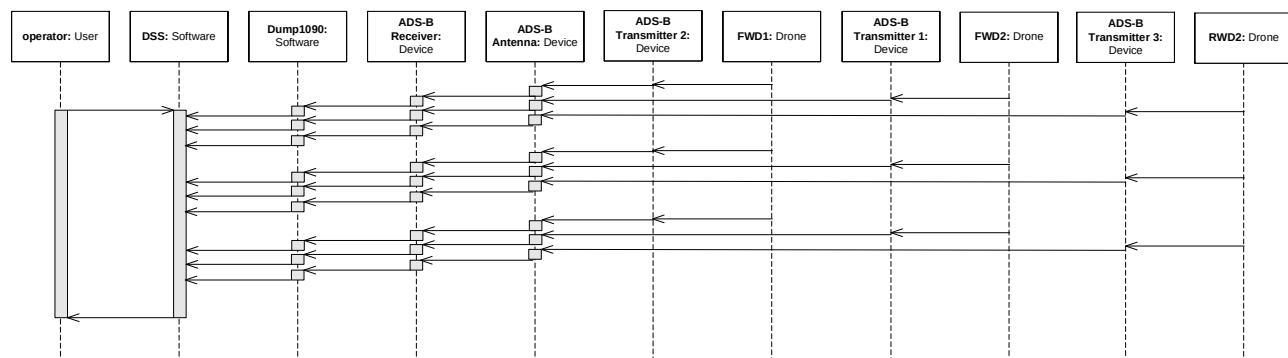


**Figure 81.** Application scenario in the field-testing trial for prototype configuration H.

Table 48 presents the test cases for the field-testing trial with prototype configuration H.

**Table 48.** Summary of test cases for the field-testing trials.

| Mission Phase | Use Case | Application Scenario | Prototype Configuration | Test Case                                   |
|---------------|----------|----------------------|-------------------------|---------------------------------------------|
| Pre-mission   | 1        | 1.2                  | F                       | RWD2 and FWD1 operation (Table 38)          |
|               |          |                      |                         | ADS-B RF link (Table 18)                    |
|               |          |                      |                         | IP/TCP data link (Table 10)                 |
|               | 2        | 2.1                  |                         | RWD1 and FWD1 operation (Table 28)          |
|               |          |                      |                         | ADS-B RF link (Table 18)                    |
|               |          |                      |                         | IP/TCP data link (Table 10)                 |
| In-Mission    | 1        | 1.2                  | F                       | SAW of RWD1 with countermeasures (Table 19) |
|               | 2        | 2.1                  |                         | SAW of RWD1 without countermeasures         |
|               |          |                      |                         | SAW of RWD1 with countermeasures (Table 19) |
|               |          |                      |                         | SAW of RWD1 without countermeasures         |
| Post-mission  | 1        | 1.2                  | F                       | DSS information logging (Table 12)          |
|               | 2        | 2.1                  |                         | DSS information logging (Table 12)          |

### 7.5.2 Pre-Mission Phase

The purpose of the pre-mission field testing for prototype configuration H is to check the functions of the framework prototype are correct and the right operation of it by means of three test cases:

- RWD2, FWD1 and FWD2 operation, targeting stable RWD2 flight as well as FWD1 and FWD2 manoeuvres when landed. All the drones with a payload (each) which is the ADS-B transmitter.
- ADS-B RF link between the ADS-B transmitter (UAvionix EchoSky 2) device (onboard RWD2 and FWD1) and the ADS-B receiver (FlightAware Pro Stick Plus) device connected to the GOS.
- IP/TCP data link between the Dump1090 application (assumed onboard RWD2) and the DSS software application. Both applications run in the GOS. This testing is also to check if the DSS is fully operational.

The test procedure for the RWD2, FWD1 and FWD2 operation test case requires: (1) the RWD2, FWD1, and FWD2 structure and onboard avionics be in one piece (one ADS-B transmitter is mounted in RWD2, one ADS-B transmitter is mounted in FWD1, and another ADS-B transmitter is mounted in FWD2), (2) the RWD2, FWD1, and FWD2 are initially off, and (3) the RWD2, FWD1, and FWD2 are positioned on the floor.

Table 49 shows the steps for the operation test case (as introduced in Table 1) of RWD2, FWD1, and FWD2 for the pre-missing field testing.

**Table 49.** Test procedure for RWD2, FWD1 and FWD2 operation test case.

| Test Step | User Action                                                                      | Expected Results                              | Observed Results                       | Result Status                                               |
|-----------|----------------------------------------------------------------------------------|-----------------------------------------------|----------------------------------------|-------------------------------------------------------------|
| 1         | Switch the RWD2, FWD1, and FWD2 on                                               | The RWD2, FWD1, and FWD2 should be on         | The RWD2, FWD1, and FWD2 are on        | The RWD2, FWD1, and FWD2 keep on                            |
| 2         | Command basic RWD2 to fly from remote controller by doing basic flight maneuvers | The RWD2 should respond according to commands | The RWD2 respond according to commands | The RWD2 provide stable flight and returns to idle properly |

|   |                                                                             |                                                         |                                                  |                                                                       |
|---|-----------------------------------------------------------------------------|---------------------------------------------------------|--------------------------------------------------|-----------------------------------------------------------------------|
| 3 | Command FWD1, and FWD2 to activate servos and motors from remote controller | The FWD1, and FWD2 should respond according to commands | The FWD1, and FWD2 respond according to commands | The FWD1, and FWD2 provide stable flight and returns to idle properly |
| 4 | Switch the RWD2, FWD1, and FWD2 off                                         | The RWD2, FWD1, and FWD2 should be off                  | The RWD2, FWD1, and FWD2 are off                 | The RWD2, FWD1, and FWD2 keep off                                     |

The test procedure for the ADS-B RF link functioning and DSS software application functioning test cases are as discussed in subsection 4.2.2.

### 7.5.3 In- Mission Phase

The purpose of the in-mission field testing for prototype configuration H is to check the correct functioning and operation of the DSS by means of a test case: SAW of RWD2 without countermeasures while FWD1 and FWD2 are taking off, climbing, descending, and landing.

The test procedure for the test case on SAW of RWD2 without countermeasures requires: (1) RWD2 and FWD1 as well as FWD2 are positioned on the floor, (2) RWD2 and FWD1 as well as FWD2 are off, (3) the ADS-B device on board RWD2 and FWD1 as well as FWD2 are off, (4) the ADS-B stick is connected to the GOS computer, (5) the Dump1090 application is ready for running in the GOS, and (6) the DSS software application is ready for running in the GOS. Table 50 shows the steps for the test case on SAW of RWD2 without countermeasures for the in-mission field testing.

**Table 50.** Test procedure for SAW of RWD2 without countermeasures.

| Test Step | User Action                                                                                            | Expected Results                                                                                     | Observed Results                                                                               | Result Status                                                                          |
|-----------|--------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|
| 1         | Run the Dump1090 application in the GOS                                                                | The Dump1090 application should be up and running                                                    | The Dump1090 application is up and running                                                     | The Dump1090 application keeps up and running                                          |
| 2         | Run the DSS software application in the GOS                                                            | The DSS software application should be up and running                                                | The DSS software application is up and running                                                 | The DSS software application keeps up and running                                      |
| 3         | Check the Dump1090 and the DSS are connected with each other using TCP/IP protocol                     | The Dump1090 application and the DSS software application should be TCP/IP connected with each other | The Dump1090 application and the DSS software application are TCP/IP connected with each other | Both applications keep connected with each other using the TCP/IP protocol             |
| 4         | Place RWD2 and FWD1 as well as FWD2 on the ground, then switch them on, also their ADS-B transmitters. | The RWD2 and FWD1 as well as FWD2 along with their ADS-B transmitters should be on                   | The RWD2 and FWD1 as well as FWD2 along with their ADS-B transmitters is on                    | The RWD2 and FWD1 as well as FWD2 along with their ADS-B transmitters keeps on         |
| 5         | Check the DSS software application receives the ADS-B data from the ADS-B transmitter                  | DSS software application should receive the ADS-B data from the ADS-B transmitter                    | The DSS software application receives the ADS-B data from the ADS-B transmitter                | The DSS software application keeps receiving the ADS-B data from the ADS-B transmitter |

|    |                                                                                                                                                       |                                                                                                 |                                                                                           |                                                                                                  |
|----|-------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|
| 6  | Check if the DSS software application displays SAW involving RWD2 and FWD1 as well as FWD2 accordingly                                                | SAW of RWD2 and FWD1 as well as FWD2 should be displayed in the DSS software application        | SAW of RWD2 and FWD1 as well as FWD2 are displayed in the DSS software application        | The DSS software application keeps displaying SAW of RWD2 and FWD1 as well as FWD2               |
| 7  | Start flying RWD2 around in locations close to the FWD1 and FWD2                                                                                      | The DSS software application should provide SAW of RWD2 and FWD1 as well as FWD2                | The DSS software application provides SAW of RWD2 and FWD1 as well as FWD2                | The DSS software application keeps providing SAW of RWD2 and FWD1 as well as FWD2                |
| 8  | Try to get RWD2 in an airspace zone that is not hazardous for FWD1 and FWD2 for different flight phases (take-off, climbing, descending, and landing) | The DSS software application should accordingly provide SAW of RWD2 flying around FWD1 and FWD2 | The DSS software application provides SAW of RWD2 flying around FWD1 and FWD2 accordingly | The DSS software application keeps providing SAW of RWD2 flying around FWD1 and FWD2 accordingly |
| 9  | Try to get RWD2 in an airspace zone that is hazardous for FWD1 and FWD2 for different flight phases (take-off, climbing, descending, and landing)     | The DSS software application should accordingly provide SAW of RWD2 flying around FWD1 and FWD2 | The DSS software application provides SAW of RWD2 flying around FWD1 and FWD2 accordingly | The DSS software application keeps providing SAW of RWD2 flying around FWD1 and FWD2 accordingly |
| 10 | Land RWD2 and FWD1 and FWD2                                                                                                                           | The DSS software application should accordingly keep providing SAW of RWD2 and FWD1 and FWD2    | The DSS software application keeps providing SAW of RWD2 and FWD1 and FWD2 accordingly    | The DSS software application keeps providing SAW of RWD2 and FWD2 accordingly                    |
| 11 | Switch the two ADS-B transmitters and drones off                                                                                                      | The two ADS-B transmitters and drones should be off                                             | The two ADS-B transmitters and drones are off                                             | The two ADS-B transmitters and drones keep off                                                   |
| 12 | Check if the DSS software application does not display SAW involving RWD2 and FWD1 and FWD2                                                           | SAW of RWD2 and FWD1 and FWD2 should not be displayed by the DSS software application           | SAW of RWD2 and FWD1 and FWD2 is not displayed by the DSS software application            | The DSS software application keeps not displaying SAW of RWD2 and FWD1 and FWD2                  |

#### 7.5.4 Post-Mission Phase

The purpose of the post-mission field testing for prototype configuration F is to check whether the DSS can log the information broadcasted by the ADS-B transmitters placed in RWD2 and FWD1 as well as FWD2. The test procedure for this test case requires: (1) RWD2 and FWD1 as well as FWD2 are landed, and (2) the ADS-B transmitters on board RWD2 and FWD1 as well as FWD2 keep off. It is the same than the one presented in subsection 4.2.4 (Table 12)

#### 7.5.5 Experimental Results

In FTR5, the operation of the drones (RWD2, FWD1, and FWD2) is meant to reproduce a (downscaled) scenario where two airplanes (e.g., a commercial airliner represented by FWD1) are taking off, climbing, descending, and landing while an AUV (represented by RWD2) fly around. FWD1 and FWD2 land by touching the runway and then they take off again, so they keep a non-stop flight cycle of two takeoff-landings.

This Subsection presents the experimental results from the field-testing trials (in-mission phase) carried out in the SWRCS facility with real values for latitude, longitude, and altitude (not normalized as in the office and garden testing trials). The following figures show details of areas (flight waypoints) which means hazards of potential collision between aircraft (RWD2, FWD1, and FWD2; real drones used). The closest distance that the aircraft can be without becoming a hazard is set at 170 units for drones in front and in the direction of the airplanes (FWD1 and FWD2) and 85 units for drones behind and not in the direction of the airplane (FWD1 and FWD2).

Figure 82 shows the trajectory produced by the ADS-B transmitter 1 mounted in RWD2 (in yellow) with the following setting: aircraft unauthorized to fly, and no countermeasure (“None” which means the UAV does not have a remote contactable pilot that can be reached in case of any manoeuvre required to keep the UAV and the MAV in question properly separated) for possible mid-air collision. The trajectory of FWD1 (in blue) and FWD2 (in pink) are also shown.

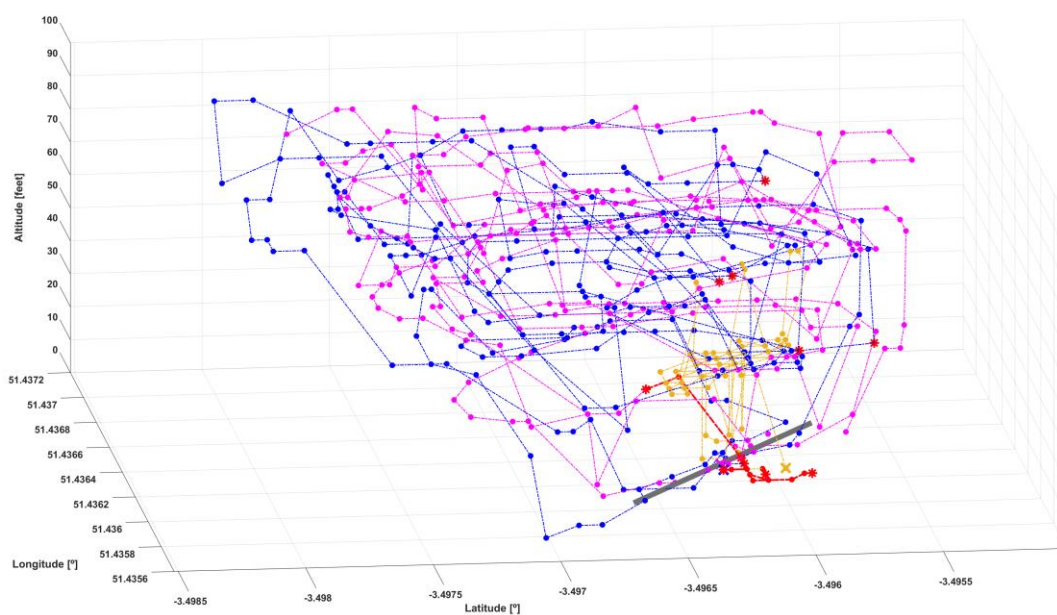


**Figure 82.** ADSB-based localization for SA of RWD2/FWD2 and FWD1 (without countermeasure).

RWD2 is initially located (yellow cross) on the right of the runway (straight line in dark grey), behind FWD1 (blue cross) and FWD2 (pink cross) which are taxied ready for take-off in that end of the runway. RWD2 is not far from them. The trial’s duration is 465 sec (7 min 0 sec).

Figure 83 shows the distance between RWD2 and FWD1 as well as RWD2 and FWD2 for each sampling time (every 1 second) in the DSS software application. The distance is calculated as a vectorial difference between the ADSB-based localization of the two pairs of drones (RWD2 and FWD1/FWD2). Vertical lines are to show the period in which each flight phase is assessed.

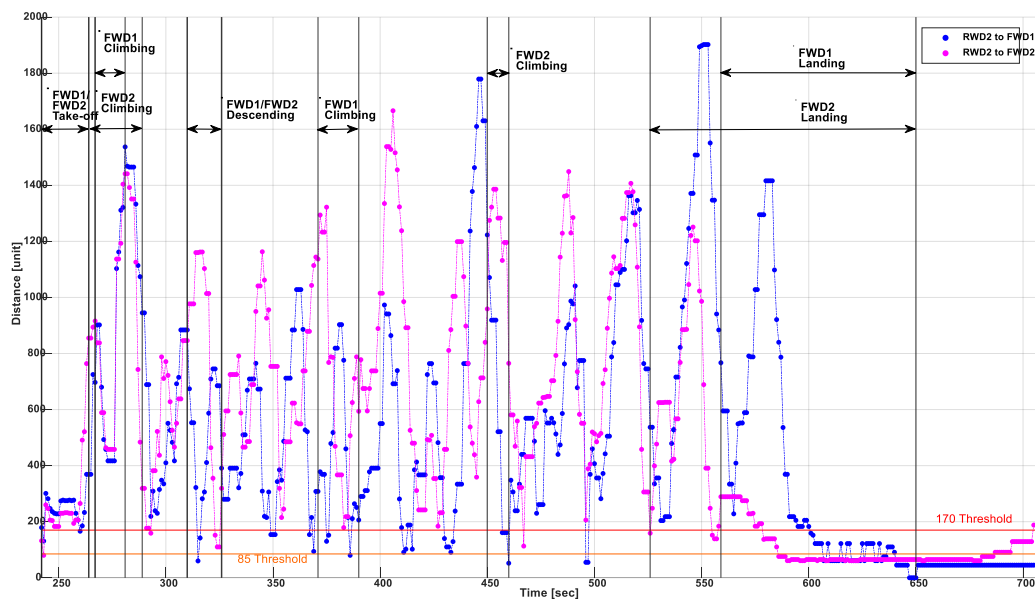


**Figure 83.** ADSB-based distance between RWD2 (without countermeasure) and FWD1/FWD2.

If RWD2 is behind FWD1/FWD2 (opposite to the direction of FWD1/FWD2) the reference distance to determine whether RWD2 flight is a hazard for FWD1/FWD2 is 85 units. If RWD2 is ahead FWD1/FWD2 (in the direction of FWD1/FWD2) the reference distance to determine whether RWD2 flight is a hazard for FWD1/FWD2 is 170 units. Both reference distances are highlighted in Figure 83. There is a critical period (648-650 secs) when the two drones (RWD2 and FWD1) get very close (no collision) and for which the current distance calculated is 0 units.

Figure 84 shows the SA provided by the DSS software application for the time the three drones are operating during the experiment. The possible outputs for this trial for RWD2 are Flight Safety Caution (FSC) where the airplane (FWD1/FWD2) under consideration is not at risk of collision with the AUV (i.e., RWD2) and Flight Safety Warning Danger (FSD) where the airplane (FWD1/FWD2) under consideration is at considerable risk of collision with RWD2.

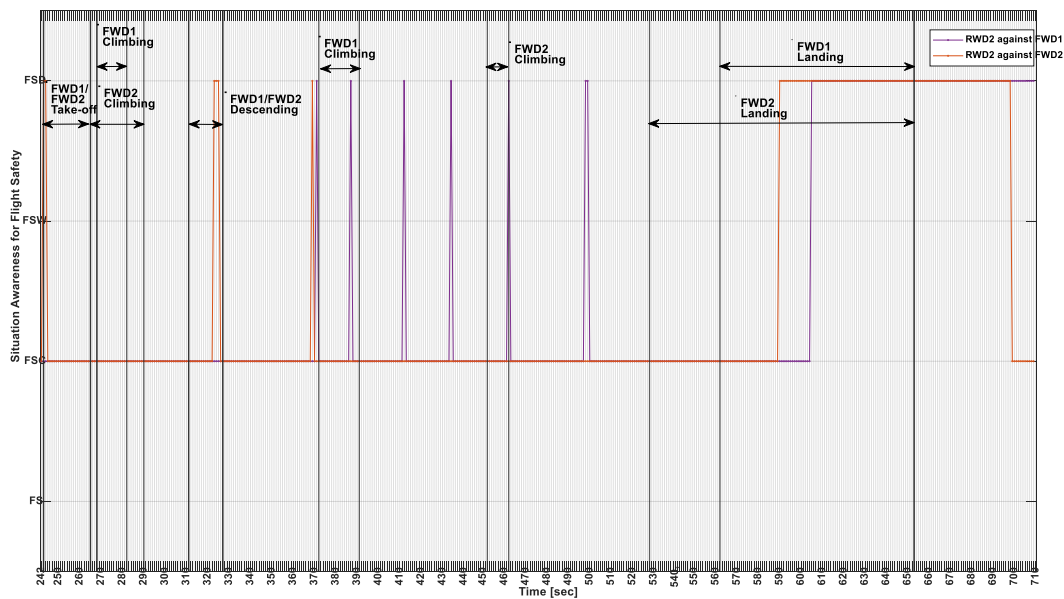


**Figure 84.** ADSB-based SA of RWD2 (without countermeasure) for FWD1/FWD2.

FTR6 and FTR7 have all the application scenarios (as stated in Section 2) but the settings for the drones playing roles are as follows: RWD2 has “PilotContact” and FWD2 has “none” as countermeasures in FTR5 and RWD2 has “None” and FWD2 has “PilotContact” as countermeasures in FTR6. Both drones play the role of UAVs. FWD1 plays the role of an airplane.

In FTR6, the limit distance is updated as follows: 185 units instead of 85 units, and 270 units instead of 170 units. This is to facilitate the proximity detection between the two FWDs (one playing the role of UAV and the other the role of MAV). There are also two runways; one for take-off (the same used in FTR4, i.e., runway 3), and the other for landing (runway 4; longer than runway 3).

Table 40 shows information in addition to the specifications shown in Table 34 to provide details from the environment of the trails using prototype configuration H for FTR5 and FTR6.

**Table 51.** Additional information for field testing trial for prototype configuration F for FTR5 and FTR6.

|                              |                                                                                                                                                                                                                                  |
|------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Date and Time</b>         | Sun, 15 Oct 2023, 11:00 - 12:30                                                                                                                                                                                                  |
| <b>Weather Condition*</b>    | Sunny, 6 °C, 1005.00mb, 83%, 21 km/h, 10 km                                                                                                                                                                                      |
| <b>Environment Radiation</b> | ADS-B Device off <ul style="list-style-type: none"> <li>• Outdoor               <ul style="list-style-type: none"> <li>○ EMF: 0 mG</li> <li>○ EF: 0 - 1 V/m</li> <li>○ RF: 0.001 – 0.010 mW/m<sup>2</sup></li> </ul> </li> </ul> |

\* Source: <https://www.foreca.com>

Figure 85 shows the trajectory produced by the ADS-B transmitter 1 mounted in FWD2 (in pink) with the following setting: aircraft unauthorized to fly, and countermeasure (“None” which means the UAV has no remote contactable pilot that can be reached in case of any manoeuvre required to keep the UAV and the MAV in question properly separated) for possible mid-air collision. It also shows the trajectory produced by the ADS-B transmitter 3 mounted in RWD2 (in yellow) with the following setting: aircraft unauthorized to fly, and countermeasure (“PilotContact” which means the UAV has a remote contactable pilot that can be

reached in case of any manoeuvre required to keep the UAV and the MAV in question properly separated) for possible mid-air collision. The trajectory of FWD1 is shown in blue.

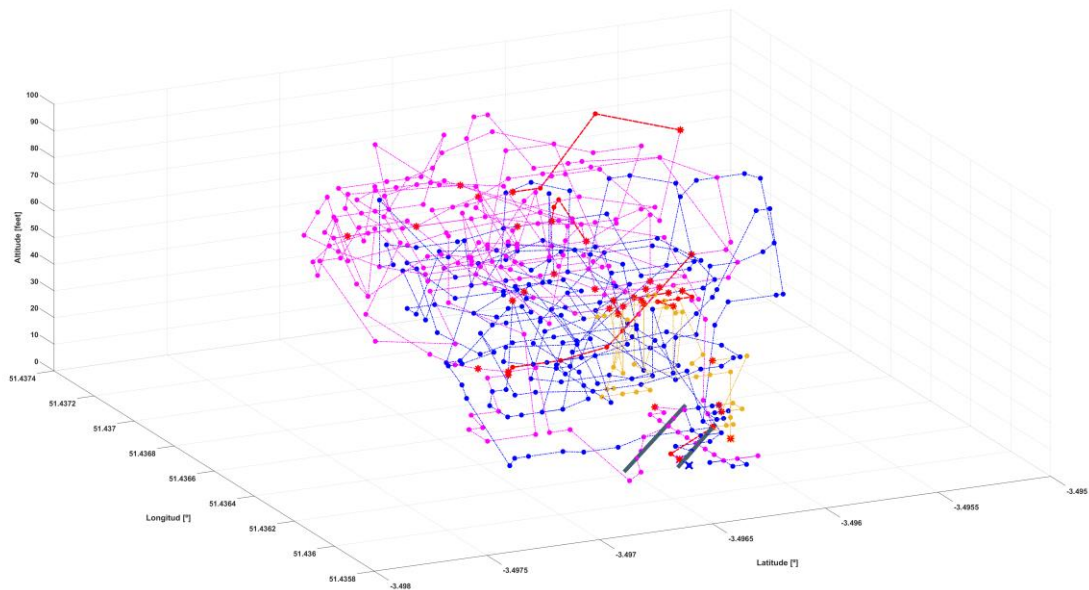


**Figure 85.** ADSB-based localization for SA of FWD2 and RWD2 (without and with countermeasure resp).

FWD2 is initially located (pink cross) at one of the ends of the runway (straight line in dark grey), ahead FWD1 (blue cross). Both FWDs are taxied ready for take-off in that end of the runway. FWD2 takes off before FWD1 does. RWD2 is initially landed ahead in the runway, slightly to the right of the runway (yellow cross). The trial's duration is 448 sec (7 min 28 sec approximately).

There are waypoints in which FWD2 does not trigger any SA FSC as it flies closely beyond the distance limit, e.g., in sample time 131 for which the distance limit is 277 units and at 175 sec for which the distance limit is 282 (both cases just above 270). Likewise, no FSD for sample times such as 53-55 secs in which FWD2 is behind FWD1 at a limit distance of more than the threshold (185 units).

Figure 86 shows the distance between FWD2 and FWD1 as well as RWD2 and FWD1 for each sampling time (every 1 second) in the DSS software application. The distance is calculated as a vectorial difference between the ADSB-based localization of the two pairs of drones (FWD2/RWD2 and FWD1). Vertical lines are to show the period in which each flight phase is assessed.

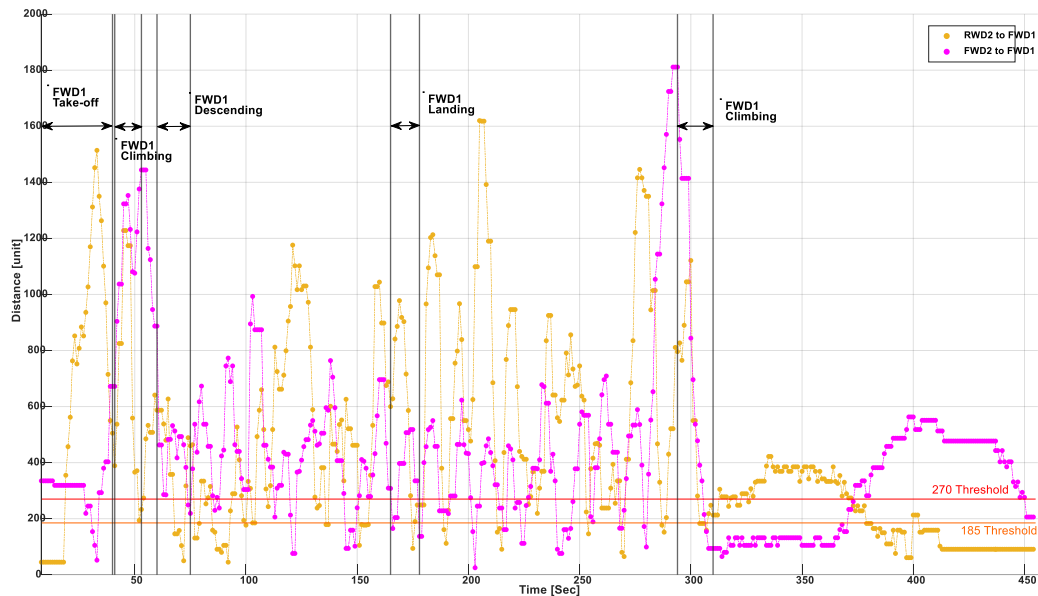


**Figure 86.** ADSB-based distance between FWD2/RWD2 (without and with countermeasure) and FWD1.

If FWD2/RWD2 are behind FWD1 (opposite to the direction of FWD1) the reference distance to determine whether FWD2/RWD2 flight is a hazard for FWD1 is 185 units. If FWD2/RWD2 is ahead FWD1 (in the direction of FWD1) the reference distance to determine whether FWD2/RWD2 flight is a hazard for FWD1 is 270 units. Both reference distances are highlighted in Figure 86. The FWD1 climbing is considered twice as the first one (41-53 secs) does not entail any mid-air collision risk according to the SA provided by the DSS software application.

Figure 87 shows the SA provided by the DSS software application for the time the three drones are operating during the experiment. The possible outputs for this trial for FWD2 are Flight Safety (FS) where the airplane (FWD1) under consideration is not at risk of collision with one of the relevant AUV (i.e., FWD2) and Flight Safety Warning (FSW) where the airplane (FWD1) under consideration is at considerable risk of collision with FWD2. On the other hand, the possible outputs for this trial for RWD2 are Flight Safety Caution (FSC) where the airplane (FWD1) under consideration is not at risk of collision with the other relevant AUV (i.e., RWD2) and Flight Safety Danger (FSD) where the airplane (FWD1) under consideration is at considerable risk of collision with RWD2.

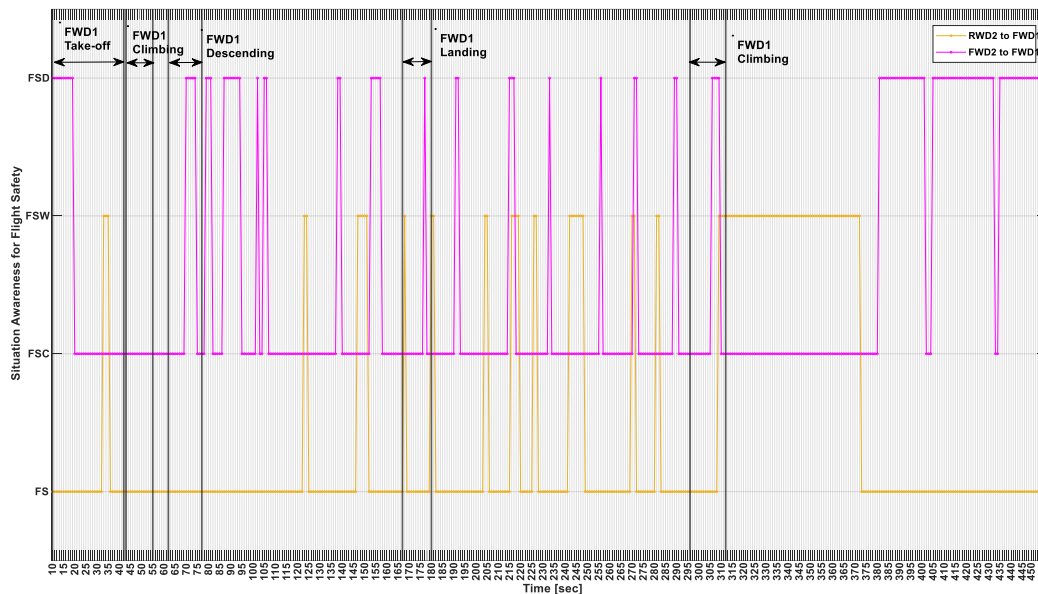


**Figure 87.** ADSB-based SA of FWD2 and RWD2 (FWD2 without, RWD2 with countermeasure).

There is a period of time (e.g., 100-115 secs) during the transition of the SA states in which values for the SA bounce for FWD2. This situation, similar to the ones from previous trials, is due to interim changes in the calculation of the distance between aircraft that suggest the threshold given by the limit distance is crossed and then it is not crossed for a sample period. The proximity of FWD2 to FWD1 is affected by the readings from the GPS of its ADS-B transmitter as the distance is borderline (threshold). On the other hand, this situation does not happen with FWD2 as the close proximity between it and FWD1 last less than the one between FWD2 and FWD1.

In FTR7, the limit distance is updated as follows: 285 units instead of 185 units, and 470 units instead of 270 units. This is to facilitate even more the proximity detection between the two FWDs (one playing the role of UAV and the other the role of MAV). There are also two runways; one for take-off (the same used in FTR4, i.e., runway 3), and the other for landing (runway 4; longer than runway 3).

Figure 88 shows the trajectory produced by the ADS-B transmitter 1 mounted in FWD2 (in pink) with the following setting: aircraft unauthorized to fly, and countermeasure ("PilotContact" which means the UAV has a remote contactable pilot that can be reached in case of any manoeuvre required to keep the UAV and the MAV in question properly separated) for possible mid-air collision. It also shows the trajectory produced by the ADS-B transmitter 3 mounted in RWD2 (in yellow) with the following setting: aircraft unauthorized to fly, and countermeasure ("None" which means the UAV has no remote contactable pilot that can be reached in case of any manoeuvre required to keep the UAV and the MAV in question properly separated) for possible mid-air collision. The trajectory of FWD1 is shown in blue.

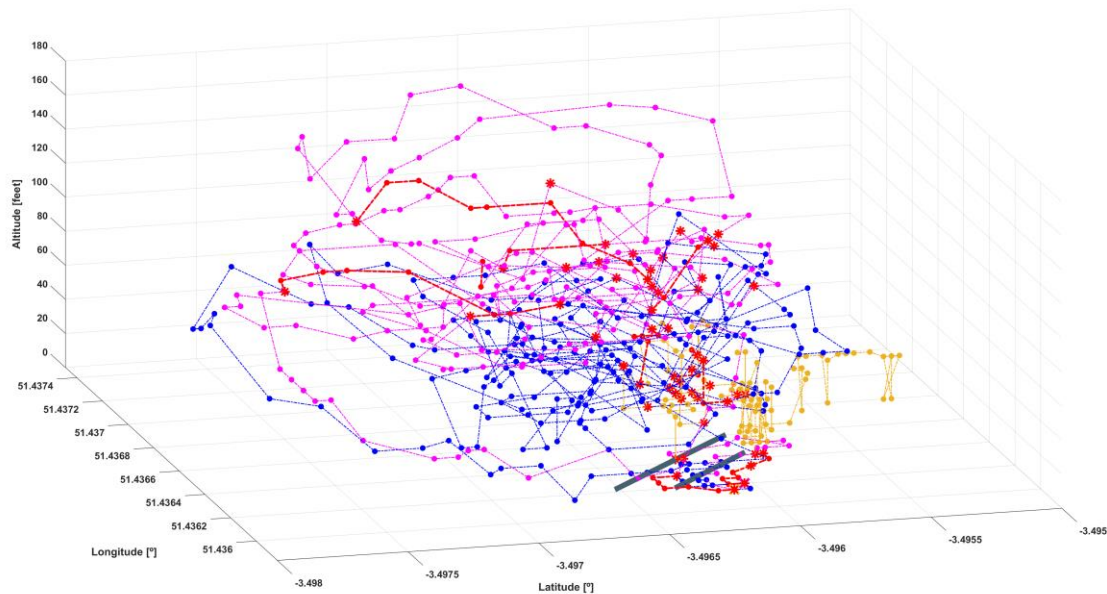


**Figure 88.** ADSB-based localization for SA of FWD2 and RWD2 (with and without countermeasure).

FWD1 and FWD2 are initially located (blue cross for FWD1 and pink cross for FWD2) next to the runway (straight line in dark grey) as it is assumed to be taxied waiting for ATC instruction to head to the runway. FWD2 takes off before FWD1 does. RWD2 is initially landed (yellow cross) behind FWD1 and FWD2 at the beginning of the runway where both FWDs are to take off. The trial's duration is 448 sec (7 min 28 sec approximately).

Figure 89 shows the distance between FWD2 and FWD1 as well as RWD2 and FWD1 for each sampling time (every 1 second) in the DSS software application. The distance is calculated as a vectorial difference between the ADSB-based localization of the two pairs of drones (FWD2/RWD2 and FWD1). Vertical lines are to show the period in which each flight phase is assessed.

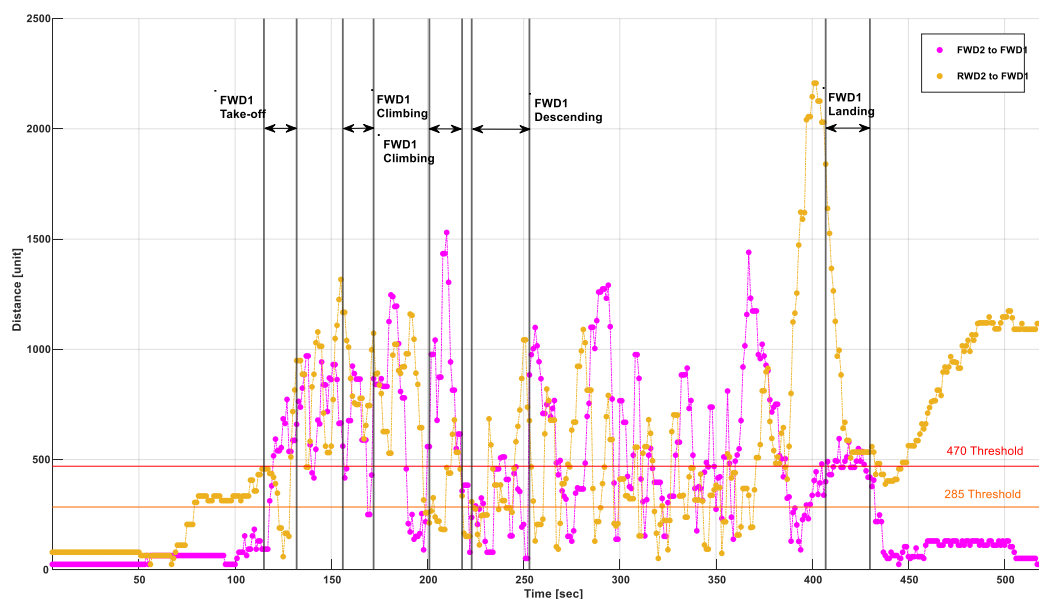


**Figure 89.** ADSB-based distance between FWD2/RWD2 (without and with countermeasure) and FWD1.

If FWD2/RWD2 are behind FWD1 (opposite to the direction of FWD1) the reference distance to determine whether FWD2/RWD2 flight is a hazard for FWD1 is 285 units. If FWD2/RWD2 is ahead FWD1 (in the direction of FWD1) the reference distance to determine whether FWD2/RWD2 flight is a hazard for FWD1 is 470 units. Both reference distances are highlighted in Figure 86. The FWD1 climbing is considered twice as the first one (156-172 secs) does not entail any mid-air collision risk for RWD2 according to the SA provided by the DSS software application.

Figure 90 shows the SA provided by the DSS software application for the time the three drones are operating during the experiment. The possible outputs for this trial for RWD2 are Flight Safety (FS) where the airplane (FWD1) under consideration is not at risk of collision with one of the relevant AUV (i.e., RWD2) and Flight Safety Warning (FSW) where the airplane (FWD1) under consideration is at considerable risk of collision with RWD2. On the other hand, the possible outputs for this trial for FWD2 are Flight Safety Caution (FSC) where the airplane (FWD1) under consideration is not at risk of collision with the other relevant AUV (i.e., FWD2) and Flight Safety Danger (FSD) where the airplane (FWD1) under consideration is at considerable risk of collision with FWD2.

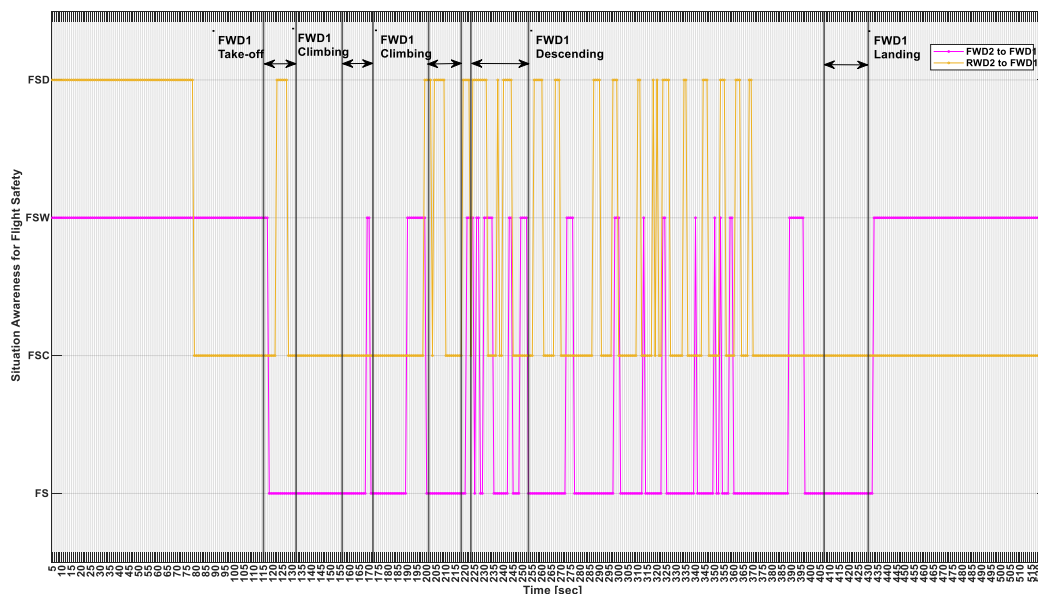


**Figure 90.** ADSB-based SA of FWD2 and RWD2 (FWD2 without, RWD2 with countermeasure).

There is a period of time (i.e., second FWD1 descending considered 201-218 secs) during the transition of the SA states in which values for the SA bounce for FWD2. This situation, similar to the ones from previous trials, is due to interim changes in the calculation of the distance between aircraft that suggest the threshold given by the limit distance is crossed and then it is not crossed for a sample period. The proximity of FWD2 to FWD1 is affected by the readings from the GPS of its ADS-B transmitter as the distance is borderline (threshold). On the other hand, this situation does not happen with FWD2 as the close proximity between it and FWD1 lasts less than the one between FWD2 and FWD1. The above situation makes sense to have more chances to occur during the descending phase as a FWD slows speed, experiencing more gliding.

## 7.6 Discussion on Experimental Field Results

The field-testing trials allow for the evaluation of all the application scenarios. The particular interest are scenarios that have not been implemented before in the other testing trials. The four application scenarios have been considered during full flights of the drones (non-stop, from takeoff to landing including climbing

and descending). The trial runs have been carried out on different days and under different weather conditions, and even locations. However, this approach for the runs of the trials does not affect the end results from the experiments.

The operation of quadcopters (i.e., RWD1 and RWD2) facilitates the proximity checks with the target airplane (FWD1) as quadcopter are easier to fly to keep desired distance from other aircraft (distance from RWDs and FWD1). The high proximity has been more difficult to reach when FWD2 has played the role of AUV in FTR5.

The operation of many drones per FTR along with the considerations to attend for each FTR has made it difficult keep record of every single aspect from the FTRs. Some FTRs include some captures of the AAO for relevant moments of the FTR.

Apart from the precision and accuracy of the GPS positions of the drones through the ADS-B transmitters, the measure of the altitude provided for them for each of the drones have not been with much resolution as not only negative values have been measured but also changes of 25 feet. This makes it impossible to show the drones have been at different altitudes within each slot of 25 feet, something that definitely is interesting to show mainly because the maximum altitude the drones have flown is 100 feet approximately.

## 8 Concluding Remarks

The project has been meant to study SAW given well defined airspace situations by reproducing real aircraft operations in downscaled application scenarios. The project objectives have been achieved and experimental results have been presented to show the performance of the framework prototype used. Different airspace situations have been discussed by means of application scenarios that used conventional RC aircraft models (RWDs and FWDs) playing the role of AUVs as potential intruders of the airspace, and MAVs as airplanes operating flights (e.g., commercial airliners) as well as alternative intruders.

The experimental results have demonstrated that the ontological SAW-driven DSS proposed has been able to correctly realize about hazardous airspace situations, notify the user of it, and advise accordingly as per the information presented in this final report.

The project has gone ahead as planned, including replanning due to the extension granted for a fourth year. The three main updates on the project plan as proposed in APR3 have been successfully implemented: (1) some tasks have been extended; T3.1: Development of the Software Application as well as T3.2: Hardware-Software Integration, (2) Task 4.1 (T4.1) intitled “Definition of Test Cases” has been brought forward, and (3) some other tasks have been delayed; T4.2: Tests of Application Scenarios as well as T4.3: Analysis of Testing Results.

Figure 91 shows the progress of the project in the reported year by means of a Gantt Chart. It also shows all the project reports as technical deliverables, including annual performance reports and quarterly financial reports.

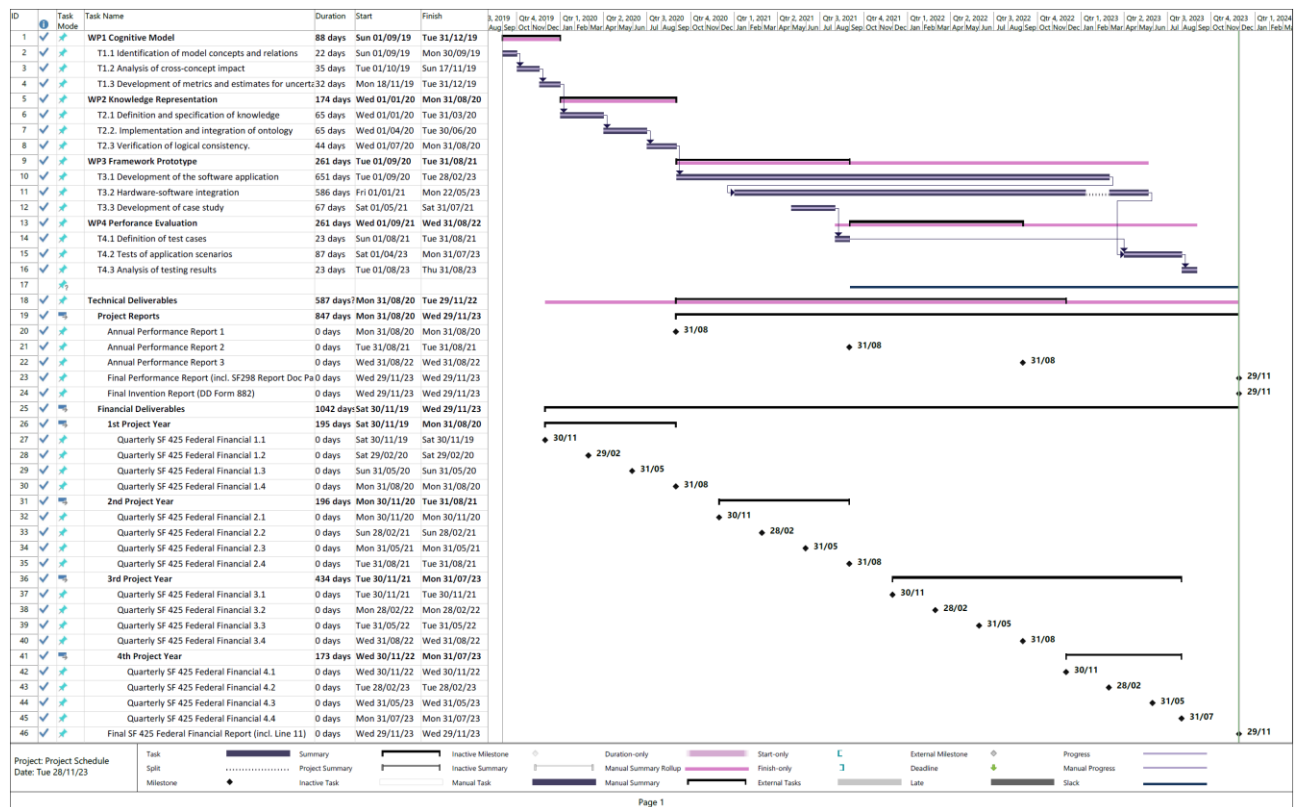


Figure 91. Final project Gantt Chart.

While the pandemic lockdown (2020-2021) has limited some project tasks and travels, including dissemination of the project results it has created opportunities to envision different technologies for the realization of the application scenarios. However, this possibility has also increased the complexity of the approaches which, on one hand, has significantly improved the materialization of the framework prototype as to the way to develop a radar system to combine sensing inputs for the DSS, and the other hand, it has added extra time to conceive such an alternative sensing capability.

## References

- [1] FlightAware Pro Stick and Pro Stick Plus - High Performance USB SDR ADS-B Receivers, available at <https://uk.flightaware.com/adsb/prostick>.
- [2] SkyEcho 2 Installation and Pilot's Guide, available at <https://uuAvionix.com/downloads/skyecho/SkyEcho-User-and-Installation-Guide.pdf>.
- [3] ZLL SG906 Pro 5G WIFI FPV, specification available at <http://myosuploads3.banggood.com/products/20201022/20201022030844SG906PRO1.jpg>.
- [4] Holybro X500 Pixhawk 4 Mini 500mm Wheelbase Frame Kit Combo 2216 880KV Motor 1045 Propeller for RC Drone, assembly guide available at [http://www.holybro.com/manual/Holybro\\_X500\\_FrameKit\\_AssemblyGuide.pdf](http://www.holybro.com/manual/Holybro_X500_FrameKit_AssemblyGuide.pdf).
- [5] Volantex RC Ranger EX, Professional FPV Platform, Manual available at <http://myosuploads3.banggood.com/products/20210506/20210506214624VolantexRangerExManual.pdf>.
- [6] ESKY Eagles 1100mm Wingspan EPO Trainer Beginner RC Airplane Glider PNP, specification available at <http://www.zondahobby.com/index.php?m=Product&a=show&id=183>

- [8] E. Baader, F. Horrocks, U. Sattler, "Description Logics", Ch. 3 in Handbook of Knowledge Representation, Elsevier, 2007. Available at <http://www.cs.ox.ac.uk/ian.horrocks/Publications/download/2007/BaHS07a.pdf>.
- [9] H. C. Beall, F. Restall, Logical Consequence The Stanford Encyclopedia of Philosophy, Fall 2009.
- [10] R. M. Keller, The NASA Air Traffic Management Ontology, Technical Documentation, NASA/TM-2017-219526, 2017.
- [11] S. Wilson, R. Suzic, and S. Van der Stricht, "The SESAR ATM information reference model within the new ATM system," in 2014 Integrated Communications, Navigation and Surveillance Conference (ICNS) Conference Proceedings, 2014.
- [12] Ground Control Station, available at <http://qgroundcontrol.com>.
- [13] Dump 1090: a Mode S decoder specifically designed for RTLSDR devices, available at <https://github.com/antirez/dump1090>.
- [14] The OWLAPI, available at <https://owlapi.sourceforge.net>
- [15] Advanced GQ EMF-390 Multi-Field, Multi-Function EMF Meter and RF Spectrum Power Analyzer, available at [https://www.ggelectronicllc.com/comersus/store/comersus\\_viewItem.asp?idProduct=5678](https://www.ggelectronicllc.com/comersus/store/comersus_viewItem.asp?idProduct=5678).

## Appendix A: Software Application for the Framework Prototype

This appendix presents the software used to build the framework prototype. It includes monitoring user interface from the Dump1090 software, the lasted version of the user interface of the DSS software application, and.

Figure 92 shows a screenshot of the monitoring application provided by the Dump 1090 software.

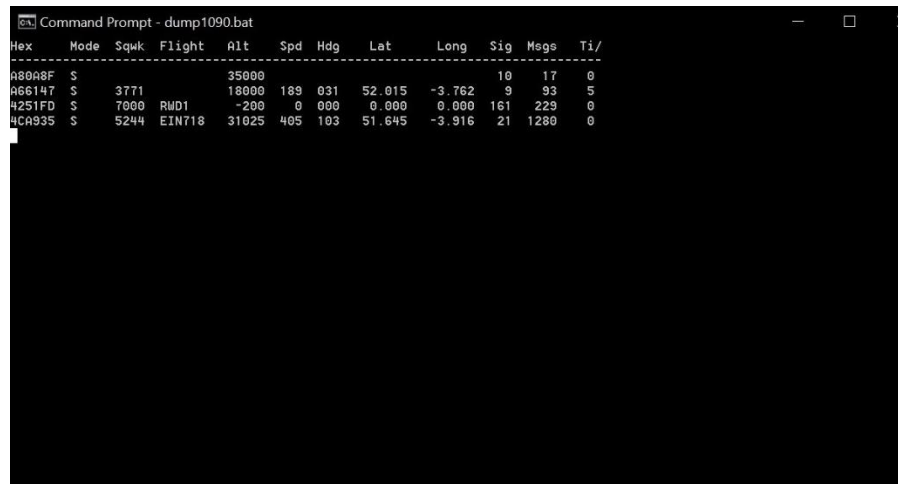


Figure 92. Dump 1090 monitoring application.

Figure 93 shows the user interface of the latest version of the DSS software application used the testing trials.

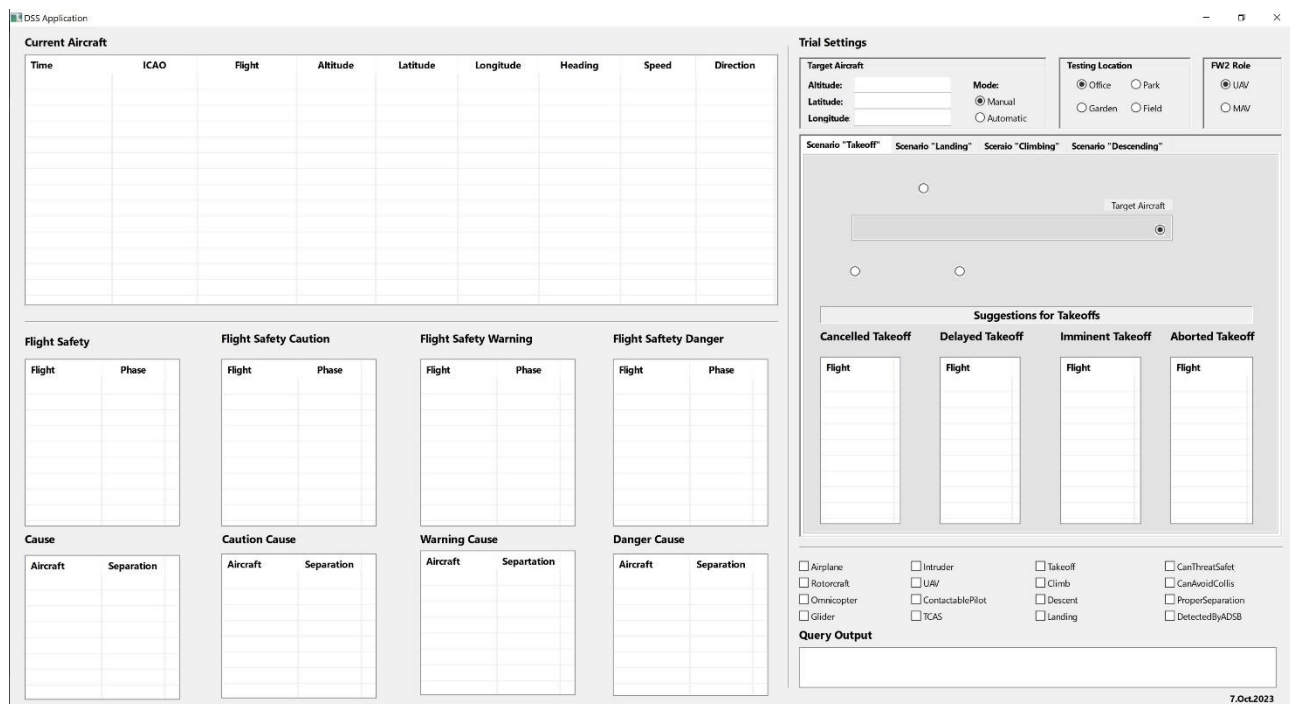


Figure 93. DSS software application.

## Appendix B: Hardware Platform for the Framework Prototype

This appendix presents the hardware used to build the framework prototype. It includes ADS-B devices, drones.

Figure 94 shows the ADS-B Receiver used by the DSS software application to get ADS-B information from aircraft. This device is used in all the testing trials. A FlightAware dongle [1] and antenna are used to pick up ADS-B messages from aircraft. The antenna gain allows for the collection of ADS-B messages from any ADSB-equipped aircraft flying nearby (around 50 miles approximately). Figure 94 shows the FlightAware dongle and antenna used to get ADS-B messages.



**Figure 94.** FlightAware Pro Stick Plus.

The drones are equipped with ADS-B transmitters for communication of information as to their location. Figure 95 shows the ADS-B transmitters used by the project.



**Figure 95.** ADS-B Transmitter – uAvionix EchoSky 2.

Figure 96 shows a RC RWD used in the framework prototype to play the role of intrusive UAV in the application scenarios of the use cases presented in Section 2.



**Figure 96.** RWD1: RC quadcopter.

Table 52 shows details of the technical RWD1 specifications.

**Table 52.** Technical RWD1 specifications.

|                    |                                                                                                             |
|--------------------|-------------------------------------------------------------------------------------------------------------|
| <b>Name</b>        | Boyero                                                                                                      |
| <b>Code</b>        | RWD1                                                                                                        |
| <b>Role</b>        | UAV                                                                                                         |
| <b>Model</b>       | ZLL SG906 Pro                                                                                               |
| <b>Description</b> | 5G WIFI FPV With 4K HD Camera 2-Axis Gimbal Optical Flow Positioning Brushless RC Drone Quadcopter RTF [3]. |
| <b>Power</b>       | electric                                                                                                    |
| <b>Wheelbase</b>   | 340 mm                                                                                                      |
| <b>Weight</b>      | 551.8g                                                                                                      |
| <b>Payload</b>     | SkyEcho 2                                                                                                   |
| <b>Range</b>       | 800-1200 m                                                                                                  |
| <b>GPS</b>         | Yes                                                                                                         |
| <b>Camera</b>      | Yes (not used)                                                                                              |

Drone setup:

1. Controller on.
2. Drone on.
3. Pairing by pressing (for few seconds until a beep) the “speed” button in the controller.
4. Calibration by pressing (for few seconds until a beep) the “camera” button in the controller.
5. Activation by pressing (for few seconds until a beep) the “video” button in the controller.
6. Unlocking by pushing the throttle stick and the directional stick to the lower left corner and the lower right corner respectively at the same time in the controller.

Figure 97 shows a RC FWD (Holybro X500 Pixhawk 4 Mini 500mm Wheelbase Frame Kit Combo 2216 880KV Motor 1045 Propeller for RC Drone [4]) used in the framework prototype to play the role of intrusive drone in the application scenarios of the use cases presented in Section 2. The RC RWD is an electric-powered quadcopter called “*Hornero*” and code RWD2 with wheelbase of 505 mm.



**Figure 97.** RWD2: RC quadcopter.

Table 52 shows details of the technical RWD2 specifications.

**Table 53.** Technical RWD2 specifications.

|                    |                                                                                  |
|--------------------|----------------------------------------------------------------------------------|
| <b>Name</b>        | Hornero                                                                          |
| <b>Code</b>        | RWD2                                                                             |
| <b>Role</b>        | UAV                                                                              |
| <b>Model</b>       | Holybro X500                                                                     |
| <b>Description</b> | Mini Wheelbase Frame Kit Combo 2216 880KV Motor 1045 Propeller for RC Drone [4]. |
| <b>Power</b>       | electric                                                                         |
| <b>Wheelbase</b>   | 1000 mm                                                                          |
| <b>Weight</b>      | 610g                                                                             |
| <b>Payload</b>     | SkyEcho 2                                                                        |
| <b>Range</b>       | 100-120 m                                                                        |
| <b>GPS</b>         | Yes                                                                              |
| <b>Camera</b>      | No                                                                               |

Figure 98 shows a RC FWD (GoolRC E88 Pro Mini Drone with Camera WiFi HD FPV Foldable Live Video Drone) used in the framework prototype to play the role of intrusive drone in the application scenarios of the use cases presented in Section 2. The RC RWD is an electric-powered quadcopter called “*Hornero*” and code RWD2 with wheelbase of 505 mm.



**Figure 98.** RWD3: RC quadcopter.

Table 54 shows details of the technical RWD2 specifications.

**Table 54.** Technical RWD3 specifications.

|                    |                                                              |
|--------------------|--------------------------------------------------------------|
| <b>Name</b>        | Benteveo                                                     |
| <b>Code</b>        | RWD3                                                         |
| <b>Role</b>        | UAV                                                          |
| <b>Model</b>       | GoolRC E88 Pro                                               |
| <b>Description</b> | Mini Drone with Camera WiFi HD FPV Foldable Live Video Drone |
| <b>Power</b>       | electric                                                     |
| <b>Wheelbase</b>   | 200 mm                                                       |
| <b>Weight</b>      | 110g                                                         |
| <b>Payload</b>     | No                                                           |
| <b>Range</b>       | 100-120 m                                                    |
| <b>GPS</b>         | No                                                           |
| <b>Camera</b>      | Yes (not used)                                               |

Figure 99 shows a RC FWD (ESKY Eagles 1100mm Wingspan EPO Trainer Beginner RC Airplane Glider PNP [6]) used in the framework prototype to play the role of airplane in the application scenarios of the use cases presented in Section 2. The RC FWD can also play the role of intrusive drone in the above scenarios. It is an ultralight electric-powered model airplane called “*Carancho*” and code FWD1 with wingspan of 1,100 mm.



**Figure 99.** FWD1: RC airplane.

Table 55 shows details of the technical FWD2 specifications.

**Table 55.** Technical FWD1 specifications.

|                    |                                             |
|--------------------|---------------------------------------------|
| <b>Name</b>        | Carancho                                    |
| <b>Code</b>        | FWD1                                        |
| <b>Role</b>        | MAV                                         |
| <b>Model</b>       | ESKY Eagles                                 |
| <b>Description</b> | EPO Trainer Beginner RC Airplane Glider PNP |
| <b>Power</b>       | Electric                                    |
| <b>Wingspan</b>    | 1100 mm                                     |
| <b>Weight</b>      | 755 g                                       |
| <b>Payload</b>     | SkyEcho 2                                   |
| <b>Range</b>       | 3000-4000 m                                 |
| <b>GPS</b>         | No                                          |
| <b>Camera</b>      | No                                          |

Figure 100 shows a RC FWD (Volantex RC Ranger EX Long Range V757-3 [5]) used in the framework prototype to play the role of airplane in the application scenarios of the use cases presented in Section 2. The RC FWD can also play the role of intrusive drone in the above scenarios. It is an ultralight electric-powered model airplane called “*Chaja*” and code FWD1 with wingspan of 1,900 mm.



**Figure 100.** FWD2: RC airplane.

Table 56 shows details of the technical FWD2 specifications.

**Table 56.** Technical FWD2 specifications.

|                    |                                                                                    |
|--------------------|------------------------------------------------------------------------------------|
| <b>Name</b>        | Chaja                                                                              |
| <b>Code</b>        | FWD2                                                                               |
| <b>Role</b>        | MAV/UAV                                                                            |
| <b>Model</b>       | Volantex V757-3                                                                    |
| <b>Description</b> | Volantex RC Ranger EX Long Range FPV / UAV platform Unibody big weight carrier PNP |
| <b>Power</b>       | Electric                                                                           |
| <b>Wingspan</b>    | 1980 mm                                                                            |
| <b>Weight</b>      | 1500 g                                                                             |
| <b>Payload</b>     | SkyEcho 2                                                                          |
| <b>Range</b>       | 3000-4000 m                                                                        |
| <b>GPS</b>         | No                                                                                 |
| <b>Camera</b>      | No                                                                                 |

## Appendix C: Photos from Trials

Figure 101, Figure 102, and Figure 103 are photographs from FTR3 (configuration I.



**Figure 101.** RWD1 land on the Commons.



**Figure 102.** RWD1 land on the Commons.



**Figure 103.** FWD1 land on the Commons.

The following figures are photographs from FTR5 (configuration L).



**Figure 104.** FWD2 land on the SWRC facility.



**Figure 105.** RWD2, FWD2 and FWD1 in SWRC facility.



**Figure 106.** Interior of FWD1.



**Figure 107.** Interior of FWD2.

## Appendix D: Disseminations During four Years of the Project

All the dissemination approaches during the four years of the project are listed below.

- **Deliverables**

1. Annual Performance Report (APR) 1, Sep 2019 - Aug 2020.
2. Annual Performance Report (APR) 2, Sep 2020 - Aug 2021.
3. Annual Performance Report (APR) 3 – Part F, Sep 2021 - Aug 2022.
4. Annual Performance Report (APR) 3 – Part II, Sep 2022 - Aug 2023 (Current document).

- **Publications**

1. C. C. Insaurralde et al., “Cognitive Computing Intelligence to Assist Avionics Analytics”, in proceedings of the 39th Digital Avionics Systems Conference (DASC), San Antonio, TX, USA, Oct 2020.
2. C. C. Insaurralde et al., “Cognitive Decision Support System for Avionics Analytics”, in proceedings of the 38th Digital Avionics Systems Conference (DASC), San Diego, CA, USA, Sep 2019.
3. C. C. Insaurralde et al., “Framework Prototype to Test Decision Support System for Avionics Analytics”, in proceedings of the 40th Digital Avionics Systems Conference (DASC), San Antonio, TX, USA, Oct 2021.
4. C. C. Insaurralde et al., “Ontology-Based Situation Awareness for Air and Space Traffic Management”, in proceedings of the 41st Digital Avionics Systems Conference (DASC), Portsmouth, VA, USA, Sep 2022. Best of Section Paper.
5. C. C. Insaurralde et al., “Ontologies to Support Space Traffic Management Awareness”, in proceedings of the 43rd IEEE Aerospace Conference, Big Sky, MT, USA, Mar 2022.
6. C. C. Insaurralde et al., “Situation Awareness Decision Support System for Air Traffic Management Using Ontological Reasoning”, Journal of Aerospace Information Systems, AIAA, vol. 19, no. 3, pp. 224-245, Feb 2022.
7. C. C. Insaurralde et al., “Avionics Analytics Ontology Experimental Results from Preliminary Tests of a Decision Support System for Avionics Analytics”, 24th Integrated Communications, Navigation and Surveillance Conference, Herndon, Virginia, USA, Apr 2024.
8. C. C. Insaurralde et al., “Experimental Situation-Awareness Results from Downscaled Framework Prototype of Drone-Based Takeoff Scenarios”, Aerospace, MPDI, to be submitted.

- **Sessions**

1. Distinguished Lecture, some material for lecture on “Ontological Decision-Making Support for Air Traffic Management”, available at <https://ieee-aess.org/presentation/lecture/ontological-decision-making-support-air-traffic-management>, Nov 2023.
2. AESS FREE Tutorial, “Intelligent Cyber-Physical Systems for Integrated Air and Space Transport Operations”, some material for Section 6, <https://2023.dasconline.org/tutorials>, Oct 2023.

- **Patents**

1. Preparing an application for a US Patent for the AAO.