Preparing for an Unmanned Future in SESAR Real-time Simulation of RPAS Missions

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***Abstract*—The insertion of RPAS in non-segregated IFR airspace has a number of well defined research gaps that need to be addressed in order to progress forward with the integration. Specially in the ATM domain, the lack of flight experience for RPAS maintains the myth that they will impose an increased burden to ATCo, thus reducing the operational safety and airspace capacity.**

The ISIS+ simulation infrastructure will allow the real time simulation of IFR operations by coupling a highly capable RPAS simulation system together with one of Eurocontrols ATC simulation environment called eDEP. Complex RPAS missions will be carried out under historic or forecast traffic obtained from Eurocontrols DDR2 database. Real ATC controllers can monitor the sectors of interest, while RPAS pilots can operate the simulated RPAS, and experienced pilots can operate the surrounding simulated IFR traffic. In all cases, voice communications, transponder and ADS-B, data-link, satellite induced latency, etc; can be reproduced as close to reality as possible. Overall ISIS+ will facilitate the reproduction of a variety of RPAS operational scenarios, asses its interaction with traffic controllers and surrounding traffic, and evaluate is any significant ATCo workload increase or capacity reductions occur for each selected concept of operation.

I. Introduction

On top of the overall regulatory framework, RPAS integration in non-segregated IFR airspace will only be permitted once they comply with the performance levels required by SESAR [1]. Most of the technological and procedural existing gaps have been identified in the Annex 2 of the *Roadmap for the integration of civil Remotely-Piloted Aircraft Systems into the European Aviation System* [2], recently published by the European Comission.

The goal of this work is to provide an environment that permits the analysis of specific areas (identified as gaps in that Roadmap) related to the insertion of RPAS in non-segregated airspace and the impact of their automated/autonomous remote operation from an ATM perspective. The research specifically addresses aspects of the separation assurance, response to RPAS contingencies, lost link procedures, RPAS-ATC interaction and the impact on controllers workload and airspace capacity due to the RPAS insertion (mainly gaps EC-1.1, EC-1.2, EC-3.1, EC-3.2, EC-5.1, EC-5.3 and EC-6.1). Combined with the introduction of additional automation technology, the research seeks to investigate the active interaction of the PiC (the legal responsible of the flight) and the ATCo through the extensive use of automation and information exchange. We intend to find how automation may help the RPAS to satisfy the operational and safety requirements; and how information can be shared between the RPAS and ATC in a proactive way through upcoming data-links or even the SWIM initiative, improving both the ATCo and RPAS situational awareness.

One of the big paradigms of RPAS technology is its lack of flexibility. RPAS mostly operate through a combination of autopilots, FMS and data-links, being the number of automated operations available to the RPAS pilot quite limited. Traditional pilots will simply take manual control to resolve any unexpected situation through a combination of technology and experience. However, an RPAS pilot located in a control room miles away from the aircraft itself has a highly limited situational awareness that narrows its options to properly react [3]–[6]. This paradigm has been already identified through the number of accidents due to "RPAS pilot error"; and the operational feedback from experienced RPAS pilots. This research seeks to guarantee that automation becomes a way to provide flexibility and situational awareness rather than become an obstacle to perform a safe operation.

Identified as one of the main gaps, RPAS still do not operate in this common non-segregated airspace scenario; therefore there is almost no practical experience that helps the analysis or evaluation of any operational proposal. To compensate for this limitation, our goal is to develop a high-fidelity real-time simulation environment in which the operation of RPAS integrated in non-segregated airspace can be reproduced and evaluated. The analysis will be performed by creating a real-time simulation environment that permits exploring those concepts; thus combining: (1) a realistic RPAS operation, (2) an ATC simulation environment that can integrate traffic and RPAS, and (3) historical or predicted IFR traffic and its corresponding airspace structure.

In addition to the understanding of the detail-level RPAS operation, a number of additional factors are still an unknown. Most of them relate to the effect, negative or neutral, that RPAS will have on the capacity of the already crowded European airspace. Capacity effects may be produced by an increase of separation conflicts due to the dissimilar performances of RPAS and airliners, due to the necessity to maintain dynamic airspace segregation, or due to the increased workload to the ATC controllers. All these factors need further understanding through the analysis of multiple scenarios in which the RPAS mission and performance, the surrounding traffic, the ATCo capacity; etc, become variables that can be explored. Nevertheless, an additional variable comes into the equation to favor the RPAS; its persistent endurance will exceed most actual flights, thus permitting the RPAS flight plan to be adjusted so that its negative impact may be minimized.

Real time simulations should provide crucial information on most aspects related to the RPAS operation and interaction with the ATC. However, any analysis cannot be limited to that, as the validation of the proposed concepts needs to be confronted with the wide range of scenarios that may exist in the real world. For that reason, real-time analysis should be correlated by a range of fast-time analysis tools that will investigate the statistical implications of the operational concepts being proposed. Two well-known tools will be employed, RAMS+ (developed by ISA Software) for the microscopic analysis of separation conflicts, contingencies, workload, etc; and NEST (developed by Eurocontrol) for the macroscopic impact of the RPAS operation on the airspace.

A crucial factor in this project is to take into account the peculiarities of this new type of vehicle, the RPAS, which exhibits different flight behavior than most manned aviation. At any phase of this project, RPAS will not be considered as a vehicle operating a point-to-point route. Instead, they will considered as a vehicle aiming at executing a commercial or civil surveillance mission which in general will contain complex flight patterns such as zigzag scans, complex holds, repetitive patterns, conditional flight legs etc. These particular behaviors are nowadays observed in some general aviation operations and represent a minority if compared with commercial aviation. Moreover, these operations are conducted under VFR and with a "highly manual" interaction with the ATC (if in controlled airspaces) or even in non-controlled airspaces in some cases. Therefore there is a paradox in which, on one hand we have highly automated and instrumented RPAS capable to adapt to SESAR concept of operations (like modern airliners); and on the other hand, this RPAS will be used to perform missions which are far away to the point-to-point missions performed by commercial airliners but more close to general aviation aircraft evolving under VFR.

II. The ISIS RPAS Simulation Environment

A. *Motivation*

RPAS simulation is a pressing requirement prior to real flight campaigns. Extensive research and experimentation is available in the area of aircraft and autopilot simulation, software-in-the-loop and even hardware-in-the-loop. However, little or no research is available in the area of mission simulation or in the area of multi-vehicle simulation [7], [8]. Modeling such scenarios is becoming urgent because the operation of RPAS need to consider and evaluate the impact of the RPAS mission execution in a shared airspace environment.

For all the aforementioned reasons, a simulation platform able to cope with a variety of civil RPAS missions with little reconfiguration time and overhead, including simulated traffic will help RPAS development and integration. This platform has to be capable of not only simulating the behavior of the RPAS from the mission point of view, but also including additional vehicles, each one modeled with different levels of detail according to requirements.

In order to achieve these goals, we have integrated two separate simulators in an heterogeneous environment called ISIS+. In one hand, we have integrated the ISIS (Icarus Simulation Integrated Scenario) simulation architecture. This simulator is in charge of running an environment in which RPAS operations and subsystems can be tested. On the other hand, we have integrated the eDEP (Early Demonstration and Simulation Platform) ATC simulator. eDEP was developed by the EUROCONTROL Experimental Center (EEC), and provides a low cost, lightweight ATC simulator platform. The eDEP functional architecture is inspired, equivalent in interfaces and general capabilities to the larger ESCAPE (Eurocontrol Simulation Capability and Platform for Experimentation) system [9], [10]). The combination of both simulators creates an environment in which the interaction between a mission-oriented RPAS and the overall ATM system can be investigated.

B. *General view of the simulation environment*

The designed ISIS simulation environment is constructed around a collection of services that cover in detail both the RPAS air segment and the ground segment. Previous publications [11]–[14] have profusely described the organization and operation of such architecture. A huge effort has been devoted (see Figure 2) to provide realistic flight plan capabilities and to clearly separate those processes that occur on-board the RPAS, those managed by the pilot on the ground, the effects of the communication interfaces, the complexity and limitations of the message-passing command and control, etc.

In this paper we mainly focus on the interface capabilities available to the pilot and to review the automated mechanisms that support the evaluation of the inherent remote operation of the RPAS. The ISIS simulator offers the pilot two different Human Machine Interfaces (HMI), each one addressing the different pilot roles along the RPAS operation: the *Flight Monitor* HMI interface (FMo), and the *Flight Plan Monitor* HMI interface (FPMo).

Flight Monitor, designed to resemble the traditional pilot interface. Offers details on the RPAS artificial horizon, synthetic front view camera, telemetry, electrical, engine and alarms information of the RPAS, etc. The pilot is able to control the RPAS from this workstation when a manual piloting style is required, although access to basic autopilot modes are available (manual waypoints, directed modes, automatic take-off and automatic landing activation). The pilot is offered a joystick and throttle for full manually control of the RPAS.

Flight Plan Monitor, designed to be the core of the automatic and/or autonomous operation of the RPAS under the pilot supervision. The interface is designed to offer the pilot access to its advanced mission-oriented flight plan definition. The pilot can interact with the flight plan, changing its embedded alternatives, updating specialized mission legs (like complex

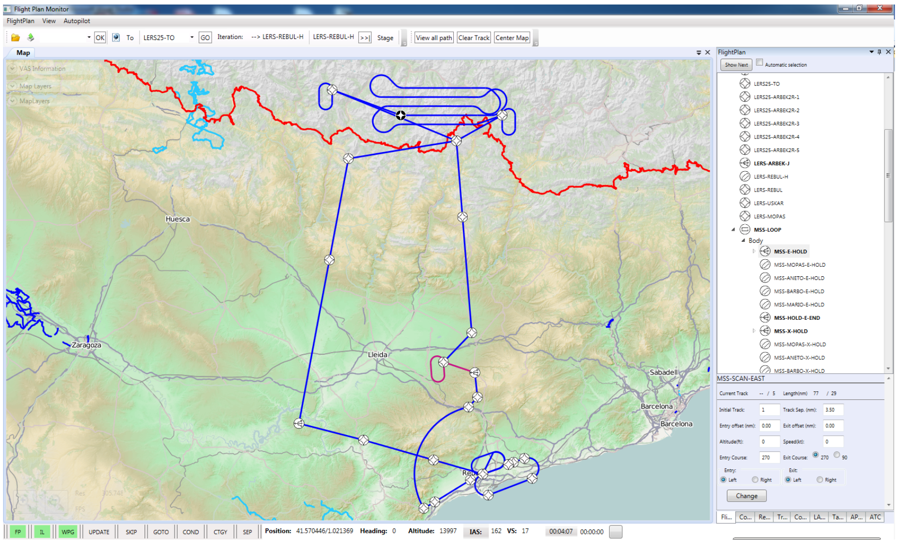

Figure 1. Flight Plan Monitor pilot interface with the selected mission on screen.

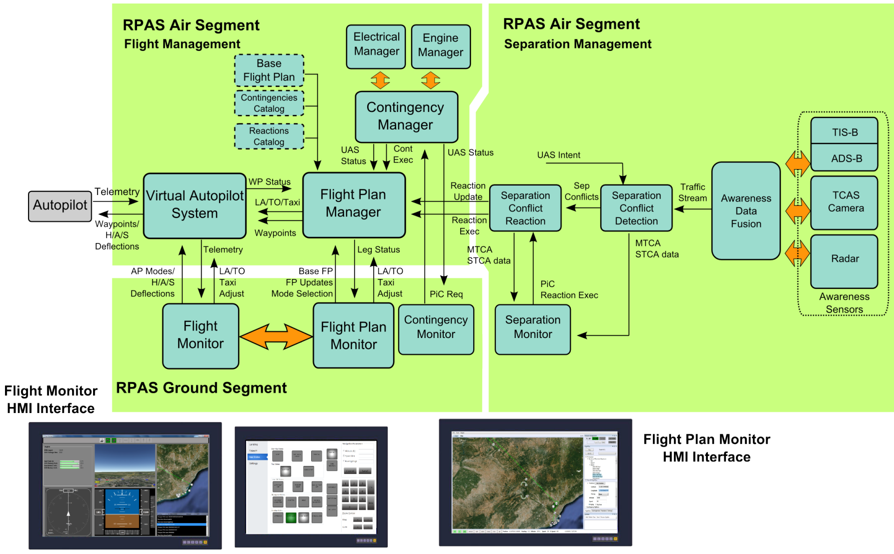

Figure 2. Detail of the internal ISIS architecture, main services and message-passing structure.

scanning operations). Multitude of additional capabilities are available from this interface:

- Alternative paths in the flight plan can be updated in real time. Iterative legs can be controlled, increasing/decreasing the number of repetitions, or forcing its termination.
- Leg parameters of mission-oriented legs can be updated; e.g. scanning legs can be modified to reuse the flight plan to re-scan another area of interests. Multiple mission legs are being developed, although its description it is outside the scope of this work.
- Pre-planned contingency flight plans and flight termination plans can be assigned or updated to each phase of the RPAS operation in real-time. The pilot can select the actual contingency procedure and ask the flight system to use the predefined ones. Once activated, the contingency flight plans can be tracked as a nominal flight plan. Deeper activations are even possible if the RPAS status degrades, forcing further decisions like the activation of flight termination flight plans.
- Lost link flight plans can be assigned to portions of the operation, and updated in real-time while the command & control links remain available.
- Access to the transponder, ADS-B Out configuration is available from this interface. The level of detail of the flight-intent mechanism can be configured upon ATC request. However, automated detail levels will be activated in case of lost-link situations.
- ADS-B In traffic can be visualized (relayed from the RPAS), with interfaces to run STCA-like MTCD-like separation conflict detection algorithms either run on the ground (or relayed from the RPAS if remotely operated).

- Basic datalink interfaces are available in order to receive / send basic navigation clearances that may reduce the radio workload. More advance datalink mechanisms can be integrated; e.g. trajectory negotiation between the pilot and the ATC for strategic separation management or real-time mission modifications.

Figure 1 depicts the general appearance of the FPMo interface, in which the RPAS operation can be tracked while flying the assigned flight plan. The whole structure of the flight plan can be inspected visually and leg by leg. Also, all the aforementioned interfaces can be access from a single interface easy to exploit.

C. Underlying aircraft model

Within the ISIS simulation environment we employ flight simulators to reproduce the airframe's flight dynamics and some of the autopilot's behavior. Initial work was carried out by integrating the FlightGear[1] flight simulator. However, the X-Plane[2] simulation environment is currently used as more realistic RPAS frame models are available with X-Plane than in other simulators. In particular models including NASA's MQ-9 Ikhana and one of its RQ-4 Global Hawk platforms. X-Plane works by reading in the geometric shape of any aircraft and then identifies how that aircraft will fly. The process is called *blade element theory*, which involves breaking the aircraft down into many small elements and then finding the forces on each individual element multiple times per second. These forces are then converted into accelerations, which are then integrated to velocities and positions.

Both MQ-9 and RQ-4 simulated vehicles have been characterized in terms of performance [15]. The objective was, not only to understand the differences between the real vehicles and the simulated ones, but to be able to model the RPAS behavior so that proper intent information could be computed. The obtained models are based on the well known BADA model [16] and are employed to both validate the flight plans and to predict trajectories in real time.

III. ISIS+ Design and Implementation

A. eDEP ATM Simulation Environment

In a non-segregated flight within a controlled airspace sector, humans play a key role in safety. Two human roles are pilots (either on-board or remote) and the ATC controller. ATC controllers have the global picture of the airspace volume and must provide clearances to the pilots to proceed. Pilots have to facilitate flight information to the ATC controller and execute the maneuvers suggested by the ATC controller. Both roles have to be integrated in the environment for a realistic simulation. Thus, a second requirement for the ISIS+ simulator is that it be designed as a Human-In-the-Loop simulator.

To achieve this, we selected the Eurocontrol eDEP simulator as the ATM component of ISIS+. There are a number of reasons and benefits to using eDEP. First, eDEP is a Human-in-the-Loop simulator and provides access to the ATC controller's capabilities and interactions. Moreover, the air traffic included in an eDEP simulation always follows the rules of the air and valid ATM concepts. eDEP provides two work stations: a Controller Working Position, which is compliant with the European Air Traffic Management Program, and a graphical Pilot Working Position, which is shown in Figure 3. eDEP is modular and extensible, so its simulations and scenarios are easy to modify. Finally, eDEP is an open-source simulator; thus, it is possible to modify its code to test new ideas and new algorithms.

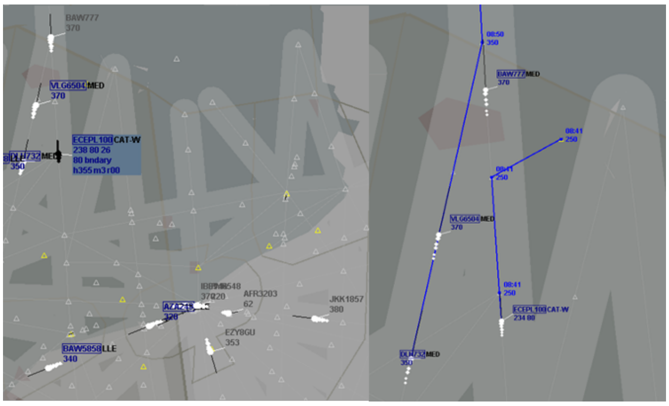

Figure 3. Early Demonstration and Simulation Platform (eDEP) screenshots.

eDEP includes the core platform functions for airspace management, flight plan preparation, flight management, trajectory prediction, coordination services and flight path monitoring. The eDEP functional architecture is inspired from that of ATM Validation Environment for Use towards EATMS [3] (AVENUE) [10] and the Eurocontrol Simulation Capability and Platform for Experimentation (ESCAPE) [9]. eDEP should contain the same functional blocks and conceptual data flows as its sibling real-time simulators.

B. ADS-B messages for the Integration of the eDEP and ISIS Environments

The integration of the RPAS (ISIS) and ATM (eDEP) environments consists of executing them concurrently, while the RPAS is able to "detect" all collaborative aircraft in the eDEP simulation and simultaneously incorporating our RPAS into the eDEP simulator. eDEP should believe that our RPAS is one of its aircraft. To obtain benefits from the two simulation tools, it is important for the aircraft information to cross the two simulators in both directions. To do this, we use the same technology proposed in the NextGen and SESAR future airspace scenarios: the Automatic Dependent Surveillance-Broadcast [17] (ADS-B) messages and data-link.

ADS-B is a surveillance technology for tracking aircraft and is the fundamental technology supporting the US NextGen and EU SESAR programs. Some countries, such as Australia,

[1] http://www.flightgear.org
[2] http://www.x-plane.com

[3] European Air Traffic Management System

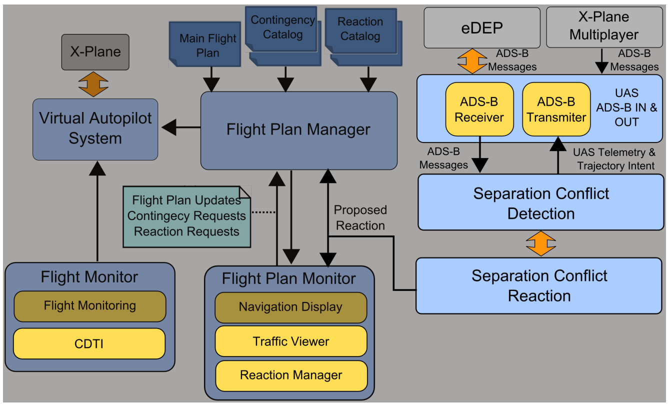

Figure 4. Integration between the RPAS simulation architecture and eDEP.

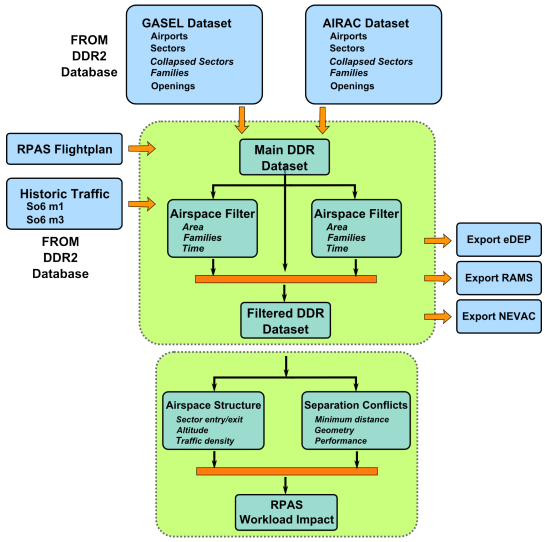

Figure 5. DDR filter mechanism to setup workload evaluations in ISIS.

have already mandated ADS-B equipment for all aircraft flying under instrument flight in its national airspace; others, such as the United States, will require it by January 1, 2020. The integration of ISIS and eDEP is straightforward using ADS-B because eDEP has ADS-B technology embedded in it; the system only requires the development of the ADS-B technology in the RPAS simulator component. A new ADS-B service will be designed as a Software-in-the-Loop component and thus will be ready to be used once the simulation validates its functionality. ADS-B messages are an ideal transparent means of communication between the simulators. eDEP can publish ADS-B messages of its aircraft once per second. At the same time, eDEP can also receive ADS-B messages from external aircraft and introduce them in the simulation. Therefore, by developing an ADS-B service in ISIS, both simulators are integrated.

The messages interchanged by eDEP and ISIS will follow the Asterix protocol [18]; specifically, the messages are those in category I021 [19]. One basic data item provided in an I021 ADS-B message is the aircraft's current position (data item I021/130). Other useful data, such as airspeed and true airspeed, are provided as data items I021/150 and I021/151, respectively. Data item I021/110 broadcasts the future flight intentions of the emitting aircraft, which is useful information to prevent navigation conflicts between aircraft. Additionally, the 4D trajectories and flight intention broadcasts are possible mechanisms to project the RPAS flight status in the near future using ADS-B. The next subsection shows the details of how ISIS has been extended with a new ADS-B service that can process incoming and outgoing category I021 messages.

C. Current ISIS+ Architecture

Figure 4 shows an overview of the simulator platform architecture of ISIS+ using ADS-B integration. ADS-B services have been developed in both the air segment and the ground segment. The new ADS-B services have two components: IN and OUT. One component receives and processes incoming messages (IN) and the other broadcasts the ADS-B messages to the airspace (OUT). Both components are present in the air segment to monitor the airspace around the RPAS using the received ADS-B messages and to broadcast the RPAS position to the other airspace users. These are the main objectives of this new service. On the ground segment, the Flight Monitor and the Flight Plan Monitor incorporate new functionality. Both services are now capable of receiving ADS-B messages and showing the information in the ground segment displays. Thus, the pilot can monitor the air traffic around the RPAS using a Cockpit Display of Traffic Information (CDTI) or the Navigation Display.

Scheduled and IFR aircraft are simulated within eDEP and linked using the ADS-B messages. eDEP is configured to transmit the ADS-B messages of its aircraft and can receive ADS-B messages from other network aircraft. The ADS-B Gateway (shown in green in Figure 4) centralizes all the ADS-B network messages coming from the RPAS and the other simulated aircraft and provides these messages to eDEP at a suitable rate and sequence. The resulting scenario is similar to real flights, where ATC controllers monitor and manage all aircraft flying within the airspace volume

Non-scheduled (but collaborative) aircraft, such as simulated VFR flights, can be also incorporated through other simulation components. In the currently available solution any VFR or IFR traffic can be incorporated through the X-Plane multi-player mode. Traffic is integrated into the simulator by equipping them with an ADS-B device. The ADS-B device can process IN and OUT ADS-B messages and is in charge of transforming the aircraft's high fidelity flight telemetry into ADS-B messages. Those messages are sent to the eDEP server that transparently incorporates that vehicle into the simulation. Figure 6 depicts several screenshots of an RPAS operating in that mixed mode with other types of IFR traffic (an Airbus A-380). In this configuration, the airliner pilot keeps all functional abilities offered by X-plane, while the RPAS pilot can detect the airliner thanks to the flow of ADS-B messages.

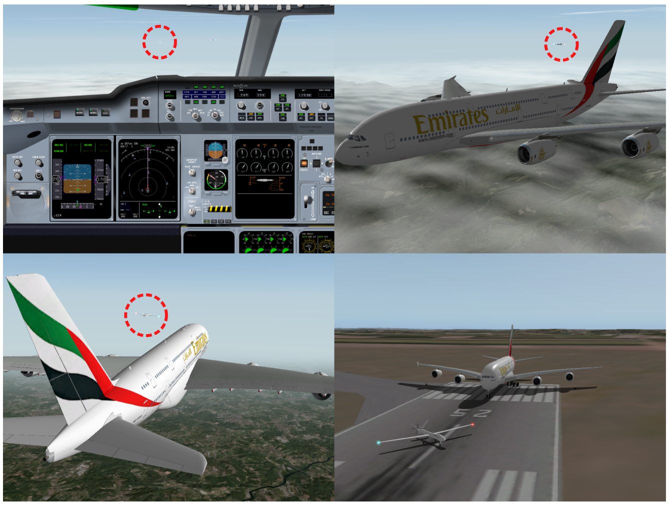

Figure 6. MQ-9 in various encounters with an A-380 simulated within ISIS.

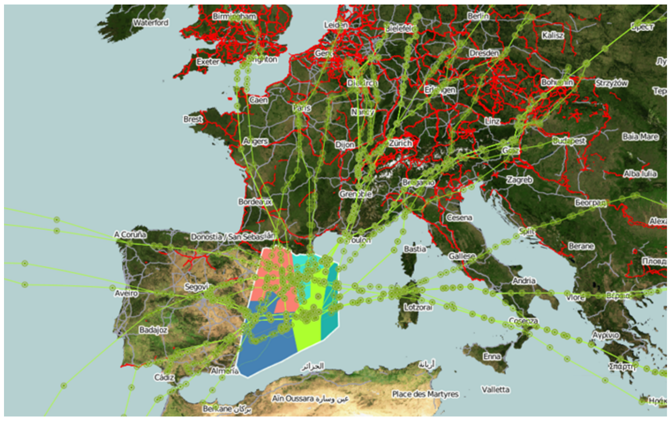

Figure 7. Filtered traffic over Barcelona's FIR and TMA where the selected validation is performed.

D. Simulated Radio Communications

In addition to ADS-B, we simulated the ATC controller's radio communications in both components using the TeamSpeak3 [4] software. TeamSpeak is a proprietary Voice Over IP software that allows computer users to speak on a chat channel with fellow computer users, much like a telephone conference call. Hence, using the eDEP controller's working position, the ATC controller can see the RPAS in his/her screen and can send commands to the RPAS regarding updates to its route or changes in altitude or speed.

E. Traffic Datasets

In order to populate the IFR traffic required for the ATM simulations, the ISIS+ tool also includes an automated data processing flow (see Figure 5. The tool is capable of digesting airspace structure and historical traffic obtaining from EUROCONTROL's DDR database. The user can select the area of interest, either as a geographical area or by specifying the FIR's or TMA's under investigation. Relevant airspace information as well as flight that cross that portion of airspace is filtered. Then, it can be further exported into a variety of formats, including those required for eDEP, but also to other fast-time analysis tools like RAMS [20] and NEST [21]. Figure 7 depicts the filter results for a typical working day over Barcelona's FIR and TMA. Using a common data source and filter mechanisms guarantees that the data that in feed both into real-time simulation tools and fast-time tools is fully equivalent, and therefore compatible in terms of ATC workload evaluation.

IV. RPAS Mission Validation

A. General concept of operation

To validate ISIS+, we simulated a RPAS surveillance mission to monitor a wildfire over the Spanish Pyrenees. The selected mission assumes a Medium altitude Long Endurance RPAS (MALE) under the form of a civil General Atomics MQ-9 Reaper. This RPAS is capable of reaching a 20.000-35.000 ft ceiling with cruise speeds between 180-240kt. Figure 8 outlines the airspace area, airport location, main routes, lost-link alternatives, etc, where the RPAS mission will occur. Figure 14 outlines the main stages of the operation and the conditional flows that exist within each stage. Each subsection will show the actual trajectories and how they are flown by the simulated MQ-9 vehicle.

This fire surveillance mission assumes that all RPAS operations occur from the Reus airport (ICAO code LERS), a regional airport south of Barcelona that merges both general aviation with national/European services provided by Ryan air and some other low cost airlines. The RPAS flighplan will cover the operation from its parking area, taxi, takeoff and departure; back to its approach, landing, and taxi back to its parking area.

The RPAS will climb to altitude after following standard departure procedures. Once at cruise altitude will proceed north following standard low/high airspace airways. After reaching the operation area, the RPAS will separate from the selected airway (A29) and hold at a pre-determined position waiting for clearance to move into a number of scanning surveillance patterns. The surveillance patterns will continue as long as necessary, although it may slightly change under request from the public safety (firefighters) authorities due to the dynamic evolution of the fire. Each time a scan pattern is completed the RPAS should hold and wait for a new clearance at some pre-determined area. After the surveillance mission is completed, the RPAS will exit the surveillance area and proceed back to the Reus airport following standard approach procedures.

Figure 9 details the structure of the surveillance mission: two scanning areas, four predefined holding points and a number of transfer routes are pre-defined. The operation always starts at the MOPAS holding point reached enroute from Reus. From there, the RPAS may only perform scanning missions over the *east operation area*, ending the scan either at the MOPAS or ANETO holding areas. The RPAS may repeat a

[4]http://www.teamspeak.com/

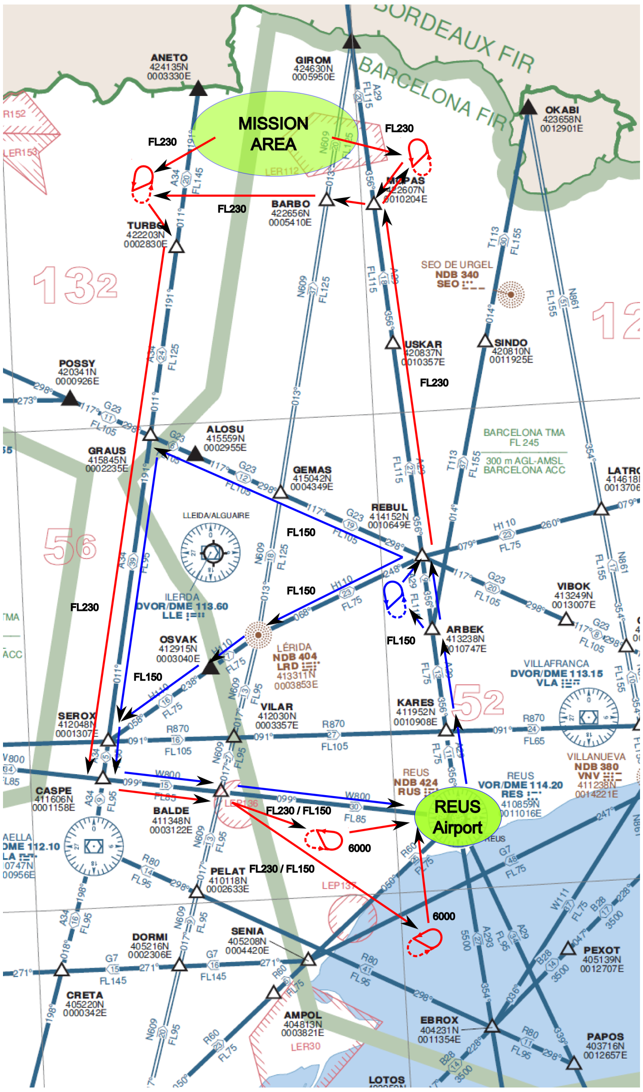

Figure 8. General view of the RPAS surveillance mission: area of operation, airport, airways, mission area and emergency lost-link routes.

similar scan or may transfer itself to the *west scanning area*, operating between the BARBO and MARIO holding areas. Specific transfer routes exist in order to move the RPAS from one operation area to the other (once ATC clearances have been obtained).

Once completed, the RPAS must abandon the mission from either the BARBO or the ANETO holding areas. Once cleared, the RPAS return to base is restricted to airway A34.

The overall flight plan structure can be visualized, for a particular selection of SID and STAR, in Figure 1. Note that the scanning and holding areas will dynamically change according to the pilots selections (once clearances have been provided).

B. Take-off and departure

Departure will occur from Reus airport (code LERS), potentially using either runway 07 or runway 25. For both

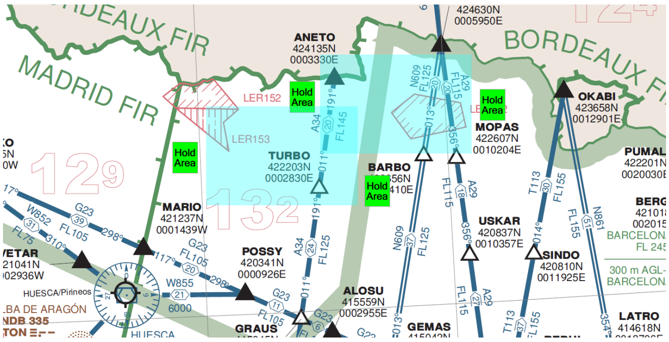

Figure 9. RPAS general mission structure.

cases, Standard Instrument Departure (SIDs) published by the Spanish ANIP provided will be employed (see Figure 10).

The RPAS will start parked at the common ramp area and, once cleared, will proceed to the head of runway 07 following the extended taxiway in order to maximize the runway available length, or to runway 25 following the standard taxiway. The runways, as well as the required taxiways are available within the simulation environment.

After takeoff clearance, the RPAS will automatically accelerate until the 110-120kt rotation speed is reached (for the selected MQ-9). The RPAS will rotate and climb until a Departure End Runway (DER) waypoint is reached, were the landing gear will be retracted and then will turn to initiate the selected departure operation. Altitude at the DER waypoint will be consistently 500ft over ground level. Once the DER waypoint is reached the selected Standard Instrument Departure (SID) procedure is initiated. Independently from the selected runway, the departure procedure will lead to the ARBEK waypoint, following the ARBEK2R SID when taking off from runway 25 (see Figure 10); and ARBEK1S when taking off from runway 07 (see Figure 10). Figure 1 shows take-off over runway 25 and departure ARBEK2R as implemented in ISIS.

Minimum altitudes at waypoint ARBEK need to be taken into account. A minimum FL80 is required when departing through ARBEK1S, while a more stringent FL120 is required when departing through ARBEK2R. The MQ-9 performance has been validated in order to check if the required altitudes can be guaranteed. When checking the lower-airway chart in that area it can be seen that waypoint ARBEK has a flight level FL75 requirement that becomes a FL115 if heading north through route A29 (see Figure 8). The equivalent airway in the upper airspace has a FL245 requirement that will never be reached due to the limitations of the operation.

The objective of the RPAS is to reach a FL200 or higher for the major part of the operation. The altitude is defined by the requirements of the sensors onboard of the RPAS and by the fact that the major part of the flight plan will be developed over the Pyrenees range.

After waypoint ARBEK is reached and to avoid interference with the remaining airspace, the RPAS will climb into its operational altitude within a constrained area (performing a climbing hold). That area will be reached from waypoint ARBEK and exited towards waypoint REBUL, once the proper altitude is reached and the ATC clearance is obtained. As it can be seen in Figure 8, that area does not interfere with the airways present within the lower airspace, but overlaps with airway UN725 within the upper airspace. However, as previously mentioned, the RPAS will never cross the FL200 which is well below the FL245 requirement when flying airway UN725.

C. Approach and landing

Return to base will be carried out through airway A34 south, from waypoint ANETO down to TURBO, GRAUS, and SEROX (see Figure 8). At SEROX we will start the approach procedure to REUS through SEROX1Q to runway 07 and through SEROX1P to runway 25.

The return to base routes will be continuously flown at cruise altitude until the initial fix for the STAR procedures are reached. In case of operating STAR SEROX1P for runway 07 (see Figure 11), the RPAS will maintain altitude until the holding position is reached at IAF DISET. Once there, the RPAS will descend to 5000ft while performing the hold, and will remain there until cleared for landing.

In case of operating STAR SEROX1Q for runway 25 (see Figure 11), the RPAS will proceed until IAF REUS and start a descending hold to reach 5000ft altitude. The RPAS will remain in the hold pattern until cleared to land.

The landing procedure to runway 07 starts from the DISET IAF where the RPAS will be performing a holding pattern at 5000ft. After leaving DISET the RPAS will align with R-246 RES while performing a number of descends. IF MOMAT will be reached at 2800ft and from there the FAF point 5NM out of DME RES at 1800ft. From the FAF fix, final descend will occur until touchdown, or land abort if any unexpected situation occurs (see Figure 11).

The landing procedure to runway 25 starts from the REUS IAF where the RPAS will be performing a holding pattern at 5000ft. After leaving REUS the RPAS will parallel runway 25 by taking course 69^o until a 9NM separation from fix REUS is attained. The RPAS will descend until reaching 2600ft of altitude at that point. Once the required separation is reached the RPAS will turn left to intercept course 249^o and start the final landing by aligning with the ILS over the FAP, 7.1NM away from the landing point. From the FAP fix, final descend will occur until touchdown, or land abort if any unexpected situation occurs (see Figure 12).

Details of the landing procedures as implemented in the ISIS flight plan language can be seen in Figure 13. Note that the tool takes into account the hold entrance direction and inserts the required insertion procedure as required for each procedure. Landing abort procedures are also fully supported as described in the corresponding landing charts. Equivalent flight plans in ISIS are not shown due to space limitations.

D. Interferences with Barcelona's SID and STAR

Another crucial factor to be taken into account is the approach and departure operations from Barcelonas airport. After checking the charts it can be seen that a number of departures cross north of waypoint ARBEK between FL120 and FL140. The selected holding area is well south of the departure routes, and once the RPAS reaches its FL200 target and head north to waypoint REBUL, the RPAS will be well above the departure route.

Similar considerations are necessary for all the Barcelonas approach operations that occur at that area. Altitudes between FL80 and 6000ft and specified, so it is necessary to guarantee that the RPAS will be well above FL80 when reaching north of waypoint ARBEK.

E. Contingency support

Flight contingencies will be supported along the simulated mission by providing pre-planned alternative flight plans. The amount of pre-planning will be somehow limited at this point as the total number of alternatives to be considered could be fairly large. Alternative flight plan will be separated in two classes, those to be employed in case of light emergencies or simply mission cancellations, or even lost-link procedures; and those required under a real emergency that requires the immediate landing (or even crash-landing) of the RPAS.

The proposed lost-link procedure will employ the same return route as the standard return to base route (see Figure 8). In case of lost-link over the mission area the RPAS will hold for a certain amount of time right or left of fix TURBO (at the same holding areas defined for the mission). The RPAS will hold there giving time to try to regain communication. If after the predefined time no communication is possible, the RPAS will autonomously proceed down airway A34 at cruise altitude and predefined speed.

Once fix CASPE is reached, the RPAS will turn towards fix BALDE and the separate from airway W800 to reach a hold position in the vicinity of REUS. The altitude will keep being the cruise altitude until the holding area is reached. Initially a holding area over land has been identified, but an alternative area over the sea can be used if deemed necessary. The second holding area has the limitation that some airways need to be crossed, in particular airway R60 and airway G7. To minimize disturbance an appropriated altitude can be pre-defined.

The RPAS will continue to hold for a certain period of time to let the RPAS operation to try to regain line of sight control of the RPAS and to let the fuel be consumed. After that security time the RPAS will automatically perform an emergency landing. The runway to be used will be set up at take-off time, but can be also modified at any time during the RPAS operation (obviously until the command and control link is lost). Holding times and altitudes will be decided upon negotiation with the ATC controllers operating the area.

When landing on runway 07, if landing occurs from the holding point over land, the RPAS will implement a direct landing by aligning with R-246 RES at 5.000ft, to progressively descend as indicated in the landing chart. If landing occurs from the holding point over sea, the RPAS will proceed straight to KERIP fixpoint and the follow the indicated landing procedure (see Figure 11). When landing on runway 25, an

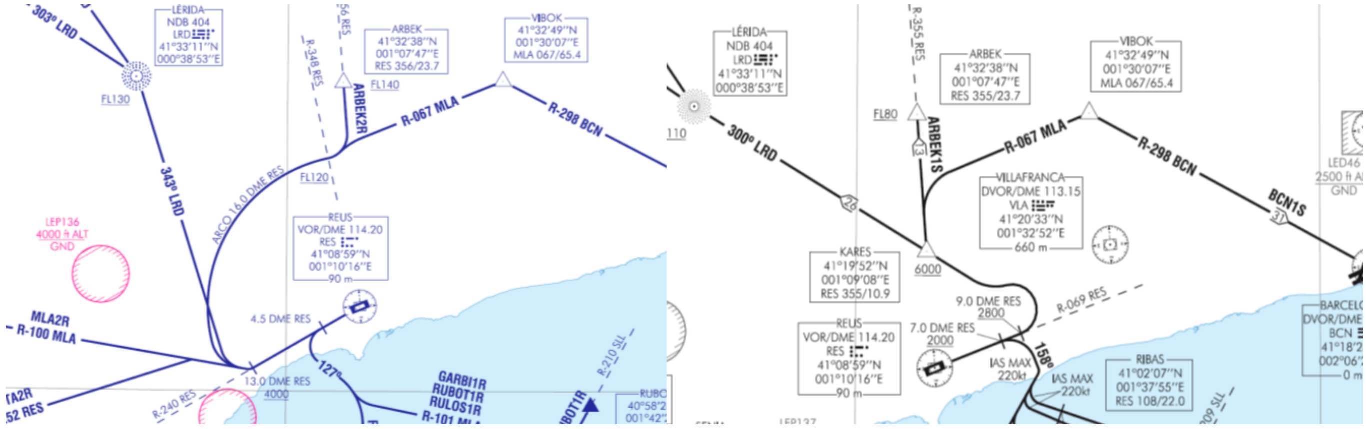

Figure 10. SID departure charts for Reus airport.

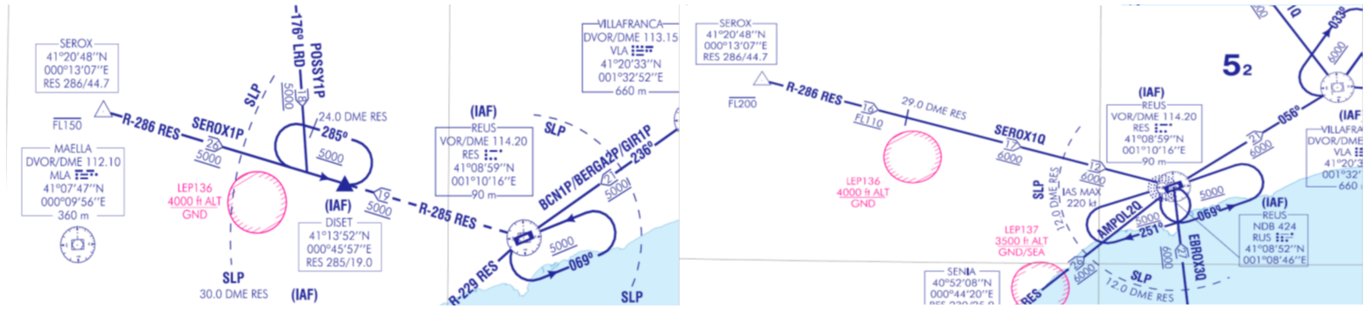

Figure 11. STAR approach charts for Reus airport.

equivalent sequence will be followed, but the RPAS will continue until DME REUS, overflying it. Once on top REUS, the RPAS will separate until 13.0 DME and turn to intercept the landing route defined by 249^{o} DME.

Two different locations are identified for an extremely urgent emergency landing, one located to the east of the operation (La Seu, code LESU) and the other one to the west (Huesca, code HUE). La Seu airfield is located north of fixpoint SINDO, and only enjoys visual approach charts. In any case direct landing procedures will be designed based on the available information provided by the local authorities. Huesca airport can be used when the RPAS is operating much to the west, or when descending through airway A34. Instrument charts are published just for one of the runways (RWY 30L), but RPAS emergency procedures will be designed for both ends of the runway. Finally, one additional airport is identified for emergency landings (other than REUS), when operating over the en-route airways. The selected airport is Lleida/Alguaire (code LEDA). This fairly new airport can be easily reached both from airways A29 (departing to the mission) and A34 (returning from the mission). Contingency procedures for these runways are not shown due to lack of space.

Several simulation exercises have been carried out for this experiment. Due to the difficulty to fully show all functional capabilities, a number of videos have been made available to be correlated with this paper. Currently available videos include:

- ISIS+: http://www.youtube.com/watch?v=2ySvKxlSLLo
- eDEP: http://www.youtube.com/watch?v=qV3yyYxLS_Q

Workload analysis will become available as soon as real-time simulations are developed with experienced ATC controllers.

V. Conclusions and Future Work

This paper introduced ISIS+, which is a Software-in-the-Loop simulator that was developed to study and evaluate complex scenarios in which RPAS are integrated into non-segregated airspace. The ISIS+ simulator provides a realistic evaluation environment where RPAS software components can be developed under real ATM scenarios while considering their peculiarities. ISIS+ minimizes both the test development and validation costs and allows easy migration of the software from the test-bed platform to the real UAS platform when it is ready to be integrated in non-segregated airspace.

The RPAS simulator is integrated with eDEP, a Eurocontrol air traffic simulator that is used for ATM research. The major eDEP contributions to the simulation environment are the inclusion of real commercial air traffic to the simulations and the access to the ATC controller capabilities and interactions. Non-scheduled flights have also been incorporated in the simulator scenarios using the multi-player capabilities of the X-Plane and Flight Gear simulators. ADS-B was used as the base technology for the integration. ADS-B messages are used

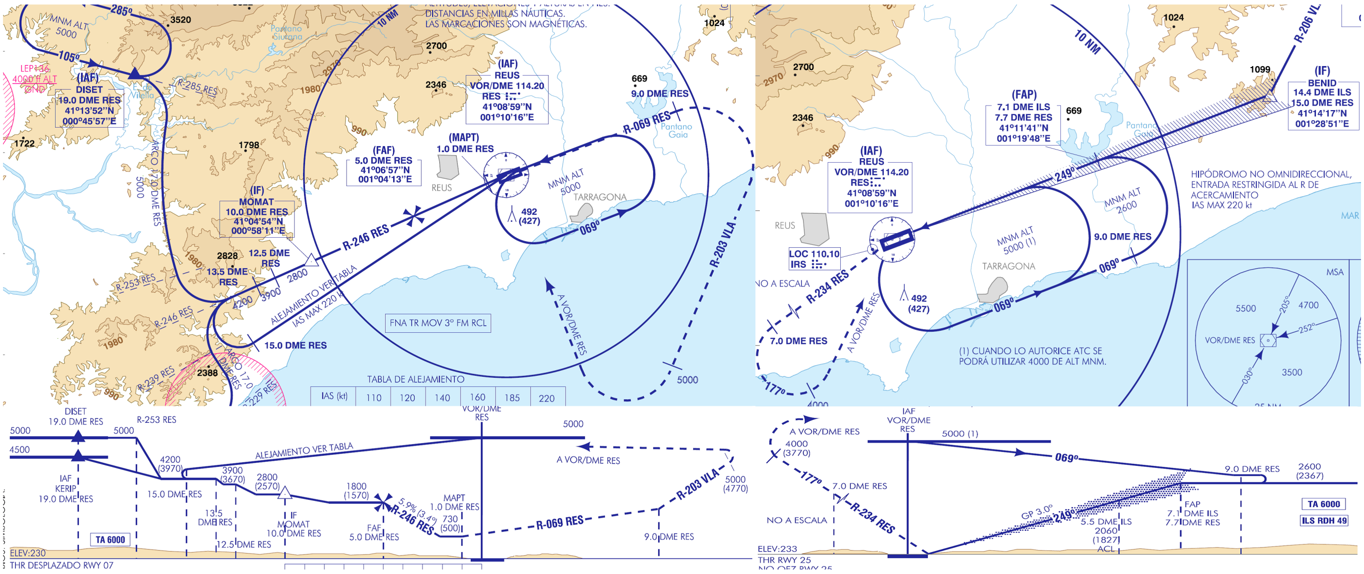

Figure 12. Landing charts for runways at Reus airport.

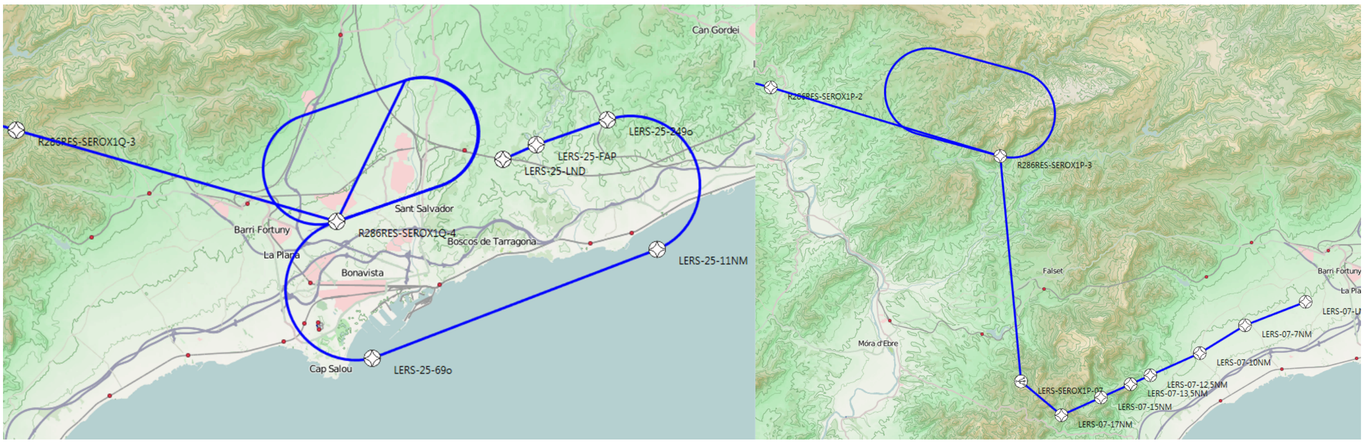

Figure 13. RPAS landing charts.

to transparently exchange flight information between all the simulators, as will be performed in future air space scenarios.

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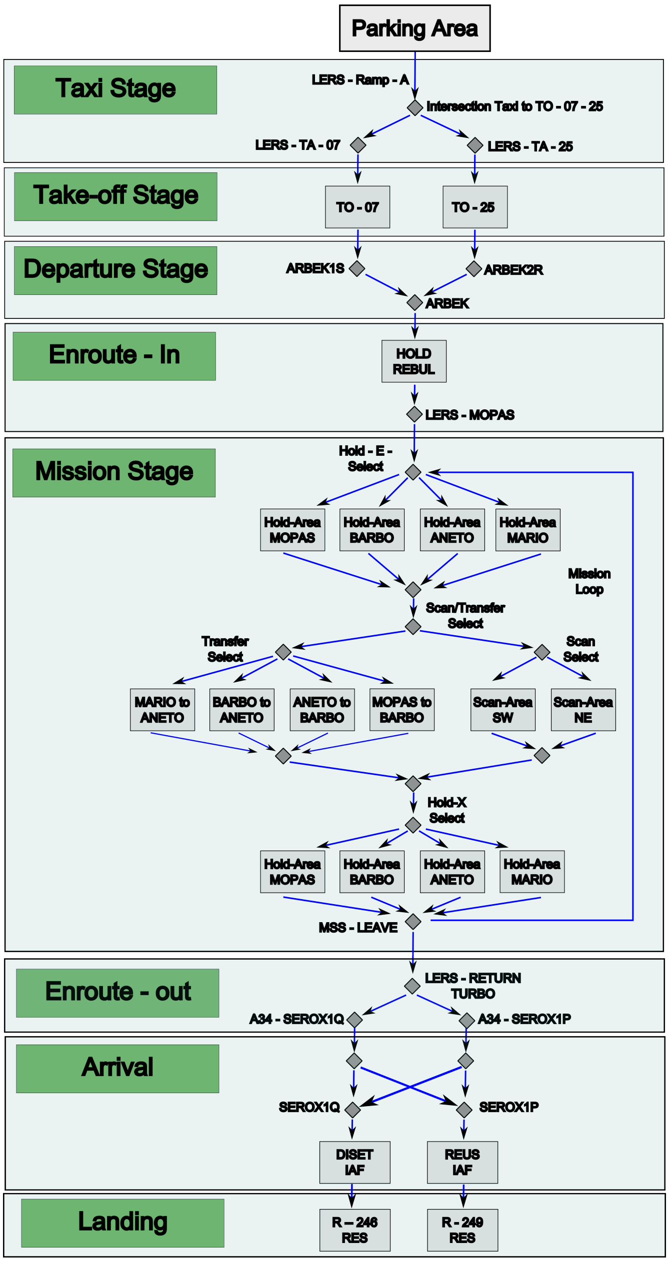

Figure 14. ISIS nominal flight plan structure.

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