Real-time Simulations to Evaluate the RPAS Integration in Shared Airspace

E. Pastor, M. Perez-Batlle, P. Royo, R. Cuadrado and C. Barrado

ICARUS Research Group

Technical University of Catalonia

Esteve Terrades, 5. 08860 Castelldefels - Catalonia (Spain)

Abstract—This paper presents the work done during the first year in the WP-E project ERAINT (Evaluation of the RPAS-ATM Interaction in Non-Segregated Airspace) that intends to evaluate by means of human-in-the-loop real-time simulations the interaction between a Remotely Piloted Aircraft System (RPAS) and the Air Traffic Management (ATM) when a Remotely Piloted Aircraft (RPA) is being operated in shared airspace. This interaction will be evaluated from three different perspectives. First, the separation management, its results are presented in this paper. Secondly, during the next year, the contingency management, also including loss of link situations and, lastly, the capacity impact of such operations in the overall ATM system.

The used simulation infrastructure allows to simulate realistic exercises from both the RPAS Pilot-in-Command (PiC) and the Air Traffic Controller (ATCo) perspectives. Moreover, it permits to analyze the actual workload of the ATC and to evaluate several support tools and different RPAS levels of automation from the PiC and ATC sides. The simulation results and the usefulness of the support tools are presented for each selected concept of operations.

I. Introduction

Technology evolution in the field of Remotely Piloted Aircraft Systems (RPAS), will affect the Air Traffic Management (ATM) performance regarding to their upcoming military and civil applications. RPAS, as new airspace users, present new challenges and opportunities to the ATM system of the future. The goal of this upcoming ATM is to improve the network in terms of capacity, efficiency, safety and security. However, the integration of RPAS poses a risk due to their inherent nature.

At present the majority of flights correspond to manned commercial aviation dealing with persons/goods point to point transportation. On the contrary, the majority of future RPAS flights may significantly differ from this paradigm. Most common RPAS mission will be surveillance, requiring flexible and uncertain flight plans executed by computers with the remote supervision by the RPAS pilot. It is true that nowadays there exists some general aviation manned aircraft performing this type of missions, but their operation is a minority and it's always a man-directed process with little direct control from computers. Point to point ferry flights by RPAS are also foreseen at some point in the future. The introduction of RPAS may exponentially increase this type of operations, placing a larger pressure into the ATM system.

Under Eurocontrol's and Federal Aviation Authority's (FAA) philosophy, the introduction of unmanned traffic should not affect ATM operations, thus RPAS should comply with the performance levels required by SESAR or NextGen. Hence, RPAS operation should be shaped to large extends to guarantee its safe and efficient interaction with the ATM system.

In aviation, several layered mechanisms are present to minimize the probability of collision between aircraft. Generally speaking, they are categorized into two main groups: separation assurance and collision avoidance [1]. Separation assurance aims at keeping minimum distances between the aircraft and potential intruders. A loss of separation is considered a serious issue and ideally, it should never occur. Nevertheless, collision avoidance functionality should prevent an imminent collision as a last resort maneuver.

While extensive research is being devoted to develop collision avoidance systems (see [2] for a review on this topic) that take into account the particularities of RPAS (the detect-and-avoid paradigm), few researchers have addressed the separation, emergency and lost-link problem for RPAS. Furthermore, at present, no assessment or methodology exists that deals with the necessity to coordinate RPAS almost automatic operations, but monitored by pilots, with all other ATM actors under nominal and emergency operations.

The WP-E project ERAINT focus on these additional aspects of the RPAS-ATM interaction that has not been previously addressed, which will determine the feasibility and effectiveness of the RPAS integration. This project is investigating such relationships in a systematic way, developing a concept of operation for both the RPAS and the Air Traffic Controller (ATCo) that may control them. The RPAS Concept of Operations (ConOps) and all the automation supporting systems will be put under test within a number of evaluation mechanisms: from a real-time simulation environment in which both the pilot and ATCo responses can be evaluated in detail; to fast time simulation models in which the statistical behavior can be studied.

This paper summarizes the work (from the validation process to the simulation trials and results) that has been done during the first year of this project. Its reminder is organized as follows: Section II presents the ERAINT project scope, paying particular attention to the main aims of the projects and its organization. Section III details the objectives pursued within the first year. Section IV and Section V define the simulation exercises that have been performed and present the derived results, respectively. Finally, Section VI concludes the paper and outlines some future work.

II. ERAINT PROJECT SCOPE

On top of the existing regulatory framework, civil RPAS integration in non-segregated IFR airspace will only be permitted once they comply with the performance levels required by SESAR [3]. 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* [4], recently published by the European Commission.

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. The research specifically addresses aspects of the separation provision, response to RPAS contingencies, lost link procedures, RPAS-ATC interaction and the impact on the controller's 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).

ERAINT specifically addresses separation provision, response to RPAS contingencies, lost link procedures, RPAS-ATC interaction and the impact on the airspace capacity due to the RPAS insertion. Also, combined with the introduction of additional automation technology, the research seeks to investigate the active interaction of the Pilot-in-Command (PiC, the legal responsible of the flight) and the ATC through the extensive use of automation and information exchange. We intend to find how automation (i.e. systems that support the RPAS pilot while he keeps the final decision) 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 System Wide Information Management (SWIM) initiative, improving both the ATC and RPAS situational awareness.

The elements under investigation are addressed in three steps, namely:

- **Step A:** En-route automatic separation management with open and closed instructions by the ATC and proactive participation of the RPAS through strategic trajectory negotiation.
- **Step B:** Contingency management with automatic or even autonomous operation by the RPAS (in case of lost-link) with active intentions interchange and negotiation between the RPAS and the ATC.
- **Step C:** Strategies to access non-segregated controlled airspace limiting the negative impact of the RPAS operation to airspace capacity and ATC workload.

The objective of the project is to validate a number of technological and operational enablers and contribute to the RPAS Roadmap. Enablers will focus on the exploitation of specific RPAS procedures as well as ADS-C / ADS-B [5] and data link technology to increase the situational awareness around the RPAS-ATC interaction, and therefore reduce the negative impact of RPAS insertion in non-segregated airspace.

In the first year Step A has been fully addressed and delivered. This paper will summarize what has been done, paying particular attention to the simulation trials and results.

III. STEP A: SEPARATION MANAGEMENT

A. Context of validation

Nowadays, separation in controlled airspace is typically responsibility of the ATCo, which issue clearances to the aircraft in order to maintain, at least, certain minimum separation values. Some systems, however, have already been proposed to increase the automation levels of these manual separation provision processes (i.e. specific tools that support the ATCo to manage the desired separation levels). For example, as an ATCo support tool, the Medium Term Collision Detection (MTCD) system computes initially the trajectory of the aircraft using the flight plan, performance parameters and meteorological information and then, refines it by monitoring the actual performance of the aircraft [6]. Similar concepts are brought at cockpit level with the Airborne Separation Assurance Systems (ASAS) [7], which aim to delegate separation tasks from controllers to pilots. Furthermore, SESAR and NextGen programs propose new paradigms that rely on accurate design and execution of four-dimensional trajectories that are expected to transition from radar control to trajectory-based operations [8].

Among all RPAS possible applications, surveillance missions will be perhaps the most numerous [9]. In these missions, RPAS will not operate as current commercial aircraft, which fly point-to-point missions. They will possibly loiter over certain areas performing all kinds of non-conventional flight plans (such as scans, perimeter loops, etc.) that will change dynamically during the flight, according to the mission needs. Moreover, most of the RPAS will have poorer flight performance than commercial airliners (in terms of cruise speed and climb/descent performance, for instance), but will likely operate at very similar altitudes. Therefore, the separation provision can become an issue in a real RPAS implementation.

This validation focuses on separation manoeuvres for RPAS and analyses the case where a RPAS needs separation from a much faster airplane flying at the same altitude. We evaluate a number of conflict scenarios between typical HALE and MALE RPAS (a Northrop Grumman RQ-4A Global Hawk and a General Atomics MQ-9 Reaper) and jet airliners present in the European airspace. Different requirements will be analysed in terms of equipment and roles for the ATC and RPAS pilot. Since today's standard separation strategies may have a negative impact on the RPAS mission, implying a deviation from the desired surveillance track, this validation will also evaluate pre-planned RPAS separation manoeuvres. They aim to improve the situational awareness of both ATC and RPAS PiC, but also to disrupt as less as possible the sequence of the mission performed by the RPAS. Strategic trajectory modifications will be proactively suggested by the RPAS pilot in order to minimize potential separation issues.

Two different missions have been designed to address this validation. A point to point mission for the RQ-4A vehicle, with a small number of alternative routes according to the desired level of transit to be encountered. A surveillance

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mission for the MQ-9 platform, with certain level of dynamic trajectory variations that try to reproduce a realistic operational scenario.

B. Validation overview

Step A of the validation has been organized around a single planned validation experiment in which a constant traffic configuration is kept, while the capabilities of both the RPAS and the ATC evolve.

The RPAS operated in a mixed-mode simulator environment called ISIS+, in which coarse-level simulated IFR traffic (provided by eDEP simulator) was mixed up with a fine-level simulated RPAS (provided by ISIS); that was managed by simulated ATC centres. The flight trial scenarios use realistic sectorization with various levels of traffic density and the RPAS operating within those sectors.

To guarantee the success of the validation, the preparation of the exercises has employed fast-time analysis tools (NEST and eDEP) that should evaluate the workload levels produced by the planned traffic scenarios to, first, pre-analyze workload levels in all traffic samples and their randomized versions and, second, to compute actual workload levels of all exercises once completed.

At all times the RPAS will operate under strict non-segregation, although it is clearly recognized that different situations need to be addressed, depending on the RPAS being enroute to/from the mission area; and the mission area itself.

The evolution of the capabilities of both RPAS and the ATC through the planned validation experiment is the following:

- **Base Level Scenario 1. No RPAS Operating:** This sample is the baseline (nominal) scenario. It is kept free from RPAS operating in the area of interest. This scenario, originating from a busy live traffic sample extracted from the DDR2 database [10], contains the traffic operating in the intended mission area of the RPAS mission. Traffic complexity is made variable over the time period under analysis. No meteorological effects will be included. The scenario will be used as a baseline to compare the results of the scenarios with RPAS flights.
- **Scenario 2. No flight-intent RPAS:** This sample features the exact same traffic than the baseline scenario 1, with one RPAS operating (either a RQ-4A or a MQ-9) over a certain mission area. The RPAS will be assumed to operate without flight-intent or data-link capabilities. Only transponder and ADS-B data will be made available to the ATC. The RPAS will be passive, only requesting mission-related clearances through voice communications and relying on separation as managed by the ATC.
- **Scenario 3. Pro-active, no data-link, flight intent RPAS:** This sample features the exact same traffic than scenario 1, with one RPAS operating (either a RQ-4A or a MQ-9) over a certain mission area. On top ADS data, the RPAS will be assumed to operate flight-intent capabilities; that is, being able to provide detailed intentions. The RPAS will act pro-actively, requesting multiple mission clearances through voice communications.

TABLE I
SUPPORTED SURVEILLANCE AND COMMUNICATION TECHNOLOGIES.

Scenario ID	Surveillance systems	Communications
Scenario 1	PSR / SSR	RTF
Scenario 2	PSR / SSR	RTF
Scenario 3	PSR / SSR / ADS-C	RTF / Limited datalink

IV. SIMULATION EXERCISES DEFINITION

A. Expected benefits/outcomes

The ERAINT simulation exercises have been all executed in the ISIS simulation infrastructure [11]. A limited number of ATC and pseudo pilot were integrated. The following list summarizes the performance expectations from the exercises per relevant stakeholders:

- **Controllers:** (1) Asses the viability of the RPAS integration and the specific separation strategies to be used to negative minimize traffic impact. (2) Asses which data link messages are necessary and sufficient to meet the needs of the concept. (3) Asses that no negative impact on operations is derived from the use of new CWP/HMI.
- **Research:** (1) Validate the relevance of the RPAS-ATC simulation environment. (2) Understand up to which level the RPAS can be a pro-active vehicle. (3) Validate that RPAS missions can be carried out when operating in shared airspace. (4) Validate which types of separation manoeuvres are best suited for RPAS.
- **SJU:** (1) Obtain assurance that the RPAS integration concepts under consideration are feasible.

B. Benefit mechanisms investigated

Figure 1 outlines the expected impacts of the RPAS insertion in shared airspace once the operational and technological elements envisaged by ERAINT are in place.

The strategic planning is impacted (Ref. (1)). Three indicators have been used to analyse this impact. The Coordination Controller (CC) workload is expected to increase since he may need to plan the RPAS trajectories in order to avoid tactical conflicts due to their limited manoeuvrability. The sector throughput is expected to keep almost the same throughput levels due to the limited number of RPAS operating in the sector, the flexibility offered by the RPAS to deviate from its planned trajectory as required by the CC and the increase in situational awareness about the RPAS intentions. Finally, the number of strategic manoeuvres is expected to increase since it is the main separation mechanism to be employed, trying to minimize tactical ones.

The tactical planning is impacted (Ref. (2)). Three indicators have been used to analyse this impact. The complexity of each tactical conflict will increase due to the RPAS limitations to manoeuvre and the conflict dissimilarity between RPAS and airliners. The number of tactical manoeuvres is expected to globally be maintained because most of the RPAS conflicts will be addressed strategically. Finally, the EC workload is expected to slightly increase because the number of RPAS induced conflicts may decrease but the individual complexity, given the RPAS limitations to manoeuvre, may increase.
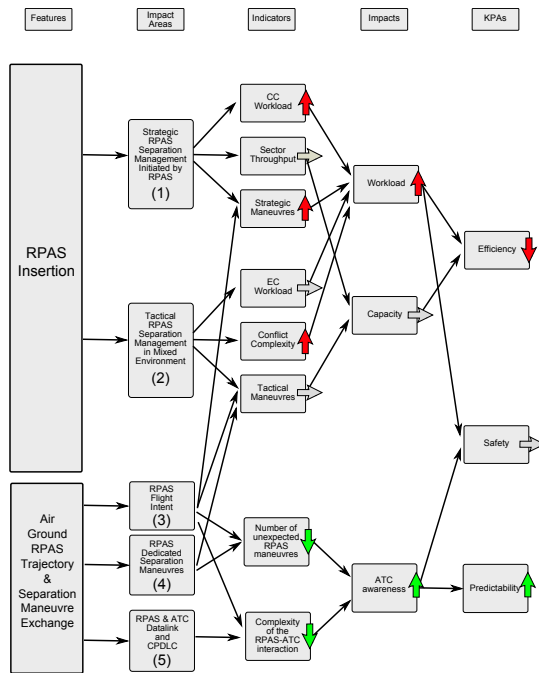
Figure 1. Benefit and impact mechanisms.

The way flight intent is interchanged is impacted (Ref. (3)). A single indicator has been used to analyse this impact. More detailed RPAS intent information will be interchanged and additional alternative intent will be interchanged once the RPAS required modifying its actual trajectory in order to comply with its mission requirements.

The way separation manoeuvres are performed is impacted (Ref. (4)). A single indicator has been used to analyse this impact. RPAS require different types of separation manoeuvres, both at strategic and tactical levels due to their performance limitations and dissimilarity, but also due to their inherent surveillance objectives.

The type and quantity of data-link interactions is impacted (Ref. (5)). A single indicator has been used to analyse this impact: Increased levels of data-link interactions are expected between RPAS and ATC in order to benefit the ATC situational awareness and to achieve the mission flexibility required by the RPAS to satisfy its mission objectives.

C. Choice of metrics and indicators

Table II introduces the metrics and indicators related to the different activities.

D. Exercise preparation

As we have stated in Section III, two different missions have been designed. A surveillance mission being performed by the MQ-9 Reaper and a ferry mission, which has been performed by the RQ-4A Global Hawk. Both of them will be described from the airspace and traffic configuration point of view.

- **Surveillance mission:** A slightly modified airspace configuration has been designed in order to better suit the simulated traffic flows. The Barcelona FIR airspace has

been divided in six sectors. A single sector has been created for the FIR airspace below FL150. The upper part has been divided into five areas. The northern half of the FIR has been partitioned into three sectors: LECBNW2, LECBNW1 and LECBNE. The first one manages all the northern arrivals two the main Balearic airports while the others manage main departure procedures. The upper southern half of the FIR is divided in two sectors, both of them managing departure and arrival procedures. Figure 2 shows a view of the implied sectors with the base RPAS trajectory as seen in the NEST analysis tool. The simulated traffic comprises all aircraft crossing the selected airspace during the RPAS mission time span.

- **Ferry mission:** For this specific mission, the RPAS flight plan crosses three different FIRs: LECB (Barcelona). LFMM (Marseille), LIRR (Rome). In order to maintain the consistency between both scenarios, the LECB airspace configuration used in the surveillance mission has been maintained. The en-route flight stage mainly occurs in LECB and LFMM and, therefore, the chosen sectors to simulate belong to this FIR. In order to maximize the number of hand-offs and coordination between both controllers and two maximize the time the RPAS is in an active sector the chosen sectors are LECBNE from Barcelona FIR and LFMMDD from Marseille FIR. Figure 3 shows a view of the implied sectors with the base RPAS trajectory as seen in the NEST analysis tool. As in the surveillance mission, the simulated traffic comprises all aircraft crossing the selected airspace during the RPAS mission time span.

V. SIMULATION EXERCISES RESULTS

This section summarizes the main results achieved during simulations, emphasizing both the RPAS and the ATC perspective. A list of recommendations to improve the analysis is also included for each one of the topics being analyzed.

A. Taskload and workload extracts

Figure 4 and Figure 5 show some of the CAPAN taskload [12] and ISA workload results captured for the MQ-9 simulations executed. The workload diagrams show the same type of structure. The vertical bars represent discrete values corresponding to the ISA input generated by the ATC at the time it was requested for a sample, which could be (VeryLow, Low, Fair, High, VeryHigh or NoData). The value NoData is recorded if the ATC does not respond in the proper timeframe. The time from the instant the ISA system queries the ATC, to the time he actually responds is shown in the continuous red line with samples centred in the ISA vars. The samples represent the time, in seconds, required by the ATC to respond. 30 seconds correspond to the upper bound the ATC has available to respond, thus all NoData samples have that time value. It will be easily observed that the higher the workload, the higher the time required by the ATC to respond.

Similarly, all taskload diagrams show the same structure. The blue line corresponds to the Number of Aircraft in the

TABLE II
METRICS AND INDICATORS AVAILABLE FOR STEP A.

Activity	Pre Simulation	During Scenario	Post Scenario	Post Simulation
Separation Scenario	Brief	Observer checklist (errors / discrepancies) ISA STCA ADS-B Recording RPAS Recording	Scenario Debrief CAPAN taskload Workload scale	Day debrief User acceptance
Baseline Scenario	Brief	Observer checklist (errors / discrepancies) ISA STCA ADS-B Recording	Scenario Debrief CAPAN taskload Workload scale	

Figure 2.   LECBNW2 and LECBNE sectors as seen in eDEP during the MQ-9 nomital trajectory.

sector, accounted at the exact instant of time that any aircraft enters or exits the sector. The yellow line corresponds to the % of time that the ATC controller is busy, as the result of adding up all the time effort for recorded events in a 30 minutes window. Taskload values are updated in the diagram at a rate of 1 minute. The taskload diagrams may also show separation events and STCA events.

- The separation events correspond to aircraft that get in the so-called 20 NM separation horizon (i.e. they get closer than 20 NM and at less than 1000 ft in vertical separation to other vehicles).
- STCA events correspond to aircraft which trajectory will put them in a collision course with a closest point less than the separation target, which has been set tp 3 NM in the horizontal plane and at that less than 1000 ft in vertical separation from other aircraft.

It is worth mentioning that, in some cases, the duration of the conflict may be less than 1 minute, thus leading to

consecutive samples that have the same value; even the zero value, as a conflict is detected and cleared in just a few seconds. Periods of time in which the RPAS was operating within the sector are indicated in semi-transparent grey areas. Note that in some cases the RPAS exits and re-enters the area . Table III summarizes both the taskload and workload results shown in the diagrams in the next subsections. For each simulation run the following elements are provided:

- Time Sector: refers to the total time in minutes during which the RPAS was operating within the sector under analysis. Baseline simulations do not show this value for obvious reasons.
- Conf RP and Conf AIL: refers to the separation conflicts between RPAS and airliners or only between airliners.
- Av CAP and Max CAP: refers to the average CAPAN taskload values during the period of analysis, and the maximum CAPAN factor observed (always as a % of available time).
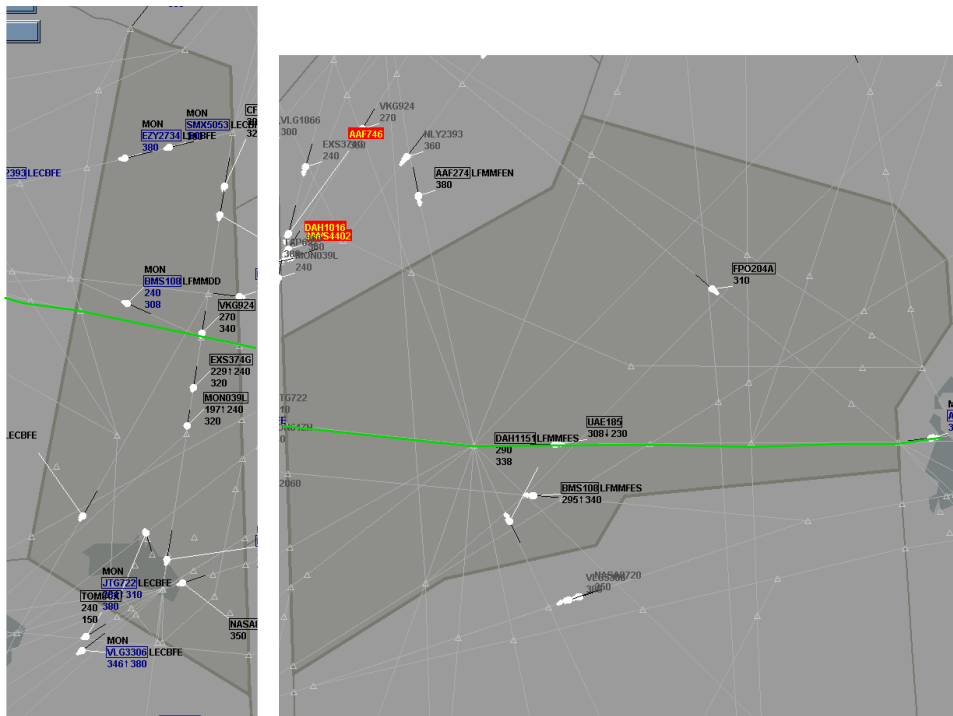
Figure 3. LECBNE and LFMMDD sectors as seen in eDEP during the RQ-4 nominal trajectory.

- **Av ISA, Act ISA** and **Sil ISA**: Average value of the ISA sample during the period under analysis (1-Very Low up to 5-Very High), number of total ISA samples, and number of sample cycles in which the controller did not respond within its assigned time-window.

RQ-4A taskload shows that the selected scenario does not include significant traffic. CAPAN levels are fairly low and the practical experience during simulation indicated that no major conflicts existed during that ferry operation. Thus, the RQ-4A ferry mission was partially disregarded and a major focus was placed on the MQ-9 mission.

The MQ-9 mission showed much more potential for separation conflicts. The analysis of the data shows a certain tendency in an increase of the CAPAN values (due to the additional RPAS activity), and also an increase in ISA samples, although no clear tendency can be concluded. Those variations are explained due to the rotation of the ATC controllers. Additional samples are required in order to extract better conclusions.

B. Mission, traffic overview and ATC procedures

From the RPAS perspective both the RQ-4A and MQ-9 missions have been created to a satisfactory level of realism. When designing further missions, it is considered that the selected design strategy keeps being valid. Departure and arrival procedures are properly executed and flight profiles are reasonably realistic.

The level of realism will be increased by improving the performance of the selected aircraft. Further steps will incorporate improved versions of both aircraft. Realistic performance data has been employed in order to improve the behaviour of the RQ-4A (MQ-9 will be in a near future). Once the RPAS models have been consolidated, a full performance analysis of both vehicles should be implemented to generate data that can be employed in a flight prediction tool; and to provide key performance figures to the ATC controllers.

From an operational point of view, difficulties have been encountered to establish a proper RPAS-ATC communication to request flight plan variations related to surveillance operations. Two different problems were identified when trying to define a proper dialog:

- **How to specify the area of operations?** ATC screens do not have proper tools to specify temporary mission areas, so controllers needed simple references, specified as a position and a radius around it. The natural process of specified the centre of the operation and the radios of the operation was not possible, as there was no way to communicate those items. Hence, in the end, the mission areas were larger than necessary, as the RPAS pilot needed to request clearances well in advance.
- **How to communicate that a mission operation was requested?** An agreement was reached about how the RPAS pilot should request a mission area by using the radio channel (no data-link was available for that process). The RPAS request should read something like *"[callsign] request mission area of radius XX"*.

The surveillance altitude is assumed to be the same than the RPAS was cleared at that very same instant of time. Only in case the request was granted, a new altitude may be requested by the RPAS following standard procedures.
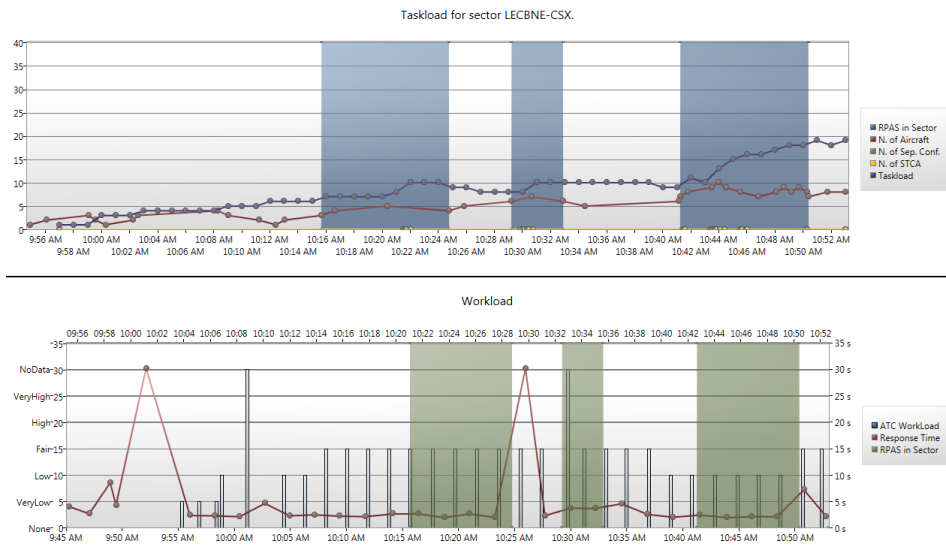
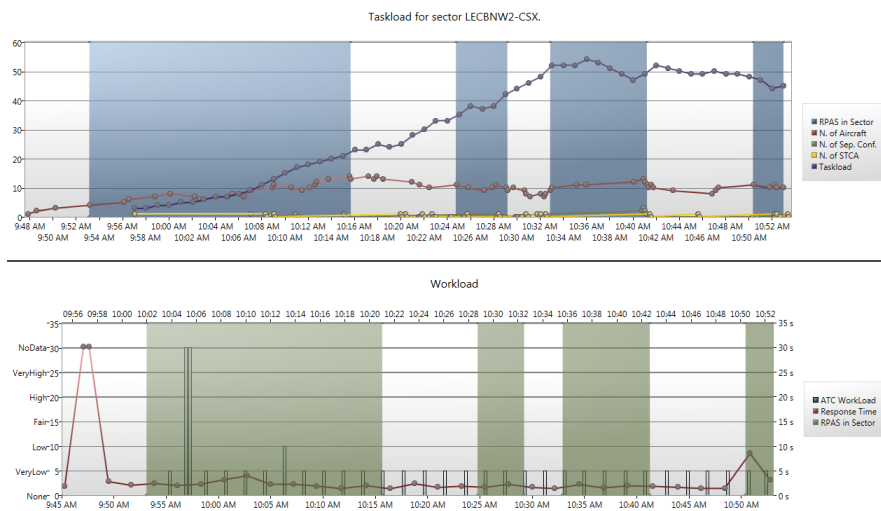Figure 4.   ISA / CAPAN load for exercise 20-03-2014-S1-ATC4 (LECBNE LELC-LELC).

Figure 5.   ISA / CAPAN load for exercise 20-03-2014-S1-ATC1 (LECBNW2 LELC-LELC).

An additional agreement was associated to any surveillance operation: before performing each one of the turns, that RPAS should notify the ATC to reconfirm the clearance to turn. Note that this agreement was implemented regardless the availability of flight intent information.

Temporary segregation like the ones explored in this research are intended to be porous to various level of density; that is, to allow traffic to cross the mission area under the ATC's criteria. As it can be seen either in figures 2 or 3, traffic can easily cross RPAS mission areas, although an obvious efficiency impact exists.

C. Representation and complexity of the scenarios

From the ATC point of view, the different types of exercises designed allowed to simulate different workloads. The type of traffic and the density could be adjusted in every exercise so that both the pilots and the ATCs could get used to the environment.

Regarding the traffic workload, it reflects a standard demand for an ordinary summer day. The arrival and departing traffic flows are complementary as can be suspected from a typical HUB operation. When the arrival flow of traffic is very dense, the departures are not, and vice versa. In the simulation, we have the same effect, when there were many arrivals to the Balearic Islands, there were not as many departures. In that case, sector LECBNE is under a light workload.

The simulated scenarios don't represent an excessive complexity regarding the managing of air traffic. The RPAS incorporation in the simulation lightly increased the complexity to the controller, due to the fact that its flight plan was well

TABLE III
TASKLOAD/WORKLOAD REVIEW FOR EACH MQ9 SIMULATION EXECUTION FOR EXERCISE.

			Sector LECBNW2								Sector LECBNE							
Date	S	RPAS	Time Sector	Conf RP	Conf AIL	Av CAP	Max CAP	Av ISA	Act ISA	Sil ISA	Time Sector	Conf RP	Conf AIL	Av CAP	Max CAP	Av ISA	Act ISA	Sil ISA
18-03-2014	S1	MQ-9 BASE	--	--	--	18	25	2.5	33	3	--	--	--	3.2	5	2.9	35	6
20-03-2014	S1	MQ-9	38.9	5	3	27.2	54	1	21	2	21.9	0	0	11.1	18	2.4	11	1
27-03-2014	S2	MQ-9 BASE	--	--	--	--	--	--	--	--	--	--	--	12.3	18	3	23	0
01-04-2014	S1	MQ-9	43.8	0	2	30.3	34	1.2	13	2	4.6	0	0	2.4	3	2.5	0	2
08-04-2014	S1	MQ-9	32.2	0	0	33	48	3.7	15	0	12.2	0	0	7.1	9	2.7	6	0
08-04-2014	S2	MQ-9	28.2	0	0	16.5	35	3.6	14	0	9.1	0	0	12	16	3	4	0
09-05-2014	S1	MQ-9	15.5	0	3	30.5	46	2.1	7	0	6.4	0	0	6.3	10	2	3	0

defined within clear boundaries. On the other hand, the RPAS increased the controller's workload. As a matter of fact, the number of ATC instructions was increased, and above all, the workload regarding the tactic planning required to prepare the descending traffic authorizations, was highly increased. Another aspect worth of mention, is the fact that the RPAS presence affects the efficiency of the civil aircraft operations. As an example: in many cases, the optimum descent for the airliners is not allowed when separation has to be provided with the RPAS.

From the RPAS PiC point of view, the levels of completion of both RPAS missions have been extremely high. The RQ-4A ferry mission has not encountered any interference. The MQ-9 surveillance mission has been also executed without almost restrictions from the ATC point of view. In fact, the level of interference is considered to be low, as almost all course changes and flight level variations were authorized.

Finally, indicate that the extension of the simulation period is considered too short to be able to reproduce the impact of extreme long duration RPAS missions. Strategies need to be identified in order to extend the duration of the operations.

D. Environment, tools, particular situations, etc

From the ATC point of view, eDEP is compliant with a real system. Some specific issues that can affect the simulation results such as the eDEP available tools, which differ from then ones used by the ATC in their work environment or the difference between the behavior of the pseudo-pilots and real aircraft pilots (in terms of phraseology, authorization negotiations, etc.) should be considered.

The conflict detection screen was sometimes useful in order to warn the controller of a possible conflict. In some occasions the alert was not real. Regarding the tool used by the ATCs in order to calculate the minimum distance in which two aircraft will cross each other, we considered it could be enhanced.

From the RPAS operator point of view, the simulation system performed satisfactory. All simulations behaved properly, and the link with surrounding tools, like eDEP and the ISA data logging subsystem also performed well.

A number of small improvements were detected such as the need to provide tools to identify the mission area, or to improve the way flight plans and intent is communicated via data-link to the ATC. Some of them were introduced during the simulation development, while others should be necessary to implement before starting further activities.

E. Intent design and use by the RPAS

During the simulations, the following information regarding the RPASs route was available under eDEP:

- RPAS presented and approved flight plan, with information regarding departure airport, arrival airport, route to the working area and a initial version of the planed work.
- Mission related intentions: RPAS operator, while flying, may transmit new information about the mission to the ATC via voice or data link. These new *intentions* will not be flown until the clearance is granted by the ATC.
- Cleared intentions: once the RPAS has received the ATC clearance, it can load the updated mission in the RPASs FMS and fly it. If the pilot wants to change the mission again, he should ask for clearance again.

In the first scenario used, only the initial flight plan was available, and the mission updating was not reflected in eDEP. The pilot transmitted via radio the *intentions* and, after receiving the clearance, started to fly the new route. The radio overload was high, and this solution is not considered appropriate in case of high-medium workload. Due to the fact that the controller didnt have the updated intention of the RPAS in the eDEP environment, ATC's blocked all the RPAS's used airspace area to the surrounding commercial flights.

In the second scenario, the pilot transmitted the *intentions* via radio, and after receiving the ATC clearance, introduced them in the FMS and flew them. In this case, the FMS loaded route was received in eDEP and was shown to the ATC. This allowed an operational improvement due to the fact that the separations between the RPAS and commercial traffic could be trimmed knowing where the RPAS was at all times.

In the third scenario, *intentions* could be visualized in eDEP before being cleared by ATC. This functionality allows a
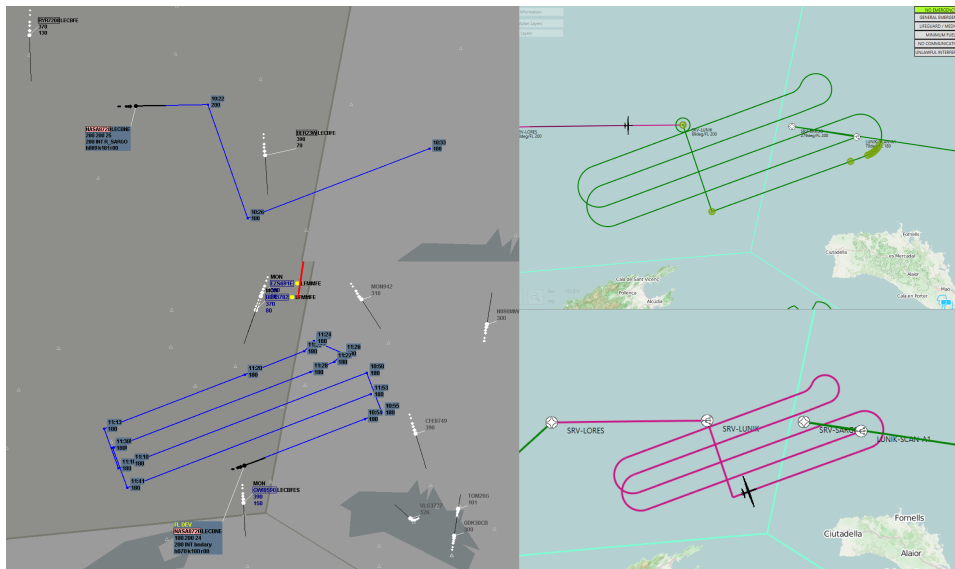
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Figure 6. RPAS flight plan versus its immediate intend when performing unplanned surveillance.

significant reduction in communications when asking for a clearance for the mission. On top of this, the controller was able to visualize the loaded route in the RPAS's FMS. As in the second scenario, this functionality allows a more efficient use of the airspace.

RPAS flight intent has shown itself as a highly valuable mechanism to facilitate the integration of RPAS in non-segregated airspace. During the ferry RQ-4A mission, flight intent reconfirmed an uneventful operation, without any separation issue and limited amount of impact with surrounding aircrafts. During the MQ-9 surveillance mission the benefits were much higher, especially in those periods of time in which the RPAS needed to divert its initial flight plan to perform scan-area or scan-point operations. Flight intent permitted the RPAS a more clear communication of its intentions, thus letting the ATC controller to provide a higher level of porosity of the temporary restricted area. Given that porosity, other traffic could cross the surveillance area (at different flight levels). Once better experience and tuning of the intent mechanism is in place, it is expected that the negative impact of the RPAS operation can be further minimized.

Even though flight intent provides clear indications that it is the way to go in terms of RPAS integration, a number of elements need to be evaluated and consolidated before further evaluations can be performed.

First, clarify the full concept of operation behind the usage of flight intent. In particular a clear differentiation is necessary to understand the role of the filled flight plan, and how flight intent is a valid mechanism to negotiate flight plan modifications, both permanent and temporary; but also to keep track of the RPAS trajectory while a temporary flight plan change is being executed.

Second, identify how each type of flight intent should be implemented in order to maximize the benefit to the ATC. In particular there is a large difference between immediate

flight intent information and flight intent designed to negotiate trajectory changes (see Figure 6 to see flight intents with different levels of detail and extension in time). Immediate flight intent should be provided to cover a short time horizon (5-10 minutes maximum), avoiding cluttering the ATC screen with too much detail. Figure 6 (top part) shows an example of that type of flight intent. Given the low speed of most RPAS vehicles, the selected 5-10 min time window will mostly cover one or two trajectory changes (as seen in the image).

Flight intent designed for trajectory negotiation may need to cover wider portions of the flight operation, so that the ATC can properly understand the mid- and long-term implications of the trajectory change. Figure 6 (bottom part) depicts an example of such type of intent. In the image the full scan area operation is visualized, together with flight time estimations. The ATC may use that information to take a strategic decision with solid intent data that covers potential interactions with multiple aircrafts covering that surveillance area.

VI. CONCLUSION

The RPAS integration into shared airspace is a challenge from several perspectives. On one hand, providing continual separation between all aircraft is a critical requirement for the integration. On the other hand, more particular aspects of RPAS such as common contingency or lost-link management have to be addressed. ERAINT project is tackling these issues. Initially, the RPAS-ATM relationship in terms of separation management has been addressed by means of several real-time simulations using different available surveillance and communication technologies. As a result of the simulations a number of conclusions can be extracted. First, mission traffic and ATC procedures are realistic enough, both from the ATC and RPAS perspectives. Second, regarding the complexity of the scenarios, it reflected a standard demand that did not represent an excessive complexity. Finally, the simulation environment

and the used tools are also realistic and useful, in particular the RPAS flight intent, even though the way the intent information is presented in the ATC screen can be improved. Simulation results have also provided some recommendations that would be addressed in the reminder of the project. For example, to extend the preliminary analysis of traffic in order to identify specific aircraft that may enter in separation conflict with the RPAS. Then, time the RPAS mission so that the conflict potentially occurs. Another recommendation would be to improve the ADS-C flight intent communication mechanism to include in a consistent way the differences between requested intent and flown intent. Further experiments need to be developed in order to analyze the impact of the RPAS integration to the flight efficiency of surrounding traffic.

REFERENCES

[1] P. Brooker, "Air traffic control separation minima: Part 2 - transition to a trajectory-based system," *The Journal of Navigation*, vol. 64, pp. 673–693, 2011.

[2] J. Kuchar and L. C. Yang, "A review of conflict detection and resolution modeling methods," *IEEE Transactions on Intelligent Transportation Systems*, vol. 1, no. 4, pp. 179–189, Dec 2000.

[3] S. SJU, "European ATM Master Plan Edition 2 - The Roadmap for Sustainable Air Traffic Management," SESAR, Tech. Rep., October 2012.

[4] ERSG, "Roadmap for the integration of civil remotely piloted aircraft systems into the european aviation system," SESAR, Tech. Rep., 2013.

[5] RTCA, "Do-242a: Minimum aviation system performance standards for automatic dependent surveillance broadcast (ads-b)," Radio Technical Commission for Aeronautics, Technical report, 2002.

[6] EUROCONTROL, "EUROCONTROL Specification for Short Term Conflict Alert Edition," EURCONTROL, Tech. Rep., May 2009.

[7] Eurocontrol, "Review of asas applications studied in europe," CARE/ASAS Action. CARE/ASAS Activity 4, Technical report, Feb 2002, available at: http://www.eurocontrol.int/care-asas/gallery/content/public/docs/act4/care-asas-a4-02-037.pdf.

[8] G. Bartkiewicz, "Enhancement of airborne conflict prediction times through automatic dependent surveillance-broadcast (ADS-B) transmitted trajectory intent information," in *Proceedings of the 20th Conference on Digital Avionics Systems (DASC)*, vol. 2. AIAA, oct 2001, pp. 7B1/1 –7B1/11.

[9] K. Dalamagkidis, K. P. Valavanis, and L. A. Piegl, *On integrating unmanned aircraft systems into the national airspace system: issues, challenges, operational restrictions, certification and recommendations*, ser. International series on intelligent systems, control, and automation: science and engineering, S. G. Tzafestas, Ed. Springer-Verlag, 2009, vol. 26.

[10] Eurocontrol, *DDR2 Reference Manual 1.0.1*, 2013. [Online]. Available: http://www.eurocontrol.int/services/ddr2

[11] P. Royo, C. Barrado, and E. Pastor, "ISIS+: a software-in-the-loop UAS simulator for non-segregated airspace," *Journal of aerospace computing, information, and communication*, In press.

[12] Eurocontrol, *CAPAN: ATC Capacity Analyser*, 2013. [Online]. Available: http://www.eurocontrol.int/services/ddr2