

Real-time Simulations to Evaluate RPAS Contingencies in Shared Airspace

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Abstract—This paper presents the work done within the second year of 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 the first is being operated in shared airspace. This interaction will be evaluated from three different perspectives. First, the separation management its results were profusely described in [1]. Secondly, the contingency management, also including loss link situations, its results are presented in this paper. Finally, the impact of the dynamic mission changes on the overall ATM system will be investigated over the rest of the year.

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 ATCo and to evaluate several support tools and different RPAS levels of automation from the PiC and ATCo sides. Preliminary results and the usefulness of the support tools are presented for each selected concept of operations.

I. INTRODUCTION

Air Traffic Management (ATM) performance will be affected by the technology evolution of Remotely Controlled Aircraft Systems (RPAS) regarding to their upcoming military and civil applications (see for instance [2], [3]). At present, majority of flights correspond to manned commercial aviation dealing with person and/or goods point-to-point transportation. On the contrary, the majority of RPAS flights may significantly differ from this paradigm. Most common RPAS mission will be surveillance [3], requiring flexible and uncertain flight plans executed by computers with the remote supervision of the RPAS Pilot-in-Command (PiC). It is true that nowadays there exists some general aviation manned aircraft performing this type of missions (see [4], [5] for examples regarding the used flight paths) but their operation is a minority and it is always a man-directed process with little direct control from computers. Point-to-point ferry flights are also foreseen at some point in the future (see for example [6]) thus placing a larger pressure into the ATM system.

Since the goal of future ATM system is to enhance its performance in terms of environment, capacity, efficiency, safety and security [7] through ambitious programmes like NextGen in USA or SESAR in Europe, it is necessary to integrate RPAS into the ATM system. Nevertheless, this poses

a risk to the ATM performance enhancement. A number of actions are currently on-going trying to move this issue forward; on the US side, NASA is leading those actions through the *Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS)* project the objective of which is to provide research findings to reduce technical barriers associated with integrating UAS¹ onto the NAS utilizing integrated system level tests in a relevant environment [8]. These barriers include: a lack of sense-and-avoid concepts and technologies that can operate within the NAS, robust communication technologies, robust human systems integration, and standardized safety and certification guidelines; on the European side, integration actions are conducted by the European RPAS Steering Group (ERSG) which have recently published the *Roadmap for the Integration of Remotely-Piloted Aircraft Systems into the European Navigation System* [9]. This Roadmap reflects the RPAS integration from not only a regulatory, research & development, but also from a social & liability perspective. It defines high level operational requirements that RPAS integration shall fulfil; identifies research gaps that shall be addressed, and; proposes a timeline for the research activities and milestones.

Under EUROCONTROL's and Federal Aviation Authority's (FAA) philosophy RPAS should not affect ATM operations and should comply performance levels required by SESAR or NextGen [10], [11]. Hence, operation should be shaped to large extends to guarantee its safe and efficient interaction with the ATM system.

While extensive research is being devoted to address some research gaps identified in the Roadmap, for example, developing collision avoidance systems (see [12] 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 problem. Moreover, emergency and lost link situations have not been tackled yet by the research community. Furthermore, at present, no assessment or methodology exists that deals with the necessity to coordinate RPAS almost automatic operations (but monitored by the PiCs) with all other ATM actors under nominal and emergency operations.

Several projects and initiatives have tackled the integration

¹The term UAS is more general than RPAS but will all be assumed to be the same for the purpose of this research.

issue from different points of view. The *UAV safety Issues for Civil Operation (USICO)* initiative, funded by UAVNET in 2001, aims at studying issues pertaining to UAV operators in civil airspace. USICO has compiled an analysis of commercial missions for RPAS; the *INnovative Operational UAV integration (INOUI, 2007-2009)* provides a roadmap for the future of the RPAS context of ever changing ATM environment. Furthermore, INOUI aims at complementing the SESAR activities with regard the operational context and the architecture. The communication issue has been deeply tackled in the *Demonstration Satellites enabling the Insertion of RPAS in Europe (DeSIRE)* demonstration project which is a joint ESA-EDA initiative aimed at demonstrating the safe integration of RPAS in non-segregated airspace using satellites capabilities for the RPAS communication requirements in order to satisfy the needs of potential user communities. Finally, the most related initiative that directly tackles the RPAS contingency procedures is the WASLA-HALE project driven by DLR [13]. This research addressed standard and emergency procedures for RPAS on the basis of an RPAS should behave like a manned civil aircraft and paying particular attention on lost link contingency. They validated this procedures by means of both real-time simulations and real flight trials.

The WP-E project *Evaluation of the RPAS-ATM Interaction in Non-Segregated Airspace (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 Operations (ConOps) for both RPAS and the Air Traffic Controller (ATCo) that may control them. The RPAS 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 validation trials and preliminary results) that has been done during the second 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 project and its organization. Section III details the objectives pursued within the second year. Sections IV and Section V define the simulation exercises that have been performed and present the preliminary derived results, respectively. Finally, Section VI concludes the paper and outlines some future work.

II. ERAINT PROJECT SCOPE

On the top of regulatory framework, civil RPAS integration in non-segregated Instrumental Flight Rules (IFR) airspace will only be permitted once they will comply with performance levels required by SESAR [14]. 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*

[9], 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 the 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 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 of radical changes in the RPAS filled flight plan on the ATC. 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:** Separation provision in TMA and en-route environments. In this step the impact of the poorer RPAS flight performance (in comparison to airliners) and latency on the separation provision will be measured, in terms of workload and safety and flight efficiency.
- **Step B:** Analysis of the impact of RPAS contingencies on the ATC. The main aim of this stage is to determine the feasibility of managing a contingency that comes from an RPAS from the ATC point of view.
- **Step C:** Analysis of the impact of radical RPAS Reference Business Trajectory (RBT) modifications on the ATC.

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 Automatic Dependent Surveillance - Broadcast/Contract (ADS-B/ADS-C) [15] and data link technology to improve the situational awareness around the RPAS-ATC interaction, and therefore reduce the negative impact of RPAS integration in non-segregated airspace.

In the second year Step B has been fully addressed and delivered. This paper will summarize what has been done, paying particular attention on both simulation trials and preliminary results.

III. STEP B: CONTINGENCY MANAGEMENT

A. Context of validation

Civil aviation authorities define sets of procedures and standardized practices that should be followed to operate different types of aircraft safely, efficiently and regularly. The criteria for safe operating practice is found in the International Civil Aviation Organization (ICAO) Annex 6, Part 1 [16] for commercial air transport operators. In these standards and recommended practices, one can find, for instance, what kind of information an operator shall provide to flight crews as well as what the responsibilities and duties of the PiC are before, during and after a flight.

To guarantee the operation safety requirements, a flight dispatching process is carried out in coordination with the PiC and the flight dispatching officer. During this flight operation, it must be verified that the airplane is airworthy; the instruments and equipment for the flight are installed and are sufficient; maintenance is up to date; the weight and balance of the aircraft are well within the the safety margins; any load carried is properly distributed and safely secured; a check has been completed indicating that the operating limitations can be respected for the whole flight; and the operational flight planning standards have been complied with. In addition to these typical dispatching tasks, specific RPAS dispatching tasks must also be performed. RPAS dispatching requires taking into account; the RPAS mission (its objectives, payload requirements, operation, flight plan, etc.), and; the RPAS airframe (its performance, systems required for managing the flight and the mission, available payload bays, fuel, and electrical architecture), the RPAS payload (its required sensors and other payload, etc.).

In addition to flight dispatching in nominal conditions, planning for contingencies is also required. Analysis of the potential contingency situations and planning the correct reaction is a critical task that must be carried out by every airplane to guarantee its safe operation. The pilot's reactions to events that may occur in flight, such a engine malfunctions, loss of electrical power, hydraulic failure, and unexpected weather are critical and will determine the fate of the flight should such circumstances arise. Contingency reactions are mainly driven by regulations; the airplane manufacturer and aircraft operator, with preanalyzed contingency scenarios and reactions covered in the airplane flight manual and operating manual, respectively; and finally, by the aircraft crew's capability and promptly react to contingency. Pilots and copilots practice in simulators to refresh and improve their reactions to such situations. However, managing contingencies on an RPAS is a much more complex problem for three reasons:

- 1) The automated nature of the vehicle may prevent direct operation by the PiC. Some remotely operated configuration changes may be necessary to achieve the desired state modification.
- 2) Remote operation adds additional communication latency.

- 3) Reduce situational awareness may prevent the PiC taking the right decisions in time.

It is well known from the short history of RPAS accidents that many of them are directly attributable to PiC errors when trying to manage an unexpected contingency without an adequate situation awareness [17]. The well known crash in 2006 of the Customs and Border Patrol MQ-9 Predator B on a nighttime border patrol highlights the importance of pilot training and of adequate support for safe contingency reactions [18], [19], [20].

One of the major problems that pilot face is the identification of feasible emergency trajectories that allow the safe landing of a crippled aircraft, ranging from the total loss of thrust to limited maneuverability from control surface jams or structural damage. Previous work by Atkins et al [21], Tang et al. [22] and Atkins [23] addressed the development of search-based trajectory optimization algorithms to identify feasible emergency landing paths in real time. Following similar objectives, Chen et al. [24] have developed pilot interfaces to facilitate the decision making. Directly related to the aforementioned automation effort is the evaluation of pilot's performance when using emergency trajectory planning tools, as in Prichett and Ockerman [25], Chen and Pritchett [24] and Watts et al. [26].

The validation focuses on the management of RPAS contingencies and analyses the case where a contingency occurs to an RPAS. We evaluate two different contingency types: 1) an engine failure in which the RPAS will glide until arriving at the preplanned alternative airport and 2) a command and control communication failure (without affecting its airworthiness) where the RPAS will proceed according to the original flight plan to the main destination airport. Two different RPAS types will be used; a High Altitude Long Endurance (HALE) RPAS-type, the Northrop Grumman RQ-4A Global Hawk; and a Medium Altitude Long Endurance (MALE) RPAS-type, the General Atomics MQ-9 Reaper. Different requirements will be analyzed in terms of equipment and roles for the ATC and RPAS pilot.

Two different missions have been designed to address this validation; a surveillance mission situated south of Iceland but departing from Germany and thus implying to fly over the high traffic density area in the central Europe and; a FRONTEX mission surrounding the Spanish Balearic islands. The first mission has been performed with the HALE RQ-4A and the latter with the MALE MQ-9.

B. Validation overview

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

The RPAS operated in a mixed-mode simulation environment called RAISE, in which a coarse-level simulated Instrumental Flight Rules (IFR) traffic (provided by eDEP simulator) was mixed 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 a fast-time analysis tool (NEST) 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 en-route 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:

1) *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 [27], 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.

2) *Scenario 2. Engine failure, no data-link, 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 suffer an engine failure that requires immediate recovery procedures if a crash should be avoided. Only transponder and basic ADS-B data will be made available to the ATC, and the exact trajectory that the RPAS will fly it is unknown to the ATC.

3) *Scenario 3. Engine failure, 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-B basic data, the RPAS will be assumed to operate flight-intent capabilities; that is, being able to provide detailed intentions and request an alternative trajectory to the ATC through a data link infrastructure. VHF and/or satellite-relay voice communications will be the primary mode of communications from the ATC to the RPAS pilot. RPAS to ATC is complemented by means of the flight intent information.

Again, the RPAS will be assumed to suffer an engine failure that requires immediate recovery procedures if a crash should be avoided. The RPAS will act pro-active providing flight intent and exploiting other data-link capabilities along the whole contingency management.

4) *Scenario 4. Lost-link, no data-link, 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 suffer a communication failure with the PiC (although the FMS and ADS-B remains fully operative) that requires a non-urgent recovery procedure to avoid extensive negative impact

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-B/C	RTF
Scenario 4	PSR / SSR	RTF
Scenario 5	PSR / SSR / ADS-B/C	RTF

over the ATM system. Only transponder and basic ADS-B data will be made available to the ATC, and the exact trajectory that the RPAS will fly will be known to the ATC through the agreed recovery routes (equivalent to the radio loss in manned aviation).

Alternative ground voice communications will be the primary mode of communications between the RPAS pilot and the ATC. Communication during the lost-link contingency.

5) *Scenario 5. Lost-link, no data-link, 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 suffer a communication failure with the PiC (although the FMS and ADS-B remains fully operative) that requires a non-urgent recovery procedure to avoid extensive negative impact over the ATM system.

On top ADS-B basic data, the RPAS will be assumed to operate flight-intent capabilities; that is, being able to provide detailed intentions and request an alternative trajectory to the ATC through a data link infrastructure. All flight intent and/or data-link communication will be generated autonomously while the RPAS is in the lost-link situation.

Alternative ground voice communications will be the primary mode of communications between the RPAS pilot and the ATC.

IV. SIMULATION EXERCISES DEFINITION

A. Expected benefits/outcomes

These simulation exercises have been all executed in the RAISE simulation infrastructure [28]. A limited number of ATC and pseudopilots were integrated. The following list summarizes the performance expectations per relevant stakeholder:

- **Controllers:** Asses the viability of the RPAS integration regarding its contingency management; asses which data should be exchanged between the RPAS and ATC are necessary and sufficient to meet the needs of the concept, and; asses that no negative impact is derived from the use of new CWP/HMI.
- **Research:** Validate the relevance of the RPAS-ATC simulation environment; understand up to which level the RPAS can be a pro-active vehicle when facing a contingency; validate if the pre-planning contingency concept is effective, and; validate which types of contingency procedures are best suited for RPAS.
- **SJU:** 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 non-segregated airspace once the operational and technological elements envisaged by ERAINT are in place. Note that the analysis refers to the validation objectives addressed in the Step B of the experimental validation (complemented by the concepts already introduced in Step-A [1]).

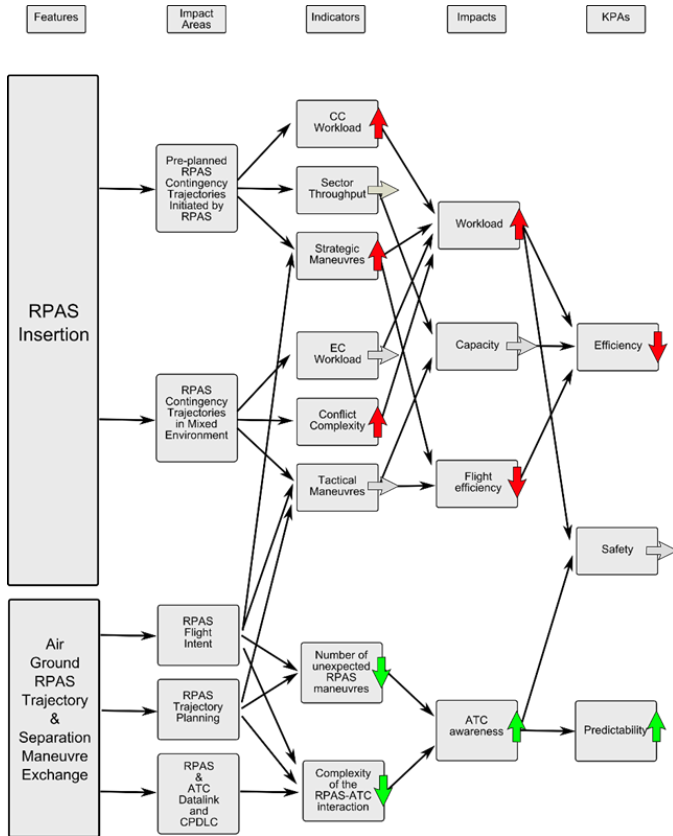


Fig. 1. Benefit and impact mechanisms.

Four main features are part of the Step-B ERAINT scope; the ATM disruption caused by the RPAS insertion in normal ATM operations; the ATM disruption caused by the RPAS insertion in contingency operations; the introduction of ADS-B, datalink capabilities, and; the amount of mission pre-planning required to properly cope with contingency scenarios.

The RPAS impacts five areas form the integration point of view.

1) *The strategic planning is impacted:* Three indicators are used to analyze it; the Coordination Controller (CC) workload is expected to increase since this controller may need to plan the RPAS trajectories in order to avoid tactical RPAS conflicts due to the contingency operation; the sector throughput is expected to moderately decrease its levels due to the disruption caused by the RPAS contingency, the potential increase in situational awareness about the RPAS intentions, and the higher levels of operational pre-planning to cover contingency scenarios, and; the number of strategic maneuvers is expected to globally increase since it is the main separation mechanism

to be employed, trying to minimize tactical maneuvers and the extension of both nominal and contingency operation may be much longer to mission duration.

2) *The tactical planning is impacted:* Three indicators will be used to analyse this impact; the complexity of each tactical conflict will increase mostly affecting airliners, as the RPAS will not maneuver during neither contingency; the number of tactical maneuvers is expected to globally be maintained because most of the RPAS conflicts will be addressed strategically, and; the executive controller (EC) workload is expected to be increased because the number of conflicts may increase.

3) *The way flight intent is interchanged is impacted:* More detailed RPAS intent information will be interchanged so that RPAS deconfliction could be implemented from a strategic point of view rather than tactically.

4) *The way separation manoeuvres are performed is impacted:* RPAS are assumed not to maneuver, in case of engine failure for performance limitation issues, and during lost link to avoid the uncertainty produced due to an RPAS performing autonomous separation maneuvers.

5) *The type and quantity of data-link interactions is impacted:* 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. Even in case of lost link contingencies, datalink should contribute positively to the ATC awareness.

C. Choice of metrics and indicators

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

TABLE II
METRICS AND INDICATORS AVAILABLE FOR STEP A.

Scenario ID	Pre Exe.	During Scenario	Post Scenario	Post Exe.
2-5	Brief	Observer checklist (errors / discrepancies) ISA STCA ADS-B Recording RPAS Recording	Debrief CAPAN Workload scale	Day debrief User acceptance
1	Brief	Observer checklist (errors / discrepancies) ISA STCA ADS-B Recording	Debrief CAPAN Workload scale	

D. Exercise preparation

As we have stated in Section III, two different missions have been designed.

1) *RQ-4A volcano surveillance mission:* This mission starts from a Hamburg Finkenwerder airport (EDHI) flying north to Iceland and the back to the same original airport (EDHI), crossing multiple portions of non-segregated airspace over Germany, Denmark and the North Sea. Surveillance will occur only one over the Iceland area, thus only departure and arrival portions of the flight are considered during the evaluation.

The selected airspace is situated in central Europe, within Germany and Denmark airspace. Two different FIRs are involved: the Danish Koebenhavn FIR/UIR (EKDK) and the German Hannover FIR/UIR (EDDY). The period of time during which the simulation will be running specifies the sector configuration for each airspace. Koebenhavn uses the configuration E3BW2, which divides the overall airspace into 6 sectors. We selected the southernmost sector (EKDKCUC) to be one of the active sectors in the simulation. From the vertical point of view, EKDKCUC starts from FL285 upwards. This sector is contiguous to EDDYHOL, the northernmost German sector of the Hannover UIR when the selected airspace configuration is CNF5.1. Note that, even though this sector is include within the German airspace, it is controlled from the Maastricht Upper Airspace Control (MUAC) centre. Hence, the selected configuration affects to the airspace of the MUAC area (the Belgian, Dutch, Luxembourg and part of the German airspace). From the vertical point of view, EDDYHOL starts from FL245 upwards. These two active sectors will be fed by the contiguous ones encompassing not only sectors from EKDK and EDDY FIR/UIR but also the southernmost ones from the Swedish airspace and a number of TMA sectors covering the lower airspace below EDDYHOL (see Figure 2) and EKDKCUC.

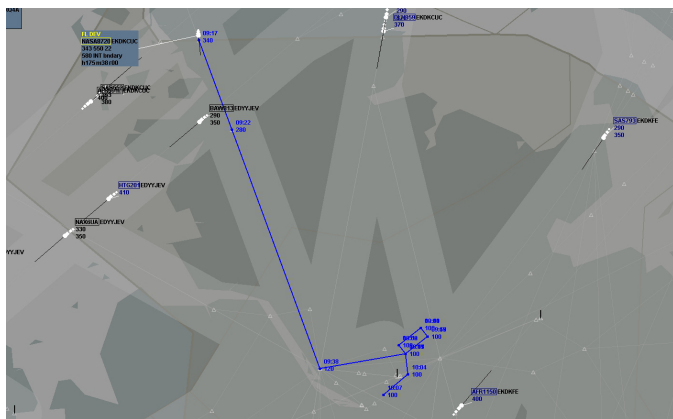


Fig. 2. Part of EDDYHOL sector as seen in eDEP during the exercise with the RPAS contingency flight intent also depicted.

2) *MQ-9 operation*: This is a point to point trajectory from the San Javier airport (LELC) to a selected surveillance-based mission area. The mission area is in full non-segregation airspace, although standard airways/fixpoints are not employed. After mission completion, a similar return to the airport of origin through standard routes. Surveillance will occur within non-segregated airspace over the Mediterranean Sea around the Balearic Islands. In particular the RPAS will loiter north and south of the Balearic Islands, well within their TMA area, simulating a potential FRONTEX and/or ship detection/identification mission.

A slightly modified airspace configuration has been designed in order to better suit the simulated traffic flows. The Barcelona FIR/UIR 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. The southern half of Barcelona FIR/UIR has been divided into two sectors (LECBSW and LECBSE) both managing departure and arrival traffic.

We selected LECBNW2 and LECBNE (see Figures 3 and 4) as active sectors and they will be fed by the rest of the sectors of Barcelona FIR/UIR; from the north by the southernmost sectors of Marseille (LFMM) and Bordeaux (LFBB) FIR/UIR; and from the west by the easternmost sectors of Marseille (LFMM) FIR/UIR.

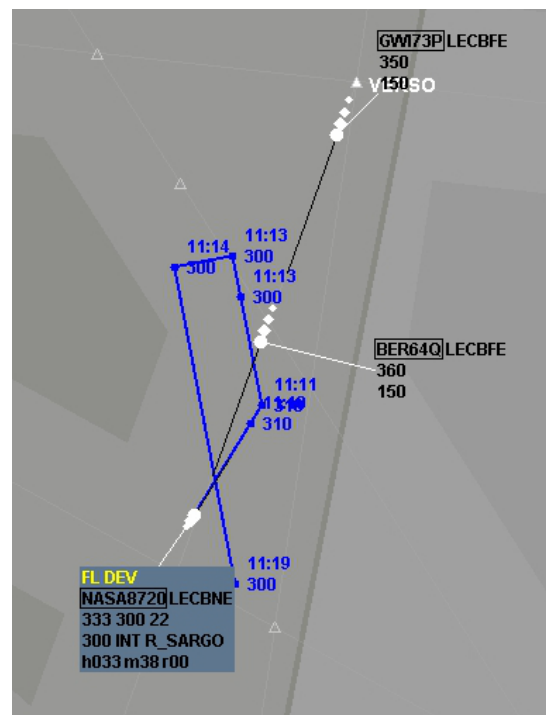


Fig. 3. Part of LECBNW2 sector as seen in eDEP during the exercise with nominal mission flight intent also depicted.

V. SIMULATION EXERCISES PRELIMINARY RESULTS

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

A. Viability of the contingency operation

The flight experiments executed during the Step-B of the ERAINT project has demonstrated that the development of contingency RPAS operation is viable and resulting into limited ATC workload impact. Independently of the type of contingency, engine failure or failure of the command and

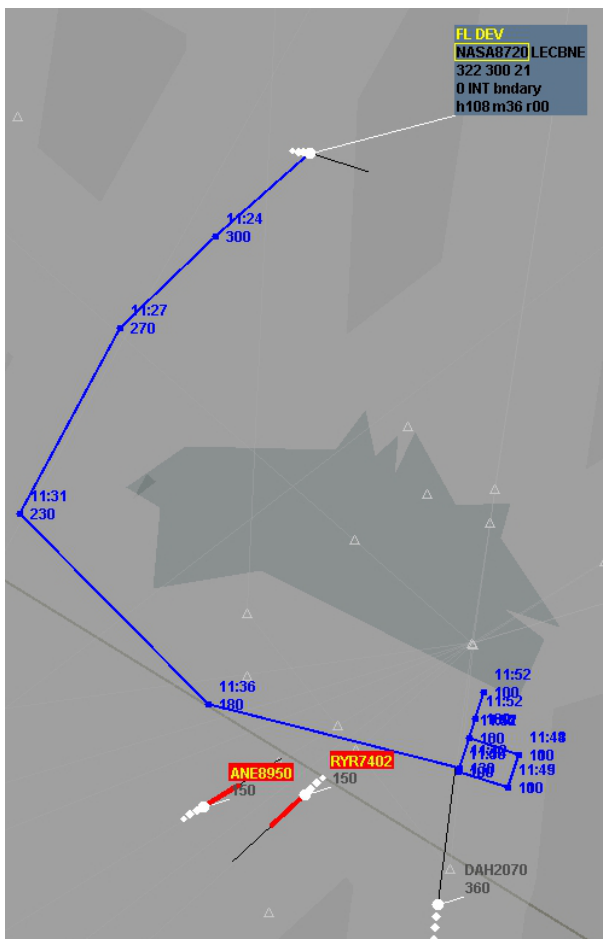


Fig. 4. Part of LECBNE sector as seen in eDEP during the exercise.

control link, the proposed concept of operation, directly linked to a well pre-planned contingency operation, are the key factors that maintain a good ATC awareness level.

It is obvious that any aircraft contingency will induce a significant ATC workload and certain penalty on the flight efficiency of surrounding traffic. Moreover, it is impossible to compare the impact of an RPAS contingency with an airliner contingency. Both the subjective and objective workload and taskload metrics clearly indicate that the impact on the ATC is well within reasonable ranges.

Coupled or chained contingencies will require further investigation, especially when a general contingency follows a loss of the command and control link, or when that command and control failure occurs directly coupled with other contingencies.

B. RPAS Flight Intent Availability

Simulations demonstrated that flight intent is a key technology enabler for contingency management. Moreover, simulations resulted on a initial concept of operations for flight intent. The flight information being visualized by means of flight intent depends on the contingency level of the RPAS. When the RPAS is not suffering any contingency at all, flight intent

is only used for tactical purposes thus limiting the amount of 4-D points being displayed in the ATC screen to those being flown within the next 10 minutes (see Figure 3). If no waypoints are planned to be flown in the next 10 minutes the immediately after waypoint is always displayed. Moreover, a fictitious waypoint two minutes ahead from the RPAS current position is also depicted. The reason why the flight intent is limited in time is to avoid to display too much (and useless) information in the ATC screen.

When a contingency issue arises, the RPAS flight intent data being shared is adapted to the type of contingency itself. In case of an engine failure contingency, in which the aircraft will leave the planned route to fly an emergency flight plan to the previously agreed alternative airport, the whole emergency flight plan will be depicted in the ATC screen (see Figure 2). This will increase the situational awareness of the ATC especially with regard to the vertical glide profile as the ATC will know the altitude of the RPAS in every waypoint of the emergency flight plan. The fictitious two minutes ahead waypoint will also be displayed for tactical separation purposes.

On the other hand, when a loss of communication link failure arises, the aircraft flight capabilities are not affected and will continue to fly its nominal flight plan. In this case, the flight intent will be used to visualize the whole planned route until the Initial Approach Fix (IAF) where the aircraft will perform a holding procedure during 30 minutes (see Figure 4). The flight intent will also be used to indicate the ATC when the RPAS will leave the last issued command to resume the nominal flight plan (recall that, in civil aviation, airliners shall maintain the last issued command during seven minutes before resuming the nominal flight plan when facing a radio communication failure). This will also increase the situational awareness of the ATC as the altitude and time of overfly will be both know for each waypoint in the flight plan. When the RPAS will be about to start the final approach by leaving the holding procedure, the flight intent depicted in the ATC screen will show the final approach procedure. In any case, the fictitious two minutes ahead waypoint will also be displayed for tactical separation purposes. Moreover, other fictitious waypoints are added when to indicate flight level changes (e.g. to indicate top of climb/descent) in order to provide the ATC with a more complete vertical profile information.

C. RPAS Contingency ConOps

In addition to aircraft mission planning for nominal conditions, planning for contingencies will be a central part of the RPAS mission design process. Analysis of the potential contingency situations and planning the correct reaction is a critical task which must be carried out by every airplane to guarantee its safe operation. The pilot's reactions to events that may occur in-flight, such as engine malfunctions, loss of electrical power, hydraulic failure, and unexpected weather, are critical and will determine the fate of the flight should such circumstances arise.

RPAS contingency procedures should be similar to those of manned aircraft and have to provide an adequate level of safety and predictability. In controlled airspace, the ATC has to be aware of any contingency affecting the RPAS. Furthermore, any expected manoeuvres, either pre-programmed or to be executed by the remote pilot, must be coordinated in advance with ATC. The design of these manoeuvres has to ensure that safety levels are not affected. In particular, RPAS operations must not suppose an additional risk to other airspace users or people on the ground. As a general principle, flight time of an RPAS experiencing a contingency must be reduced to a minimum.

Contingency reactions will be mainly driven by regulations; the airplane manufacturer and aircraft operator, with pre-analysed contingency scenarios and reactions covered in the airplane flight manual and operating manual respectively. However, managing contingencies on a RPAS is a much more complex problem due to three reasons:

- 1) The automated nature of the vehicle may prevent direct operation by the PiC. Some remotely operated configuration changes may be necessary in order to achieve the desired state modification.
- 2) Remote operation adds additional communication latency.
- 3) Reduced situational awareness may prevent the PiC taking the right decisions in time.

The preliminary elements that should define the high-level operational concept to manage RPAS contingencies is proposed as an experimental concept of operation that will require further investigation. The concept of operation will be divided, at least, in three separate areas:

- 1) The airport selection for each type of situation,
- 2) The contingency trajectory to be followed according to the type of contingency and location of the aircraft,
- 3) The RPAS pilot ATC dialogue along the operation, before, at the time of and during the contingency; including how data-link can be exploited to contribute to the situational awareness of the ATC.

D. RPAS 4D Trajectory Prediction

Nowadays, the majority of aircraft trajectory predictions for ATM purposes are based on the Base of Aircraft Data (BADA). Therefore, the integration of RPAS into non segregated airspace must involve the creation of BADA-based APM for RPAS.

A number of issues arises when trying to create those models; first, unlike commercial airliners, no one really knows exactly the flight performances of future RPAS that will populate our skies thus hindering the development of accurate APM. To make matters worse, the information on performance of currently flying RPAS is not flowing smoothly; second and even worse, it is not clear if BADA family 3 APM will provide accurate trajectory prediction of RPAS because of the model itself was not intended to model aircraft with such dissimilar flight performances. This issue is particularly evident when

trying to predict the descent phase of an RPAS and even worse in the case of an engine failure. Nevertheless, the latter issue may be solved if RPAS are modelled using BADA family 4 which provides more flexibility when creating APM.

E. ATC support tools

Even though the RPAS integration should be transparent to the ATM system, the development of RPAS technology to support the integration in non-segregated airspace should be coupled with an improvement of the systems that ATCs employ to track traffic (e.g. ADS-C). Current airliners do not exploit to the full extent that type of technology, thus, ANSP will not invest in improving the ATC control screens until a clear business case exists.

We propose to develop the concept of operation for an ATC support tool which integrates a solution for RPAS flight intent management, separation provision, contingency management and vortex avoidance. The main objective of this tool is to improve the situational awareness of the ATC controller when managing RPAS flight plan dynamism, facing potential separation conflicts involving an RPAS and an airliner or its vortex, and finally RPAS contingencies.

F. Improved taskload and workload models

Among other factors, the impact on sector capacity of an RPAS is determined by the number of potential interactions with airliners operating within the same sector. This impact is generally measured through the identification of loss-of-separation events (for example in CAPAN). However the available experience has demonstrated that existing metrics do not capture with enough realism the implications of mission-oriented RPAS trajectories.

RPAS surveillance operations will include an increased amount of heading changes inside or even outside the filed flight plan. Not each one of those changes may require a full pilot-ATC interaction as groups of them may be part of the same global manoeuvre (like a procedure turn during a scanning operation). Moreover, ATC may require extra mental activity to maintain the RPAS separation due to the RPAS performance, that it is not properly captured in the taskload models.

This project concludes that further investigation is necessary to determine which of the RPAS particularities, especially those related to the mission profiles, need to be taken into account as additional taskload factors, as most of the existing metrics do not contemplate scenarios beyond the point to point airliner operations. The correct evaluation of capacity under RPAS operations is critical to properly authorize the intended missions to avoid overloading the ATC in an unexpected way. Such type of event will decrease the safety of the operation and will negatively impact future permissions for RPAS to operate.

Overall, further metrics need to be proposed to analyse RPAS impact on the overall ATM system performance. This should include:

- Flight efficiency metrics (e.g. vertical profile (e.g. stepped descent, Top of Descent (TOD) location), distance and time flown, deviation from predicted time/trajectory)
- Capacity metrics (e.g. number of aircraft in the sector, time spent in the sector, area density maps to reflect airspace used)
- Safety metrics (e.g. separation infringement, Traffic Collision Avoidance System (TCAS) activation, conflict geometry).

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 conventional contingency or lost-link management have to be addressed. ERAINT project is tackling these issues. During the last year, the RPAS-ATM relationship in terms of contingency management has been addressed by means of several real-time simulations using different available surveillance and communication technologies. Two different contingencies were simulated (an engine failure and a lost-link) each one in two completely different scenarios (en-route and TMA areas). Simulations represented realistic airspace structure and traffic that did not represent an excessive complexity. As a result of the simulations a number of conclusions can be extracted. Regarding the viability of the contingency operation, simulations demonstrated that it is viable and resulted into limited ATC workload impact. Simulation results have also provided ideas regarding the flight intent, thus permitting an initial development of a concept of operations for its use. Moreover, simulation results also showed that further research needs to be done regarding the RPAS 4D trajectory prediction as BADA family 3 does not properly cover degraded flight performance. Additionally, improved taskload and workload models that take into account the RPAS particularities should be also investigated.

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REFERENCES

- [1] E. Pastor Llorens, M. Pérez Batlle, P. Royo Chic, R. Cuadrado Santolaria, C. Barrado Muxí *et al.*, "Real-time simulations to evaluate the rpas integration in shared airspace," 2014.
- [2] T. Coffey and J. A. Montgomery, "The emergence of mini uavs for military applications," *Defense Horizons*, no. 22, p. 1, 2002.
- [3] Z. Sarris and S. Atlas, "Survey of uav applications in civil markets (june 2001)," in *The 9th IEEE Mediterranean Conference on Control and Automation (MED'01)*, 2001.
- [4] D. Perovich, W. Tucker, and K. Ligett, "Aerial observations of the evolution of ice surface conditions during summer," *Journal of Geophysical Research: Oceans (1978–2012)*, vol. 107, no. C10, pp. SHE–24, 2002.
- [5] J. L. Morgan, S. E. Gergel, and N. C. Coops, "Aerial photography: a rapidly evolving tool for ecological management," *BioScience*, vol. 60, no. 1, pp. 47–59, 2010.
- [6] S. Tsach, A. Peled, D. Penn, B. Keshales, and R. Guedj, "Development trends for next generation uav systems," in *Israel Aircraft Industries Ltd., AIAA Infotech@ Aerospace Conference proceedings*, 2007.
- [7] P. Brooker, "Sesar and nextgen: investing in new paradigms," *Journal of navigation*, vol. 61, no. 02, pp. 195–208, 2008.
- [8] J. Griner, "Uas integration in the nas project: Project overview," in *Integrated Communications, Navigation and Surveillance Conference (ICNS)*, 2011. IEEE, 2011, pp. 1–23.
- [9] ERSG, "Roadmap for the integration of civil remotely piloted aircraft systems into the european aviation system," SESAR, Tech. Rep., 2013.
- [10] P. E. Ross, "When will software have the right stuff?" *Spectrum, IEEE*, vol. 48, no. 12, pp. 38–43, 2011.
- [11] R. R. Cordón, F. J. S. Nieto, and C. C. Rejado, "Rpas integration in non-segregated airspace: the sesar approach."
- [12] J. K. Kuchar and L. C. Yang, "A review of conflict detection and resolution modeling methods," *Intelligent Transportation Systems, IEEE Transactions on*, vol. 1, no. 4, pp. 179–189, 2000.
- [13] B. Korn and A. Udovic, "File and fly procedures and techniques for integration of uavs in controlled airspace," in *ICAS Conference*, 2006.
- [14] S. J. Undertaking, "European atm master plan," 2012.
- [15] RTCA, *Minimum Aviation System Performance Standards for (MASPS) for automatic dependent surveillance broadcast (ADS-B)*, Radio Technical Commission for Aeronautics, Washington, DC (USA), Jun 2002, document Do-242A.
- [16] ICAO, *Annex 6 to the Convention on International Civil Aviation - Operation of Aircraft*, International Civil Aviation Organisation, Montreal (Canada), 1996.
- [17] K. W. Williams, "A summary of unmanned aircraft accident/incident data: Human factors implications," DTIC Document, Tech. Rep., 2004.
- [18] G. Carrigan, D. Long, M. Cummings, and J. Duffner, "Human factors analysis of predator b crash," 2008.
- [19] C. W. Johnson, "The hidden human factors in unmanned aerial vehicles," 2008.
- [20] E. Schoitsch, *Computer Safety, Reliability, and Security: 29th International Conference, SAFECOMP 2010, Vienna, Austria, September 14-17, 2010, Proceedings*. Springer, 2010, vol. 6351.
- [21] E. M. Atkins, I. A. Portillo, and M. J. Strube, "Emergency flight planning applied to total loss of thrust," *Journal of Aircraft*, vol. 43, no. 4, pp. 1205–1216, 2006.
- [22] Y. Tang, E. Atkins, and R. Sanner, "Emergency flight planning for a generalized transport aircraft with left wing damage," in *AIAA Guidance, Navigation and Control Conference and Exhibit*, 2007, pp. 20–23.
- [23] E. M. Atkins, "Emergency landing automation aids: An evaluation inspired by us airways flight 1549," in *AIAA Infotech@ Aerospace Conference, Atlanta, Georgia*, 2010.
- [24] T. L. Chen and A. R. Pritchett, "Development and evaluation of a cockpit decision-aid for emergency trajectory generation," *Journal of Aircraft*, vol. 38, no. 5, pp. 935–943, 2001.
- [25] A. Pritchett and J. Ockerman, "Emergency descent plans, procedures, and context," in *Proceedings of the International Conf. on Human-Computer Interaction in Aeronautics*, 2002, pp. 74–79.
- [26] R. Watts, P. Tsiotras, and E. Johnson, "Pilot feedback for an automated planning aid system in the cockpit," in *Digital Avionics Systems Conference, 2009. DASC'09. IEEE/AIAA 28th*. IEEE, 2009, pp. 5–B.
- [27] Eurocontrol, *DDR2 Reference Manual 1.0.1*, 2013. [Online]. Available: <http://www.eurocontrol.int/services/ddr2>
- [28] P. Royo, C. Barrado, and E. Pastor, "Isis+: A software-in-the-loop unmanned aircraft system simulator for nonsegregated airspace," *Journal of Aerospace Information Systems*, vol. 10, no. 11, pp. 530–544, 2013.