Human and Technical Performance Aspects in RPAS Integration Trials in Controlled Airspace

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Abstract—**Flight trials are one important step to assess the viability of RPAS integration in non-segregated and controlled airspace. The DEMORPAS project, with the financing support of the RPAS Demonstrations Programme launched by the SESAR Joint Undertaking, studied the viability of RPAS flying in a controlled airspace shared with manned aircraft by performing two real flight trials where an RPAS and a manned aircraft where provided with air traffic control by different ATC dependencies; ground, tower, approach and en-route. Moreover, specific RPAS aspects such as the need to modify on short notice its initial flight trajectory, emergencies which do not happen in manned aviation or conflicts between an RPAS and a manned aircraft. Our results show that human factors related with the communications between remote pilots and air traffic controllers (ATCOs) need to be improved as well as ATCOs need to be trained to improve the perception of RPAS. Technical aspects such as communications means to enable remote pilots to contact ATC dependencies out of radio line of sight as well as remote pilot situational awareness have to be further studied and validated by future flight trials.**

Keywords-RPAS, integration, controlled airspace, ATC, remote pilots.

I. INTRODUCTION

In the last years, technical, technological and regulatory efforts to achieve an orderly and safe integration of remote piloted aircraft systems have increased to a point that society is considering as an important driver to bring benefits in several areas of application as well as to increase economic benefits and job opportunities.

However, there are still problems that are needed to solve to enable the coexistence of RPAS and manned aircraft in an environment subject to air traffic control. This paradigm shift is not only applicable to commercial and transport aviation, but to any airspace user which will be subject to the integration in the future ATM system.

On another hand, despite the work undertaken for the integration of RPAS in non-segregated airspace under the current ATM environment, it is needed to take into account that the future Single European Sky implies a change in the air traffic management paradigm. As stated in [2]. RPAS are considered as de-facto users of airspace. As legitimate airspace users, RPAS are required to be integrated with current and future ATM systems as any other airspace user without impacting on manned aviation [3].

The entity conducting the research and development of the ATM paradigm shift is the SESAR Joint Undertaking. SESAR is aware of the need that RPAS must participate in the future ATM system and launched an initiative to execute several demonstration projects across Europe that could show the viability, or not, of RPAS integration in non-segregated airspace and to draw conclusions that could serve to define the research activities in future programmes. The DEMORPAS project has been one of those demonstration projects co-financed by SESAR.

DEMORPAS has been coordinated by ISDEFE and counted with the participation of ENAIRE, INTA, FADA-CATEC and CRIDA. It has also been supported by the Spanish Aviation Safety Agency (AESA) and the Spanish Air Force.

To achieve the objective of assessing the viability of integrating RPAS in non-segregated airspace, DEMORPAS planned and executed two exercises involving one RPAS and one manned aircraft. These exercises were conducted by following a stepwise approach, increasing the complexity in successive steps. The final objective was to assess the feasibility of RPAS flights in controlled environment targeting human and technical performance of ATCOs, remote pilots and RPAS. A future formal validation will be needed.

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In order to define the exercises, two main activities were performed: 1) analysis of SESAR initiative with regards to the scope of the demonstrations projects, 2) conversations with Spanish aviation authorities (civil and military) to establish the type of flights that could be allowed to do in Spain.

In addition, a literature review of previous flight trials was performed.

Moreover, through a request from the SESAR Joint Undertaking a dedicated session was held between DEMORPAS and the rest of the nine demonstration projects co-financed by SESAR, namely CLAIRE, AIRICA, TEMPAERIS, RAID, ODREA, MedALE, INSuRE and ARIADNA. The objective of this session was to establish a coordination to avoid duplication of results.

In the first DEMORPAS exercise, the RPAS flew individually following two different scenarios. The first scenario was considered as a familiarisation flight (operational scenario) so that the ATCO and the RPAS (including the remote pilot) could get used to each other and with the flight procedures and voice communications. At the same time, an unplanned change in the initial trajectory was requested by the remote pilot to study the reactions of participants. This change of trajectory was planned as a consequence of one of the principal purposes by which RPAS are considered to be used, that is, not to fly a fixed point to point trajectory but to perform a mission which, at any moment, may be requested to be changed due to the need to observe a specific target. The second scenario (emergency scenario) was to see participants' reactions in the presence of specific RPAS emergencies (loss of telemetry, loss of GPS and partial loss of engine), as well as to test the viability of the procedures developed.

In the second exercise, besides the RPAS, a manned aircraft was introduced, so that the complexity was increased. Both aircraft were flying in the same portion of airspace in a way that a conflict was produced and avoided by following ATCO instructions.

II. EXERCISES DEFINITION

The DEMORPAS flights were executed in Spanish airspace. This aspect was of special relevant when defining the exercises.

At the moment of planning the flights, there was not any Spanish regulation allowing the free flight of RPAS. Although during the execution a preliminary regulation appeared allowing RPAS flights under restricted conditions, such conditions were so much limiting that none of the DEMORPAS objectives could have been met [4]. For this reason, the Spanish Aviation Safety Agency advised us to conduct the exercises under military supervision.

The main drawback of executing the exercises under military supervision was that the flights would be conducted in a segregated airspace. However, after coordination with the Spanish Air Force, it was found feasible to emulate a non-segregated airspace, enabling the operation of RPAS and

manned aircraft simultaneously, as well as to provide air traffic control from the different ATC dependencies that would be involved in the flight, namely ground, tower, approach and en-route ATCOs. This situation was feasible due to the existence of Spanish Air Force rules for flying military RPAS in segregated airspace [5].

The selected place was Matacán Air Base, close to the Salamanca city. This air base is immersed inside two restricted areas LER71 A and LER71B. While the Air Base was used for taking-off and landing, flights transited through LER71B until arriving to the work area inside both, LER71B and LER71A. The overall operations area extended for more than 30 NM from the Air Base.
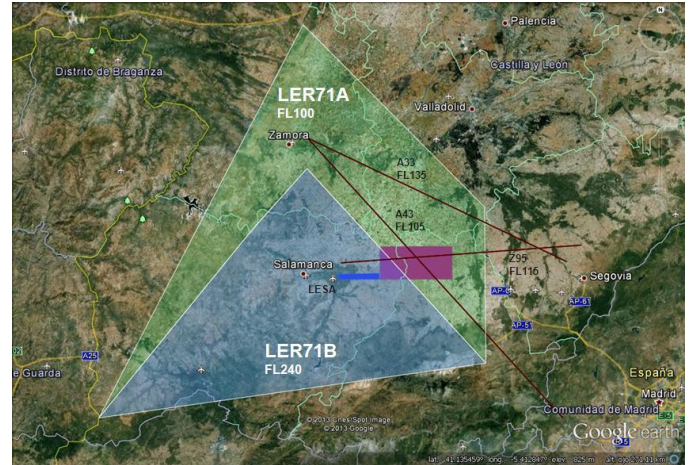

Figure 1. Location of the operations area inside the restricted areas LER71B and LER71A.

In [4] it is requested to develop a viability study showing that the flights are going to be performed in a safe manner. In addition, the viability study [6] also included, apart from the horizontal extension shown in Figure 1. vertical profile (Figure 2.) and the procedures to enter and exit the operations area. Moreover, to avoid the loss of lives or properties on ground, in case controlled flight into terrain was necessary, a study of the ground settlements including the number of inhabitants as well as terrain elevations, rivers and roads was requested to be included in the viability study.

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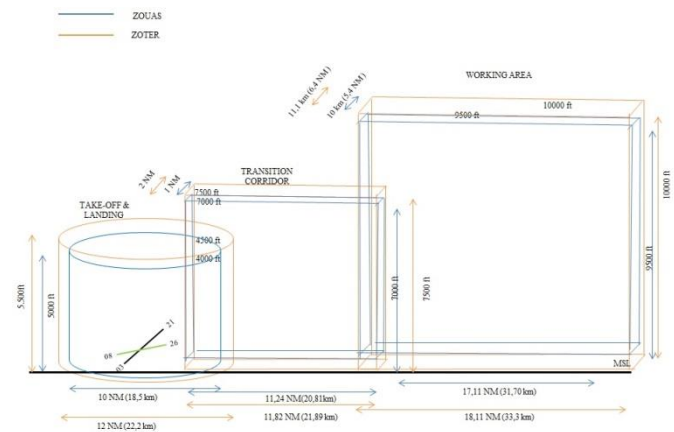Hosted by Technical University of Delft, the Netherlands

Figure 2. Vertical profile of the operations area.

During take-off, the RPA reached an altitude not greater than 4000 ft to proceed to the transition corridor where it climbed gradually until reaching 7000 ft before enter the working area. At the entry point of the working area the RPA reached its final altitude (8000 ft). The manned aircraft followed the same procedure to reach the working area. In fact, during the initial climb and transition through the corridor, both the manned aircraft and the RPA flew at same altitude in parallel to perform a calibration of altitude sensors and guarantee that vertical separation was maintained during the scenario execution inside the working area.

A very important aspect for defining the exercises and for guaranteeing safety of the lives and properties on ground was the definition of crash sites/recovery areas. These areas were selected based on the study of the ground settlements and the capability of the RPA to descend once the parachute has been deployed. The selected crash sites were selected based on the absence of population and buildings, and considering the RPA capability for gliding from different points inside the working area assuming that the RPA starts gliding at mid altitude inside the hexahedron defining the working area. Moreover, these areas had a radius of 500m.

In order to emulate as much as possible a usual controlled airspace and to provide proper air traffic services, several fictitious fixed points and airways were defined as shown in Figure 3.
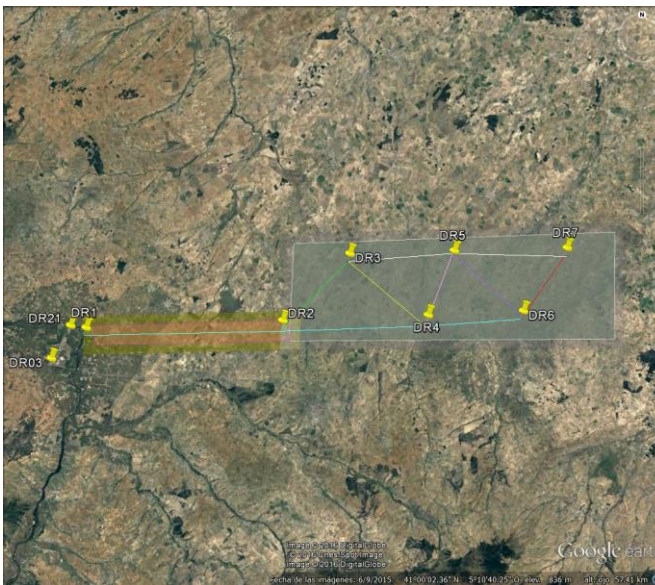

Figure 3. Fixed points and airways.

III. PLATFORMS AND SYSTEMS

Two types of platforms were used in the DEMORPAS flights: one RPAS and one manned aircraft. Both are owned by INTA.

The RPAS used was ALO (Avión Ligero de Observación or Light Observation Aircraft). ALO was integrally developed by INTA and it is used as a test bed platform as well as proposed to be used in some missions of the Spanish Army. ALO is close to mid-range class I small RPAS providing real time reconnaissance, surveillance and target visible and infrared images by means of a gyro-stabilized mini dome on board the air vehicle. ALO is commanded and controlled from the Remote Pilot Station (RPS), where also the images gathered by sensors are presented to the operator. The RPA flies a previously planned mission, except when any modification to the trajectory is needed. At any moment, the Remote Pilot can take over control of the RPA, through the automatic or semiautomatic modes available in the RPS, to modify the trajectory according to the objectives of the flight.

ALO's most important parameters are:

- Maximum take-off weight: 60 kg

- Wingspan: 3.84 m

- Length: 2.35 m

- Maximum Speed: 180 km/h

- Cruising speed: 150 km/h

- Climbing speed: 5 m/s

- Service ceiling: 14000 ft.

- Range: 100 km (LOS)

- Endurance: more than 5 hours (depending on payload)

- Take-off distance: 120 m

- Landing distance: 160 m

ALO also has some take-off limitations related to the atmospheric conditions:

- Maximum wind: 7 m/s

- Maximum wind gusts: 3 m/s

- Maximum lateral wind: <= 4 m/s

- Clouds ceiling: <<250 m

Figure 4. ALO RPA together with its RPS.

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On the other hand, the manned aircraft considered in the exercises was a STEMME S-15 aircraft, purchased by INTA and adapted to conduct scientific research operations. STEMME S-15 is equipped with a turbo charged engine (115 hp), an appropriate navigation equipment, a mode S transponder to fly in controlled airspace as well as with a two axis autopilot system with control unit for IFR standard applications (level, altitude, heading, vertical speed, approach, holding).

Some STEMME S-15 specifications are the following:

- Length: 8.52 m

- Height: 2.45 m

- Wingspan: 18 m

- Never exceeding speed (V_{NE}): 143 kts / 265 km/h

- Maximum Structural Cruising Speed (V_{NO}): 113 kts / 210 km/h

- Maximum ceiling: 16000ft (cabin not pressurized. At this altitude oxygen is requested)

- Maximum climbing ratio: 591 ft/min / 3 m/s

- Empty weight: 640 kg

- MTOW: 1100kg

- Maximum endurance: 6 h (at minimum scientific payload and maximum fuel)

- Maximum range: 1100 km (Considering 75% engine power, landing gear retracted, operating speed of 180 km/h and neutral flap)

It is type certified according to EASA Restricted Category for Utility Aircraft, allowing it to conduct C-VFR day/night operation.

Figure 5. STEMME S-15.

One of the key aspects in DEMORPAS flights was to provide communications between the remote pilot, located in the Matacán Air Base and area air traffic controllers located in Madrid ACC. Since the remote pilot was not on-board the RPA, such communications could not be performed as in a manned aircraft.

The first proposed solution was to install a communications relay on-board the RPA. The communications relay installation experienced serious problems. Apart from the delay in providing the relay to INTA, by an external company to the consortium, the installation was not successful due to the problems in communications transmission between the remote pilot and Madrid ACC. This problem led to device a different solution which required further work on the remote pilot station.

The solution found was to install a telephone line via ENAIRE's SCV (Sistema de Comunicación por Voz or Voice Communication System). This solution was successful in the context of the first exercise due to it was possible to establish bidirectional communications between the remote pilot and Madrid ACC.

However, in the second exercise, the fact that the RPAS and the manned aircraft need to fly simultaneously emulating a controlled environment, provoked that the telephone line was no longer applicable because the communications between the remote pilot, the manned aircraft pilot and air traffic controller at Madrid ACC had to be performed using the same communications frequency as it occurs in a normal situation.

To solve this problem, an additional installation was required. ENAIRE equipped the remote pilot station with an ATC communications system consisting of Frequentis audio equipment linked by telephone line with Madrid ACC. In this way communications from the remote pilot were broadcasted through the frequency, permitting the rest of pilots using the same frequency to hear all the control communications between the remote pilot and the air traffic controller, as in the normal practice. In addition the remote pilot was also able to hear, through a loudspeaker, all the communications from air traffic controller and from the rest of pilots using the same frequency.

Moreover, in order to perform the exercise providing enough situational awareness to the remote pilot, additional equipment was installed on the RPS consisting of a PC connected to SINA (Air Navigation Information System). SINA is an element of SACTA system in charge of providing users external to ACC with real time radar track information as it is presented at Madrid ACC. Both, RPAS and also the other aircrafts involved into the flight trials must be equipped with SSR transponder to be represented in SINA. Since both the RPAS and the manned aircraft used in the exercises were equipped with SSR transponder, they could be represented in SINA.

The PC was installed into the remote pilot station with a connection to a building with RESINA/REDAN or RECOA nets connection available in the Matacán Air Base. A specific SINA client was customized to the Matacán Air Base area, including the appropriate maps.

Communications were configured and secured to link the PC to SINA via REDAN (Air Navigation Data Network).

IV. TRIAL SCENARIOS

In the first exercise, during the operational scenario, once the RPA reached the working area, the remote pilot asked Madrid ACC air traffic controllers to modify its flight plan to directly fly to a certain point in order to perform a surveillance

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mission. Once the surveillance mission was finalised, the remote pilot asked to resume its initial flight plan to leave the working area.
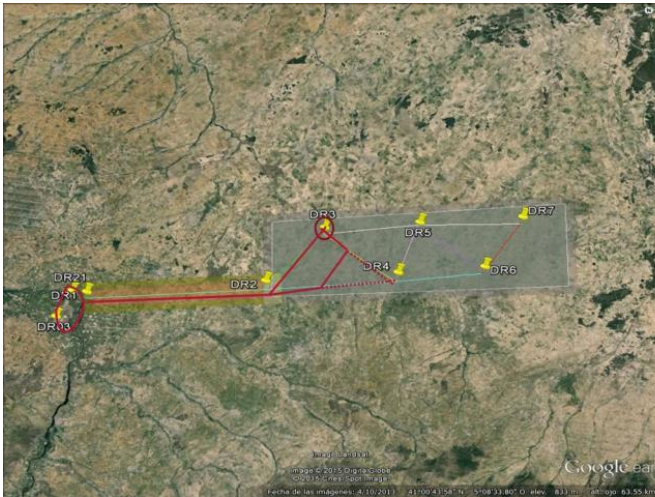

Figure 6. Operational scenario in the first exercise.

During the emergency scenario of the first exercise, the RPA flew its nominal flight plan until a loss of telemetry emergency is declared. This emergency consisted in flying around the point where the telemetry was lost for two minutes. After these two minutes the RPA was commanded to fly to a recovery area to fly over it for two more minutes. Air traffic controller confirmed the arrival to the recovery area as the remote pilot did not have telemetry information. Once the telemetry was recovered the RPA asked to resume its initial flight plan. On another point in the flight, the RPA declared a loss of GPS emergency. The RPA was commanded to fly towards another recovery area following inertial navigation. After two minutes over the recovery area, the loss of GPS emergency was finalised and the remote pilot asked air traffic control to resume its initial flight plan.
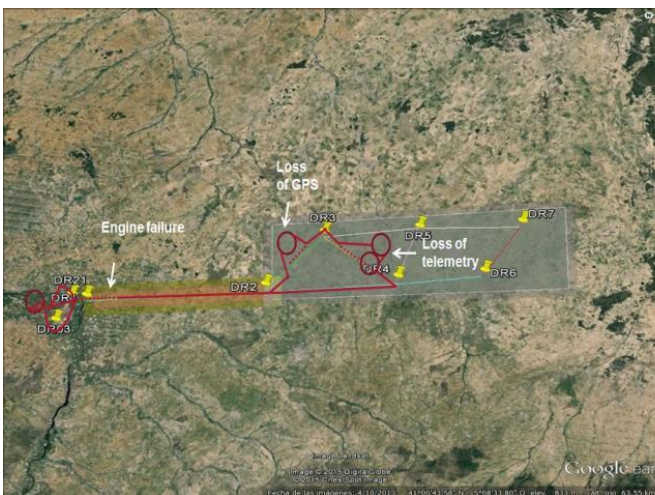

Figure 7. Emergency scenario in the first exercise.

When the RPA was approaching Matacán Air Base for landing, the remote pilot declared a partial loss of engine. The air traffic controller instructed the RPA to fly towards a recovery area inside the aerodrome where the RPA could descend safely in order to deploy the parachute if needed. When the RPA arrived the recovery area and started the descent, the emergency was finalised and the RPA proceeded for a usual landing.

In the second exercise, the RPAS and manned aircraft STEMME S-15 flew simultaneously in the same area. The RPA was performing its initial flight plan when at a certain moment a loss of telemetry, as in the previous exercise was declared. After finalising the emergency the RPA asked air traffic control to resume its initial flight plan. In the meantime the manned aircraft continued with its flight, but because of the loss of telemetry emergency of the RPAS a conflict between both aircraft occurred. The conflict was detected by air traffic control and instructed the manned aircraft to climb 1000 ft. to avoid the conflict. The decision to define the procedure to instruct the manned aircraft to climb instead of the RPAS was that there exist more confidence in manned aircraft performances than in RPAS ones. Therefore by instructing the manned aircraft, it was considered that the separation procedure would be safer. After the conflict was solved, both aircraft continued its flight to leave the working area and proceeded for the approach as usual. In the case of the RPA the procedure did not imply a direct descent. Instead of it, it flew along a circuit over the aerodrome to lose altitude. The manned aircraft proceeded following manned aircraft procedures.
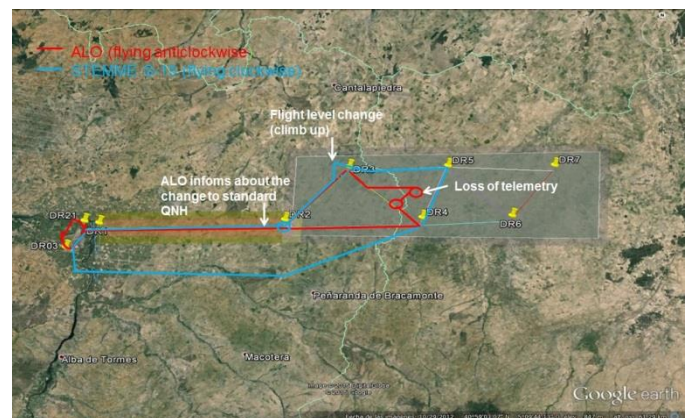

Figure 8. Second exercise scenario.

V. ANALYSIS OF RESULTS

In order to obtain significant results from the trials, two types of analysis were performed. The data used for the analysis were obtained through two different sources. On the one hand, the information gathered through questionnaires and de-briefings from air traffic controllers and remote and manned aircraft pilots, participating during the flight from all the ATC dependencies involved in the exercises, was used to perform a human factor assessment. On the other hand, radar, flight plan and telemetry information was used to perform a trajectory analysis.

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A. Human factors analysis

The human factors analysis was focused on the interaction of remote pilots with ATCOs and manned aircraft pilots. Aspects like situational awareness, stress and opinion on operational feasibility were captured through ad-hoc questionnaires and debriefings after each flight.

The ATC radar information provided to remote pilots through the SINA position was very useful in order to be aware of other flights close to the airspace the RPA was flying. It was also found extremely useful in the case of a command and control loss due to, during these events, no information about the position of the RPA is provided to the pilot through its own telemetry. Using the SINA position the remote pilot improves its knowledge of the location and attitude of the RPA.

Currently remote pilots fly in an environment not controlled by ATC. During the flights, they were in permanent contact with ATC, which is an activity they are not used to. This situation provoked an increased workload as it is an additional activity to their usual tasks. This situation was also provoked by the lack of knowledge of communications and aeronautical phraseology. In order to reduce the workload, an intensive training took place after the execution of the first exercise in order to improve the communications and phraseology. This reduced the workload but still was a bit high due to the number of tasks performed by the remote pilot. In contrast, in manned aviation, the pilot and co-pilot have separated but complementary tasks, so that the workload is reduced.
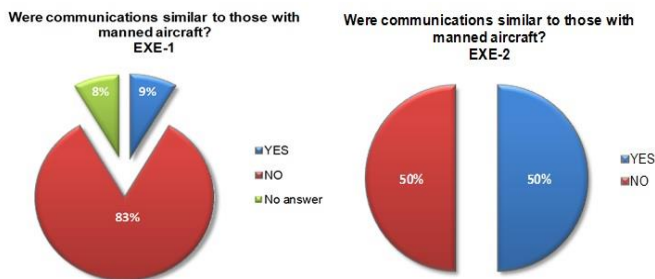

Figure 9.   ATCOs´ percepcion of communications during both exercises.

Human factors affecting Air Traffic Controllers were also largely assessed.

First it was considered the feasibility to follow ATC instructions and procedures by the RPA and remote pilot, such as the transference of control between ATC units. Three different ATCOs, one per ATC unit for every flight, were asked about how they perceived the execution of any instruction or clearance. 89% of ATCOs considered that the RPAS followed ATC instructions correctly. However, the extensive preparation of the flights during the days before the exercises execution makes that this result may be overestimated as remote pilots knew in advance the type of instructions they were going to receive during the flight execution.

ATCOs situational awareness with regard to RPAS location was also studied. RPAS evolution was easily predicted by Tower ATCOs. This result is due to Tower ATCOs are controlling visually the evolution of the flight. In addition, and according to controllers´ feedback, remote pilots performed very well in reporting the progress associated to each predefined event. However, ACC controllers perceived a different situation. ACC ATCOs rely basically on radar information. ATCOs highlighted that monitoring the RPAS evolution was more difficult due to the specific performances of the RPAS in comparison with manned aircraft, especially in turns with small radius, what increased the complexity to foresee the position of the RPA.
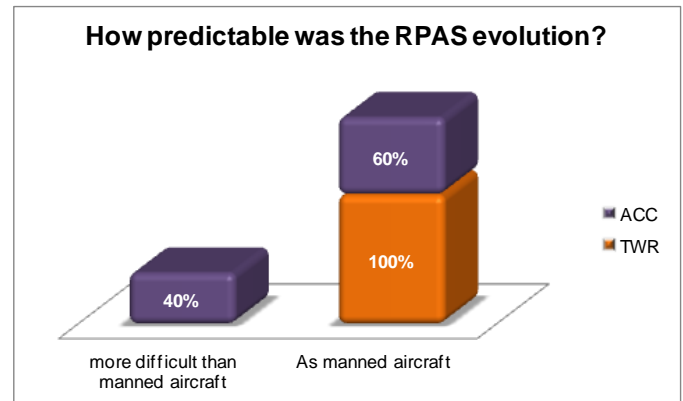

Figure 10. Predictability of RPAS evolution perceived by ATCOs.

Furthermore, the lack of knowledge on communications and phraseology of the remote pilots as mentioned above, make more difficult the work of ATCOs increasing the time dedicated to the RPAS compared to manned aviation. As an example, in one occasion the remote pilot interrupted a communication between another pilot and a controller. This situation provoked a confusion which resulted in the other pilot trying to follow the instruction provided to the remote pilot which in turn increased the workload of ATCO to solve the situation.

Finally, according to ATCOs perception, the remote pilot read back time for the instructions provided by them was considered appropriate without distinctions made between any ATC dependencies.

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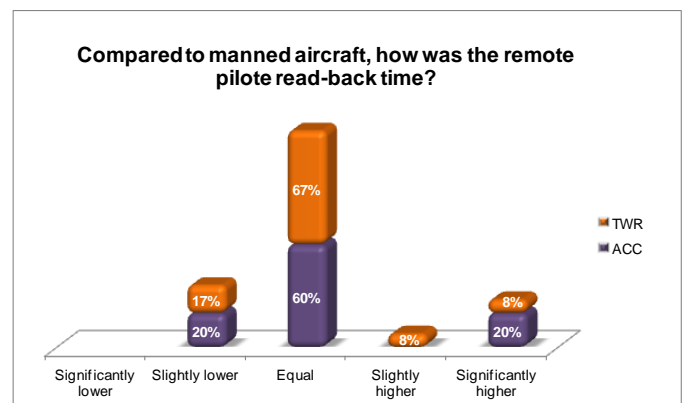Hosted by Technical University of Delft, the Netherlands

Figure 11. Remote pilot read-back time.

For the first time in Spain, it was assessed the impact of RPAS specific procedures on current controlled airspace.

The analysis paid attention to the integration of take-off and landing procedures designed for this type of RPAS with published standard ones.

Manned aircraft pilots also provided their feedback after the execution of the second exercise. They considered that take-off and landing procedures of the RPAS were a potential risk to manned aircraft, especially for VFR flights. This perception was endorsed by ATCOs. Currently RPAS follow their own designed take-off and landing procedures which are much more different than the standard ones used by manned aircraft. It was strongly suggested that RPAS should follow standard procedures when possible. It standard procedures had a negative impact on capacity, specific RPAS procedures should be published and executed by all RPAS operating in a specific airfield.

Other key milestone of the project was the assessment of RPAS specific emergency procedures and how they could impact on controlled airspace as well as in ATCOs work.

Also, the integration of RPAS emergency procedures for loss of command and control and loss of GPS were seen by both, manned aircraft pilots and ATCOs as potential sources of conflicts for other aircraft, especially those flying VFR. ATCOs and manned aircraft pilots also supported the need of having more information about emergency procedures. They would prefer that RPAS emergency procedures are harmonised for all RPAS and that specific recovery point for all RPAS flying in each specific sector are published.
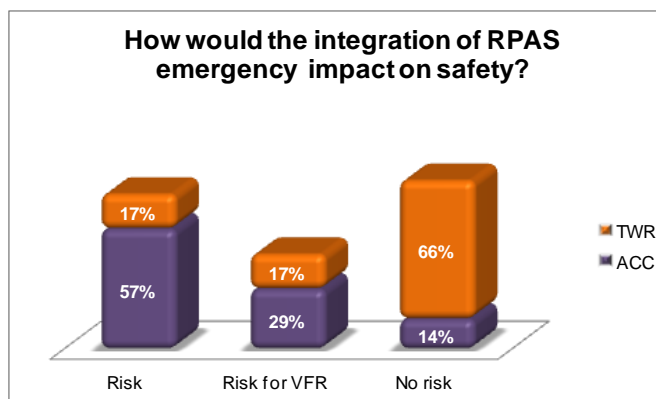

Figure 12. Perception of RPAS emergency impact on safety.

B. Trayectory analysis

The trajectory analysis performed was based on the comparison of ATC radar information and telemetry data received from the RPA. Such telemetry data came from GPS, altitude and barometric sensors installed on-board the RPA.

The comparison was considered in the horizontal and vertical planes.

In the horizontal plane, the largest error was recorded during the RPA turns, due to the small radius needed by this RPA. The discrepancy is provoked because the ATC system display refreshes the radar presentation every 5 seconds, while telemetry records 8 samples every second.

It is important to highlight that the Spanish surveillance system used under the premises of DEMORPAS exercises meets the required accuracy and performance for providing safe operation on today's en-Route and approach environments.

The low equipage of RPAS of this size in terms of antennas could make more difficult for radars to obtain consecutive answers from the transponder especially when the aircraft is rolling. When this occurs, ATC systems continue showing a potential radar track based on internal algorithm estimations that are not customized for the performances of this type of aircraft.

Therefore, in the case of a small radius turn, the RPA behaviour is different than the extrapolation, based on internal algorithm estimations, made from the radar data, which was considered a distraction by ATCOs.

The more turns performed in the flight, the larger average difference between the radar data and telemetry. Thus, the difference is increased when the RPA has to loiter over some points.

However, ATCOs considered acceptable this average difference in radius taking into account that when the largest difference was found, the turn radius implied only 300 m.
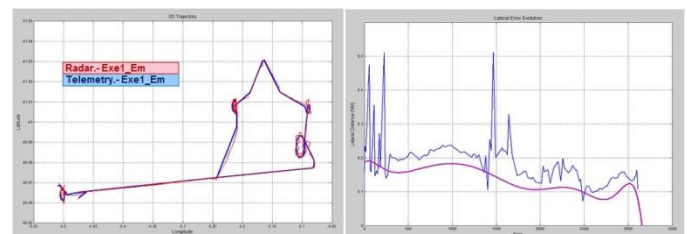

Figure 13. Comparison of trayectories based on radar information and telemetry data in the horizontal plane. Left: 2D trayectory. Right: Lateral error evolution.

In the vertical plane, differences between radar and telemetry data were found during climbs and descend. It has to be considered that, for navigation purposes, the RPA uses GPS altitude while the transponder transmits barometric pressure. The differences are therefore understood when it was detected that the RPAS used standard mean seal level pressure instead of the local one.

This difference was corrected for the second exercise and the average difference was reduced in the analysis. However, due to the lack of ATC background of the remote pilots, the change from local pressure to standard sea level pressure was performed, by the remote pilot, below the transition layer, which in Spain is established between 6000 ft and FL70.
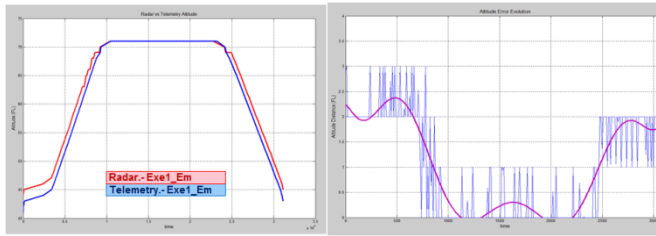
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Figure 14. Comparison of trayectories based on radar information and telemetry data in the vertical plane. Left: Radar vs telemetry data. Right: Altitude error evolution.

VI. CONCLUSIONS

From the execution of the exercises in DEMORPAS, several conclusions can be extracted.

Remote pilots do not usually have a background as commercial pilots, therefore they lack of education on communications and phraseology. Communications should be, therefore, included in training programs for remote pilots.

Coexistence between specific RPAS procedures and manned aircraft procedures presents an operational risk that has to be reduced. RPAS should follow standard procedures and when it is not possible, the RPAS specific procedures should be harmonised to reduce the impact on safety as well as on capacity. These procedures, if developed, should be included in ATCOs training courses to improve their situational awareness.

RPAS have specific emergency procedures that are an operational risk too. These procedures should be reflected as well in ATCO training procedures and potential recovery areas should be fixed and included in aeronautical charts. In addition the creation of a specific transponder code for RPAS specific emergencies would have a positive impact in reducing operational risks.

The situational awareness of remote pilots is of extreme importance to maintain the safety of flights; it is therefore needed to improve it by developing specific equipment and procedures. As shown during the exercises, the use of a SINA position was very useful. Although this was a solution solely used in DEMORPAS to obtain further information and increase situational awareness, remote pilots would obtain a great benefit of a similar source of information besides the RPA telemetry received on the remote pilot station.

Remote pilot workload can be considered as having a big impact on safety. It is recommended to further assess remote pilots workload emphasizing the impact that maintaining communications with ATC could have on it.

RPAS manoeuvres have been found too abrupt for ATC environments. Technical developments to reduce the impact of such manoeuvres are required so that ATCOs attention is not altered during the supervision of a RPAS flight. In addition, RPAS specific performances should be included in ATCO training courses to raise awareness about the different performances between the manned aircraft they are used to and RPAS.

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