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Concept of Operation for integrating RPAS into terminal airspace

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Abstract. Remotely Piloted Aircraft System (RPAS) is a capital issue for the majority of aviation actors nowadays. The integration of RPAS is an extremely demanding task that must be tackled by multiple standpoints: economic, social, technological or environmental among others. U-space is the answer from Europe to design the operation of multiple and different types of RPAS. U-space is a set of novel services designed to support efficient, safe and secure access to airspace, from the very low level to the upper airspace. This paper focuses on the terminal airspace to design the operational concept for the integration of RPAS in conjunction with conventional aircraft and general aviation. This work develops a holistic methodology to analyse the way RPAS integration affect crucial factors and tries to bring to the light different issues that can frustrate their integration. First, we focus on detailing the requirements specified by RPAS legislation. Second, all the requirements are gathered into different categories to perform further analysis. The categorisation identifies navigation, communication, surveillance, air traffic management and control, and safety as crucial categories (security is out of the scope of this study). The results provide for each category a proposal about how to solve the integration and implementation of RPAS in a TMA.

1. Introduction
This project execution underlies a first endeavour for the integration of Remotely Piloted Aircraft System (RPAS) within the airspace. The aviation community is taking greater strides towards this integration; however, the current implementation is scarce, in the majority of scenarios. In the following years, RPAS will be another airspace user, bringing about new possibilities according to their specific characteristics. However, the use of RPAS for diverse applications, such as agriculture, infrastructure surveillance and urban transport shows promising expectations in the long run [1]. For instance, forecasts expect more than seven million RPAS operators will fly in Europe in 2050 [2].

The operation of RPAS in different airspaces is a major issue for Air Navigation Service Providers (ANSPs). RPAS demands to the Air Traffic Management (ATM) system to take into account these new airspace users. “Integration refers to a future when RPAS may be expected to enter the airspace routinely without requiring special provision” [3]. The integration of RPAS is a complex challenge and particularly the Terminal Manoeuvring Area (TMA) increases the limitation because of the characteristics of its airspace. Unmanned Traffic Management (UTM) is the evolution of the concept of ATM. Although UTM is a broadly extended concept, it is denoted differently depending on the geographical area. U-space is Europe’s UTM for unmanned aircraft [4]. U-space tackles the different phases for the integration of every airspace (from the ground to beyond upper airspace) and airspace user (from RPAS to conventional aircraft). The roadmap is to introduce RPAS gradually into the airspace, starting from lower airspace volumes (particularly with the Very Low Level) and evolving to upper airspace until reaching full integration with conventional aircraft. In addition, RPAS are split into three categories depending on the operational risk: open, specified and certified [5].

Nowadays, RPAS operation in lower and upper airspace can be deployed because RPAS aircraft fulfils the technological needs [6]. Then, no higher technological developments are required. Nonetheless, two aspects limit their operation: first) there are legal restrictions to operate RPAS in non-segregated airspaces and their implementation is far behind that RPAS technological developments [7], and two) there is no clear guidelines and Concepts of Operations (ConOps) for the operation of RPAS in the different airspaces [8]–[11]. One of the problems for both aspects is each country set forth its own rules and the implementation of U-space services is not homogeneous.

Particularly, there is a mix of concepts about navigation for RPAS that are not accepted for conventional aircraft [12], [13]. The communications based on RPAS operations require an extra link for communications between the RPAS operator and the aircraft [14]. Surveillance in a TMA is complex because in low levels surveillance cannot be accurate as demanded. European Aviation Safety Agency (EASA) demand RPAS integration without exceeding current safety levels [15], [16]. The integration of RPAS in a TMA will increase the risk levels so regulators need to define which the current safety level is. Therefore, many operational aspects affect and are crucial to achieving a safe and useful integration of RPAS in a TMA.

This work provides a framework or guidelines to develop a ConOps for the operation of RPAS in a TMA. The ultimate goal is to establish how could be the introduction of RPAS in a TMA bearing in mind the different requirements and other airspace users without implying a safety reduction. Due to space constraints, the requirements identified are not showed in this work. This paper is structured as follows. Section 2 briefly describes the methodology. Section 3 provides the primary results for the different aspects to consider in the ConOps. Section 4 summarises the primary outcomes of this work.

2. Methodology

This section describes the way the integration of RPAS affect and can modify the current concept of operation of the TMA. This works encompasses a holistic methodology to evaluate the implications of the RPAS operations considering the main and crucial aspects for the TMA. This work is the result of the analysis, evaluation and identification of the different requirements to operate RPAS. The information has been extracted from Spanish and European legislation [8], [17], [25], [18]–[21], [21]–[24], and, although it can be considered for every country, it can present features of the Spanish legislation. It has been considered also information provided by ICAO [12], [26]. Due to space constraints, the requirements identified are not showed in this work.

The requirements to operate RPAS tackles five crucial aspects: navigation, communication, surveillance, ATM&ATC and safety. Figure 1 shows graphically the methodology followed to achieve this work. The reason to select these elements of the air transportation system is that they cover the vast majority of issues that can be affected by the integration of RPAS in a TMA. However, other issues should be analysed in further work, for instance, security is out of the scope of this study. Moreover, the goal of this work is not to provide in-depth details about the integration of RPAS but to provide the key points that should be considered.

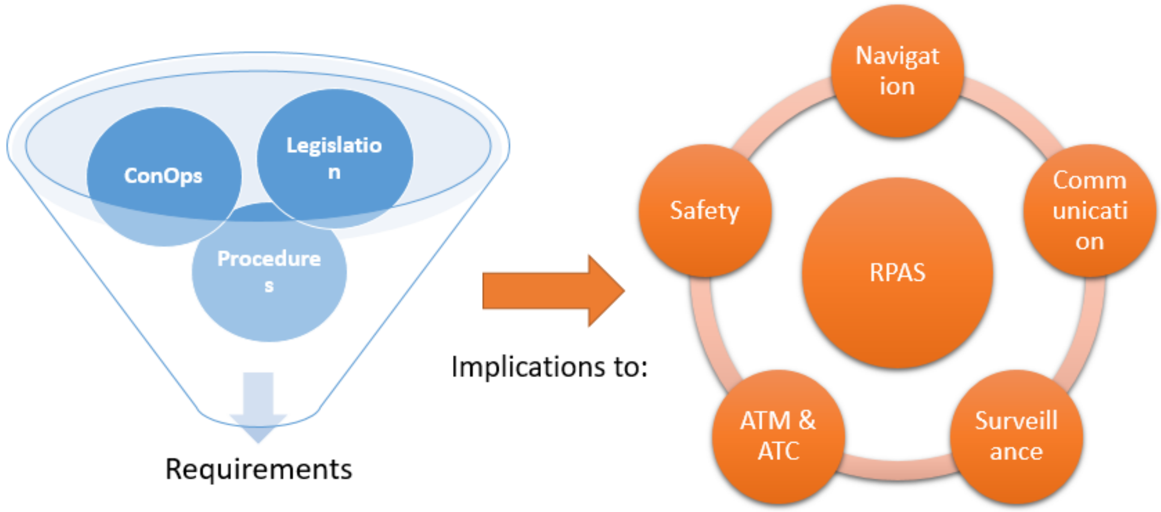

Figure 1. Methodology description.

3. ConOps description

3.1. Navigation

Different airspace users and aircraft can operate in the TMA based on the flight rules: Visual Flight Rules (VFR) or Instrumental Flight Rules (IFR). These two types of flight rules allow conventional aircraft and general aviation to operate following flight procedures previous defined by ANSPs. RPAS are new airspace users that must follow the same rules of the air to operate in the TMA. However, RPAS are not typically defined based on this type of flight rules. RPAS operation is denoted differently as a function of the communications and data link between the RPAS pilot and the RPAS aircraft [18]:

- **VLOS (Visual Line Of Sight):** RPAS operation where the pilot keeps direct visual contact with the RPAS aircraft, without any technological device. This type of operations cannot operate in a TMA.
- **BLOS (Beyond Line of Sight):** RPAS operation where the pilot does not keep direct visual contact but with other technological devices.
- **RLOS (Radio Line Of Sight):** RPAS operation where the transceivers and receivers are within the radio coverage and the communications are performed through the on-ground network.
- **BRLOS (Beyond Radio Line Of Sight**): RPAS operation where the transceiver and receivers are not RLOS. It covers every space-based communication networks and a set of on-ground communication networks. For instance, BRLOS operations are not allowed currently in Spain.

In this way, **Table 1** relates the RPAS operations allowed in the TMA depending on the all. The primary limitations are VFR operations does not allow VLOS and RLOS and IFR operations do not allow VLOS.

Table 1. Types of operations for RPAS allowed in a TMA.

Allowed operations in a TMA	Allowed operations for RPAS
VFR approach and departure	BRLOS and BVLOS
IFR approach and departure	BRLOS, BVLOS and RLOS
Low altitude Operations segregated for VFR/IFR	BRLOS, BVLOS and RLOS
Holdings	BRLOS, BVLOS and RLOS

As currently there are only two types of flight rules allowed for operations, RPAS must relate their types of operations with current flight rules:

a) RPAS can fly with IFR similar to conventional aircraft. RPAS follow IFR approach and departure procedures and Air Traffic Control (ATC) instructions. The type of RPAS that can operate this type of operations is Certified.
b) RPAS can fly with VFR similar to general aviation. RPAS follow VFR approach and departure procedures and Air Traffic Control (ATC) instructions. This type of RPAS do not follow specific missions and they can fly freely as general aviation does. The type of RPAS that can operate this type of operations is specific and certified.
c) RPAS can fly with automatic navigation. Automatic-navigation operations for RPAS are being developed and they could be one of the most used by RPAS. This type of operations refers to every operation based on the specific area following a particular mission within the TMA.

Table 2 gathers the different types of operations based on the RPAS category and the flight rules demanded. What is clear is that open operations cannot operate within the TMA.

Table 2. Summary of types of operations for RPAS.

Type of RPAS Operation	RPAS category	Flight rules
BVLOS	Certified	VFR / IFR
	Specific	VFR
BRLOS	Certified	VFR / IFR
	Specific	VFR
RLOS	Certified	VFR / IFR
	Specific	VFR

Automatic operations are not considered in **Table 2** because the requirements are not currently published and it is required a further in-depth analysis about the risks of the RPAS for this type of operations. These results are limited by the airspace class of the TMA. Several TMAs are denoted as Class A where only can operate IFR flights. These scenarios will limit the integration of RPAS to IFR movements. The rest of airspaces classes, from B to G, will allow the integration of RPAS both IFR and VFR movements. The implications of these limitations will be considered in further work.

3.2. Communications

RPAS operations mean a modification of the current communications in air navigation due to the RPAS pilot is not on-board. The possibilities to provide voice and data communications between ATC and RPAS pilot for VLOS and BVLOS [12] are:

- Through the RPAS aircraft. It does not demand any infrastructure or new equipment for ATC dependency. One problem is about a wider communication band for C2 data-link is required.
- Through new datalink device directly from the ATC dependency and the RPAS pilot.

The possibilities to provide voice and data communications between ATC and RPAS pilot for RLOS and BRLOS are:

- RLOS requires that transceivers and receivers are located within the same radio coverage and they can communicate directly between the ATC dependency and the RPAS pilot.
- BRLOS can use the RPAS aircraft as the link to communicate information between ATC dependency and RPAS pilot or to use satellites.

Conversely to conventional aircraft, RPAS do not have the requirement of two on-board VHF radio equipment. Then, in the case of failure, VHF communications are handled by the RPAS aircraft and communicated to the RPAS pilot and vice versa.

Moreover, it is required to some requirements about communication between the RPAS pilot and aircraft that can forbid the RPAS operation. The communication requirements are *Required Communications Performance* (RCP) and *Required C2 Link Performance* (RLP), characterized in ICAO's Doc. 9869 [14]. RCP refers to ATM functions and RLP to RPAS C2. Both of them are critical issues because they define the maximum time to receive the answer from a communication. Then, each TMA should have published RCP and RLP requirements to ensure the integration and acceptation of RPAS.

Lastly, it could appear communication failures due to coverage issues in the TMA. The analysis of the communication coverage in the airspace is one of the requirements established in the SORA's safety analysis [5]. If there is coverage, an RLOS operation should be performed. This type of operations can be performed in areas where no direct oral or data-link communications are allowed due to terrain jamming. The RPAS manufacturer provides the range of maximum coverage and limits this type of operations. Otherwise, RPAS perform BRLOS operation. This type of operations presents greater communication delays than RLOS. This factor is crucial to define the communication performance of the TMA based on BRLOS operations. Besides, it entails requirements for separation minima for RPAS and conventional aircraft.

3.3. Surveillance

An aeronautical surveillance system provides to the ATM the aircraft position and, depending on their capabilities, some extra information about the aircraft intent. Other information such as vertical speed, ground speed, aircraft type, or wind can be provided as well. Currently, a TMA has several primary and secondary radars to monitor the aircraft operations. One of the requirements in a TMA is that every aircraft that operate within the TMA must fly with Mode-S transponder activated [27]. Similar requirements will apply to specify or certified RPAS [18].

Similar to communication issues, surveillance in a TMA presents coverage failures in specific areas near to the ground. This is not only a problem of one specific radar but also various radar that cannot provide the required surveillance accuracy. Therefore, the operation of RPAS requires the implementation of Automatic Dependent Surveillance-Broadcast (ADS-B) in conjunction with secondary radar. This solution will provide surveillance capacity to ATC with the required accuracy and will increase the safety of the operation in the TMA with RPAS.

3.4. ATM

Air Traffic Management refers to every system that assists air traffic operations including air traffic services, airspace management (ASM) and air traffic flow and capacity management (ATFCM). The introduction of RPAS demands to analyse how their integration affects into each service. Flight planning management corresponds to the ATFCM and each RPAS must provide flight planning to operate in a TMA, similar to conventional aircraft. Regarding airspace capacity and demand, the TMA can handle the specific number of aircraft (capacity) without exceeding ATC workload limits. Then, the integration of RPAS must adapt to current conventional aircraft flows and scheduling demand. **Figure 2** represents the schedule distribution with conventional aircraft (blue bars) and RPAS (orange bars) that could operate in the TMA throughout 24 hours.

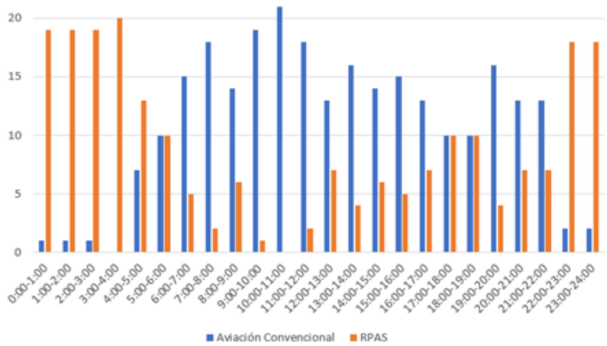

Figure 2. Histogram of conventional aircraft and RPAS demand distribution.

Throughout the "night period", there is no conventional demand and the capacity can be used by RPAS. However, conventional aircraft demand service during the "day period" and RPAS should be allocated where there is extra capacity. In this case, the solution provides some specific hours that should not be operated by RPAS (from 9 to 12 a.m.). One of the implications of this solution is that safety will be affected by the combination of different airspace users in the same airspace.

ASM is affected considering the introduction of RPAS by two new requirements:

1. The definition of new airspace procedures for RPAS. These procedures should avoid interactions for RPAS and conventional aircraft from the airport to the TMA, considering aircraft performances of RPAS.
2. New airspace volumes for RPAS only. These RPAS-only airspaces are similar to currently restricted areas where the RPAS could operate free of interactions from conventional aircraft. They must ensure IFR separations with conventional aircraft and airspace procedures. The RPAS could operate with new and specific separations and procedures in these airspaces.

Finally, ATS refers to air traffic control (ATC) in the TMA where is split into the approach control and tower control. Currently, ATC handles IFR and VFR aircraft operating the TMA. Depending on the operation of RPAS (IFR or VFR), ATC will have different responsibilities with the RPAS such as conventional aircraft, general or military aviation. **Figure 3** (left) shows the current distribution of airspace users controlled by ATC.

However, in a TMA there is airspace volumes that can be "free" used by RPAS without interacting with conventional aircraft, maintaining separation minima standards. In this case, new ATC controllers should be required to handle RPAS in these specific airspaces for RPAS. New ATC procedures must be required to conduct RPAS from conventional airspace to RPAS-only airspace. This solution is depicted in the right picture of **Figure 3**.

Figure 3. Left) Current ATC airspace distribution and right) Future ATC airspace distribution.

3.5. Safety

Safety focuses on incidents and accidents investigations to determine the causes aiming to avoid future accidents with similar causes. The introduction of a new operator as RPAS in the TMA implies the increase of risk and reduces safety levels in the case no organizational measures are implemented beforehand. Safety is a crucial factor for the integration of RPAS in the TMA demanding at the beginning two new systems: Specific Operations and Risk Assessment (SORA) and Detect and Avoid (DAA).

Currently, every RPAS operation must perform a previous risk assessment based on the SORA methodology to operate in a controlled airspace [5]. SORA provides a methodology to guide the operators and the ANSPs regarding the requirements to operate in a specific environment. Particularly, SORA addresses to a specific category, however, it brings to the light issues that can be applied to certified or open categories.

DAA systems allow RPAS to avoid other airspace users. ICAO's definition of DAA as "the capability to see, sense or detect conflicting traffic or other hazards and take the appropriate action" [27]. DAA provides to the remote pilot information about surrounding traffic based on different alert levels. The remote pilot uses the traffic information, alerts and navigation assistance to take the appropriate actions to manoeuvre and avoid risks. DAA's capacity for RPAS can operate based on three levels [12]:

a) Detect and avoid. It provides resolution manoeuvres to avoid risk.
b) Detect and notify. It provides a set of potential resolution manoeuvres that the pilot have to select one and perform it.
c) Detect and inform. It provides information about potential risks to the pilot, such as meteorological or situational awareness issues.

Moreover, one of the crucial aspects to consider is not to exceed current safety levels by the integration of RPAS.

4. Conclusions

This paper brings to the light operational issues that affect the introduction of RPAS in TMA airspace. The authors pretend that this work underlies the further development of a Concept of Operations for RPAS in a TMA. The methodology split and dug into five operational factors: navigation, communication, surveillance, ATC and safety. Security and regulation were out of the scope of this work. The analysis assumed that both the RPAS operator and the RPAS fulfilled with the different requirements imposed by national regulations to operate within a TMA. The integration of RPAS in European TMAs should be done in a gradual and homogenous way, without causing major issues or modifications to the current ATM system. In terms of navigation, the ANSP should develop different airspaces specifically for RPAS, procedures for their entry and exit of the TMAs, and rules of the air considering conventional aircraft, general aviation and RPAS. In terms of communication, it should be ensured that there are no communication issues between RPAS, RPAS operators and ATC. In terms of surveillance, current radars were not sufficient to cover the whole airspace of the TMA, particularly in low altitudes. Then, it was required to integrate the ADS-B service to gather RPAS geo-awareness for ATC. It was not clear if the RPAS operator should ensure that their operation fulfilled above requirements or the ANSP should ensure them. In terms of safety, separation management, collision avoidance and new SORA concepts should be determined in advance. Finally, this analysis allows the identification of different operational issues that should be developed in further work. ATC is one of the critical aspects due to lack of RPAS operations. Communication latencies is a critical issue for the operation of RPAS in a TMA that can affect safety and collision risk. Development of collision avoidance techniques and new separation minima for RPAS pairs. Implications of GNSS failures in complex and high-density airspace. Analysis of new ATC operators for only RPAS operations in specific airspace volumes for RPAS.

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