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Chapter

Risk-Based Framework for the Integration of RPAS in Non-Segregated Airspace

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Abstract

Remotely Piloted Aircraft Systems (RPAS) are new airspace users that require to be safely integrated into the non-segregated airspace. Currently, their integration is planned for the horizon 2025, but there is a lot of pressure by RPAS operators to fly as soon as possible. This research focuses on the development of a risk-based framework for the integration of RPAS in non-segregated airspace. The risk-based framework relies on a hierarchical methodology that is split into two time horizons: design and operation. Different operational and geometrical factors characterise each stage. Then, a set of risk and operational indicators are defined for each stage. These indicators evaluate the operational airspace state and provide information about how the integration of RPAS should be. Primary results provide information about geographical and temporary restrictions. Geographical restrictions refer to the airways that favour or inhibit the integration of RPAS, and temporary restrictions denote the time span when the RPAS can pierce into the airspace.

Keywords: air traffic management, risk assessment, risk-based framework, RPAS, RPAS integration

1. Introduction

The integration of Remotely Piloted Aircraft System (RPAS) in non-segregated airspace is one of the most complex and demanding challenges for the aviation community in the years ahead. The beginning of RPAS integration in non-segregated airspace is expected to be reached by the time frame 2025, according to European RPAS Steering Group [1]. This aim requires broad and structured analysis of the current situation as well as the potential solutions to be implemented. In this way, the development of a risk-based framework to ensure the safe integration of RPAS is crucial for its achievement.

RPAS operation in upper airspace does not require higher technological developments, but it demands detailed analysis about the safety of their integration with conventional aircraft. European Aviation Safety Agency (EASA) and Federal Aviation Administration (FAA) require that the integration of RPAS must not imply a diminish on current safety levels [2, 3]. This requirement means that further research is required to accomplish this goal. A new framework will be compulsory in the future to take the operational features of RPAS into account. One of the goals

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of this framework is to allow setting out the safety of the RPAS operation jointly with conventional aircraft [4–6].

Could RPAS fly safely in non-segregated aircraft? The complexity of the answer does not fall into a yes or not issue, because it must be yes, but instead we must focus on how. Currently, conventional aircraft fly according to prefixed routes that are modelled according to air traffic flow patterns, although there are several airspaces based on free-route [7]. Then, RPAS must adapt to the current airway network and current air traffic patterns. One of the main concerns is that RPAS operational patterns can differ from conventional aircraft ones [8, 9]. Although RPAS could be assumed to be modelled as slow conventional aircraft, there are uncertainties about communications, navigation and surveillance issues that must be analysed in advance [10].

Due to this lack of operational and technical knowledge about RPAS operation, regulators and Airspace Navigation Service Providers (ANSPs) seek to introduce RPAS based on a minimum interaction with conventional aircraft [11, 12]. The problem arises when both airspace users operate jointly in the same scenario where the interaction between them cannot be avoided. The first solution to his problem is the segregation of specific air traffic volumes for the different airspace users. However, this segregation should only focus on specific flight levels (FLs) or airways, as airspace cannot be completely segregated in different air traffic volumes for PRAS and conventional aircraft. One of the expected outcomes of this work is to appraise airways or FLs segregation for RPAS.

The most complex assessments about RPAS integration focus on three research areas. The first deals with the global problem of risk management. Clothier et al. [13] developed a framework for structuring the safety case of the RPAS operation. Moreover, various regulators assessed the primary difficulties that must be solved before RPAS operation [14, 15]. The second research area analyses the risk imposed by the single flight for one RPAS in terms of the number of casualties. Several authors developed different risk models to calculate what kind of populated areas are riskier for on-ground pedestrians [16–18]. The third research area involves the development of collision/conflict-risk models for the integration of RPAS. There are several studies about RPAS collision avoidance [9, 19, 20] (similar to conventional aircraft situations) but few of them focus on conflict risk [21, 22]. Conflict risk is a prior indicator of collision risk. However, none of those studies responds either how the RPAS integration should be or where RPAS could fly in non-segregated airspace.

With the goal of responding to the above research questions, it is required to assess the safety level of the airspace and to develop one specific methodology. Manual 9689 of International Civil Aviation Organisation (ICAO) [23] sets out that airspace planning requires a thorough analysis of every factor that could affect safety. In [24, 25], authors claimed the need for airspace design fulfilling levels of safety under different operational features. Different models were developed to evaluate the collision risk based on airspace geometry [26, 27]. A step further, Netjasov [28] developed a conflict-risk model to assess the level of safety, including air traffic flows. However, there is not a unique methodology that allows analysing the airspace risk-state for the integration of RPAS.

Therefore, the main goal of this research is to develop a risk-based framework to provide geographical and temporary restrictions for the safe integration of RPAS. The risk-based framework is split into two different temporal horizons: design and operation. The risk-based framework evaluates the state of the scenario regarding different risk-based indicators. The risk-based indicators relies on geometrical and operational features of airspace. The risk-based indicators sort airways and crossing points to detect airways (or flight levels): (1) where RPAS can operate because their integration is safe, and (2) when should be planned the operation of RPAS depending on a particular schedule of conventional aircraft. A further aim is to set out the pillars of a future decision-making process for ANSPs.

The rest of the article is structured as follows. Section 2 presents the structure of the risk-based framework and defines the different types of variables and indicators that must be considered. The risk-based indicators constitute the main outputs of the methodology that permit to assess the viability of the RPAS integration. It also describes the methodology for the design phase and the operational phase. Section 3 presents the case study and the application to one Spanish airspace volume and discusses the results. Lastly, Section 4 summarises the main contributions and further works.

2. Risk-based framework

The risk-based framework aims to analyse the safe integration of RPAS in non-segregated airspace. In non-segregated airspace, both conventional aircraft and RPAS must operate together. The problem arises when RPAS operate with different technical and operational features than conventional aircraft. Then, the integration of RPAS focuses on reducing their impact on conventional aircraft; in other words, RPAS must adapt themselves to current operations reducing their impact on current aviation. The risk-based framework is split into two phases depending on the operational information available:

- design phase: this phase aims to appraise the impact of RPAS in non-segregated airspace for strategical phase. It can be applied both for design purposes and for analysing the operation of one particular scenario. This phase works with basic information of an airspace volume: airway structure and air traffic flow; and

- operational phase: this phase addresses a temporal horizon where 1-hour schedule of conventional aircraft is evaluated. The goal is to analyse how the introduction of RPAS affects one specific schedule.

2.1 Design phase

This phase evaluates the way the integration of RPAS affects the airspace in a design or strategic phase. Thus, this analysis covers different input variables as the morphology or geometry and the main characteristics of the air traffic flow that operates at the airspace. The main results of this phase are:

- thorough knowledge of the current airspace state, where it is intended to integrate RPAS jointly with conventional aircraft; and

- identification of the airways and FLs that allows their segregated use for RPAS. The segregated use implies that the RPAS can fly without any affection to the conventional aircraft.

Design-phase indicators provide information about the state of the airways and the crossing points. They are the most elementary components to analyse the current operational situation of the airspace. These indicators separately evaluate the morphological and geometrical features of the airspace (static indicators) and their operation (dynamic indicators).

2.1.1 Static indicators

Static indicators provide information to analyse the current state of the airspace based on its morphology and geometry. The goal is to perform a prior analysis setting out the airspace design. Static indicators focus on the basic airspace components: airways and crossing points.

2.1.1.1 Static indicator of airway complexity

The complexity of an airway is characterised by the sections that are exposed to risk. The risk in an airway is modelled by the locations of the airway that are exposed to conflict with aircraft of other airways. These sections are denoted as critical sections ($d_{i,j}$) around the crossing point. The static indicator of airway complexity relates to the ratio of the airway that is exposed to conflict in regards to the whole length of the airway (L_i).

$$\begin{aligned} \beta_i &= \frac{\sum_{j \neq i} d_{i,j}}{L_i} \\ d_{ij} &= \frac{2S_{min}}{\sin \alpha_{ij}} \end{aligned} \tag{1}$$

where i and j are the airways that intersect at the crossing point, $\alpha_{i,j}$ is the angle between both airways, and S_{min} is the separation minima (typically 5 Nautical Miles—NM).

2.1.1.2 Static indicator of crossing-point complexity

The complexity of a crossing point depends on the number of intersections between the airway pairs that coincides at it and the angle between the airway pairs. In this way, combining both factors, it can be calculated the static indicator of crossing-point complexity:

$$\gamma_n = \frac{\sum_{WP_n} d_{i,j}}{d_{elem}} \tag{2}$$

where $\sum_{WP_n} d_{i,j}$ is the sum of all critical sections in a crossing point (WP_n) and d_{elem} represents the elementary critical section. The elementary critical section is calculated for the crossing angle of 90^0, which provides the minimum critical section.

2.1.2 Dynamic indicators

Dynamic indicators focus on the operational features of the airspace. This allows analysing the operational characteristics of the air traffic flows to select the airway that favour or inhibit the RPAS integration.

2.1.2.1 Dynamic indicator of airway density

This indicator provides information about the number of aircraft that operates an airway. It relates the real airway density (Q_i) and the theoretical maximum air traffic flow through it $\left(Q_i^{max}\right)$.

$$\delta_i = \frac{Q_i}{Q_i^{\acute{m}ax}}$$
$$Q_i^{\acute{m}ax} = \frac{(\overline{v_i})}{S_{min}} \tag{3}$$

where $(\overline{v_i})$ is the average speed of aircraft in airway i.

2.1.2.2 Dynamic indicator of crossing-point density

Taking into account the operational characteristics of the airspace, the dynamic indicator of crossing-point density provide an indicator of the number of aircraft that pass through it.

$$\epsilon_n = \sum_{\substack{i,j \in WP_n \\ i \neq j}} \delta_i \tag{4}$$

2.1.2.3 Dynamic indicator of airway conflict

This indicator evolves from the previous dynamic indicators with a different goal. δ and ϵ are relative counters of the air traffic through the airways and crossing points, while ζ is the dynamic indicator of airway conflict. This indicator provides information about the possibility of conflict depending on the airspace operational features.

$$\zeta_i = \sum_{\forall n \in i} \sum_{\substack{i,j \in WP_n \\ i \neq j}} \delta_i \delta_j \tag{5}$$

Moreover, this indicator also works as a reference value to analyse the air traffic segregation by airways and FLs. Therefore, it is needed to calculate the total value for the whole airspace based on the sum of every airway conflict indicator:

$$\zeta_{tot} = \sum \zeta_i \tag{6}$$

2.2 Operational phase

The operational phase focuses on a different temporal horizon than the design phase. The operational phase is characterised by the disappearance of generic air traffic flows (modelled by airway density and average ground speed), and it entails a one-hour schedule. This schedule of air traffic fulfils the operational characteristics of the scenario, but each aircraft has its own characteristics (speed and entry time). Besides, this concept will relay on further work based on 4D trajectories. The operational phase allows the introduction of RPAS in specific schedules. Apart from analysing how this introduction affects the risk indicators, this phase provides the following results:

- in-depth knowledge of the path evolution from the conventional aircraft schedule;

- safety assessment for the RPAS integration for different schedules based on the risk indicators; and

- identification of airways and FLs that favour or inhibit the introduction of RPAS based on the airway availability.

Operational-phase indicators provide information about the whole airspace. In this way, they permit to appraise the airspace situation by the RPAS integration. These indicators conclude if the integration of RPAS is feasible and the temporary restrictions.

2.2.1 Number of conflict

N_c is the number of times that the separation minima are infringed (5 NM in European en-route airspace).

$$N_c = Number\ of\ times\ \min\left(sep(t)\right) < S_{min} \tag{7}$$

where $min\ (s(t))$ is the minimum distance between an aircraft pair.

2.2.2 Conflict severity

Conflict severity (θ) is an indicator of the seriousness of the conflict, as not every conflict implies the same severity. Conflict severity is calculated by the combination of the conflict time span (τ) and the minimum distance reached by an aircraft pair:

$$\theta = \min\left(sep(t)\right)\tau \tag{8}$$

2.2.3 Airway availability

This indicator aims to calculate the risk exposition of an aircraft flying an airway. This indicator is called airway availability because it links the time span the aircraft can safely fly an airway with the time span the aircraft can suffer a conflict. Knowing the airways that present higher availability (the time span the aircraft can safely fly without suffering a conflict), it can be extracted the airways that favour or inhibit the integration of RPAS.

λ_i indicator is based on the Temporary-Blocking Windows (TBWs) concept [29, 30]. The TBWs are calculated for every aircraft pair, i.e. the time span that the airways are blocked because a separation minima infringement will occur. The primary features of the TBWs are:

- the time duration of the TBWs depends on the crossing angle of the airways and the ground speed of the aircraft involved; and

- the time location of the TBWs depends on the entry time of the conventional aircraft and RPAS, length of the airways, the ground speed and the distance between the airway entry-point and the crossing point.

λ_i is calculated by the size of overall TBW (d_{BW}) that affect the airway i. Therefore, the risk exposition of an aircraft relates the non-available time (t_{NA_i}) and the exposition time (t_{exp}):

$$\lambda_i = 1 - \frac{t_{NA_i}}{t_{exp}} \text{ where } 0 \leq \lambda_i \leq 1 \tag{9}$$

Herein, the exposition time relates to a one-hour schedule. A minor TBW implies a bigger airway availability, which reduces the risk exposition. Moreover, airway availability is a novel indicator defined in this work. There is no previous knowledge about the threshold that this indicator should acquire. Then, the authors propose a division into four stretches (0–25%, 25–50%, 50–75% and 75–100%). Airways with airway availability greater than 50% are airways where RPAS could be included.

3. Risk-based framework application

The risk-based framework was applied to the air traffic volume LECMPAU (Pamplona) in Spain. This airspace is constituted by 24 airways and 55 crossing points. The period of study was July and August 2016, and the operational data was obtained from NEST [31].

3.1 Design phase

This section introduces the results of the design phase in the strategical horizon. This is the most valuable innovation of this work, and a further motivation is related to the fact that this methodology could also be applied to a pre-tactical phase. The design phase focused on a fix air traffic distribution for the whole day while in the pre-tactical phase, a temporary variation of the air traffic flow for a specific day could be considered. However, the application for a pre-tactical phase was out of the scope of this work. The process was as follows:

1. airways and crossing point were characterised based on the geometric information (length, angle and critical section) and operational information (air traffic flow and average speed); and

2. static and dynamic indicators were calculated for each airway and crossing point. With this information, we ordered and analysed which of them had a greater impact on safety.

3.1.1 Design-phase indicators

Firstly, design-phase indicators are calculated for LECMPAU both for airways and for crossing points. However, for the sake of clarity, we only present the results for the airway due to the high number of crossing points. **Table 1** shows the results for the design-phase indicators of the LECMPAU airways.

β_i indicator was constituted by the number of crossing points, the number of intersecting airways, their crossing angles and their lengths. The primary conclusions were:

- most of the values of β_i were, in general, very high because LECMPAU presented 55 crossing points and 24 airways;

- the lowest values referred to the airway UM190 ($\beta_{UM190} = 0,7518$) because there were only two intersections. This airway presented 75% of complexity

Airway	β_i	δ_i
UN858	1.00	0.0037
UM190	0.75	0
UP181	3.18	0.0090
UL176	4.40	0.0267
UQ262	5.42	0
UQ148	2.07	0
UN10	3.25	0.0267
UN857	3.92	0.0046
UL866	7.17	0.0005
UN995	7.03	0.0043
UN976	3.14	0.0275
UM601	2.84	0.0478
UM176	4.00	0
UQ57	3.04	0
UQ73	3.94	0
UT430	2.09	0
UP152	4.03	0.0034
UN725	1.21	0.0385
UQ400	1.18	0
UQ88	1.46	0
UL184	1.93	0
UQ424	1.45	0
UQ300	1.52	0
UQ268	2.10	0

Table 1.
Design-phase indicators for LECMPAU airways.

that was very high, although this was the lowest value. This meant that throughout the 75% of the airway length, an aircraft could suffer conflict with other air traffic flows; and

- the highest values were referred to as airways UQ262 ($\beta_{UQ262} = 5,4207$ with 6 intersections), UL866 ($\beta_{UL866} = 7.1743$ with 9 intersections) and UN995 ($\beta_{UN995} = 7,0303$ with 9 intersections). It was obvious that the number of intersections implied higher values of complexity, but it was also remarkable that the length of the airways was a crucial factor for complexity. Therefore, the crossing point PPN was the most concurred and provided the highest value of complexity.

Therefore, the highest values of the airway complexity static indicator were referred to the airways that concurred at crossing point PPN. **Figure 1** shows a representation of the static indicators of the airway and crossing-point complexity.

Regarding the dynamic indicator of airway density (δ_i), see **Table 1**, there were 13 airways without air traffic (54%) and 25 crossing points without air traffic (45%)

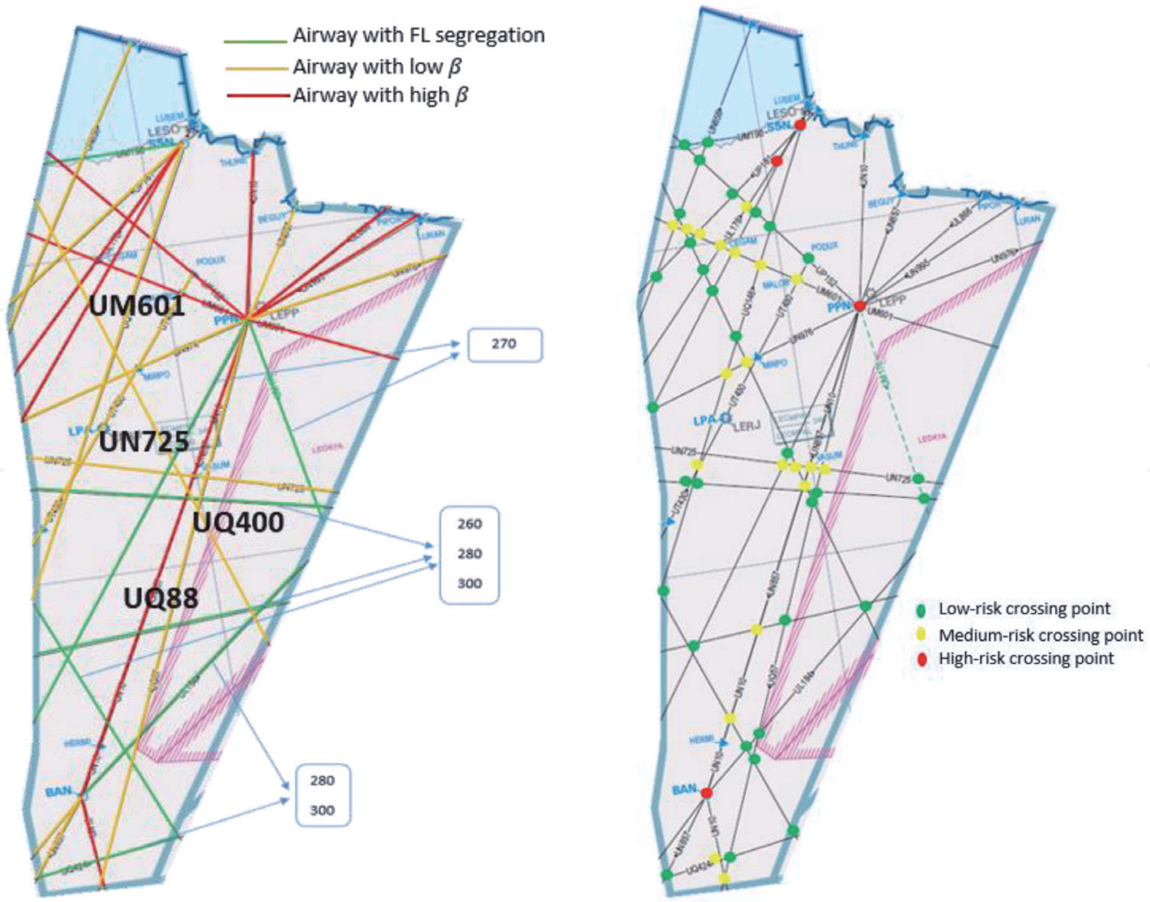

Figure 1.
Results of the design-phase analysis.

in this airspace. This implied that the air traffic flow distribution was rather concentrated in specific airways and crossing points.

3.1.2 Airway segregation

The airway segregation aimed to identify the airways (or geographical restrictions) that allowed the safe integration of RPAS because they did not generate conflicts with conventional aircraft. First, the total value for the whole airspace of the dynamic indicator of airway conflict ($\zeta_{tot} = 0.0037$) was calculated. Second, the airways without air traffic were individually evaluated by the introduction of RPAS through them ($\delta_i = 0 \rightarrow \delta_i = 1$). Then, ζ_{tot} was recalculated to check if the new ζ_{tot} exceeded the base-scenario value. In this case, the airway could not be segregated because the introduction of RPAS increased current risk levels; otherwise, RPAS could be introduced because they did not cross with other air traffic flows. **Table 2** presents the results of the indicator ζ_i.

As can be seen in **Table 2**, no airway was identified for its segregation.

3.1.3 FL segregation

The primary conclusion of the previous section was that no airway could be segregated at LECMPAU. In spite of this limitation, this work evaluated the existence of specific FLs that allowed the safe integration of RPAS. The process was similar to airway segregation but focusing on the FLs of interest: from FL250 to FL300.

Airway	ζ_{tot}
UM190	0.0108
UQ262	0.1449
UQ148	0.1567
UM176	0.0422
UQ57	0.0689
UQ73	0.0422
UT430	0.1210
UQ400	0.0304
UQ88	0.0304
UL184	0.0350
UQ424	0.0350
UQ300	0.0304
UQ268	0.1837
Base-scenario ζ_{tot}	0.0037

Table 2.
Results of ζ_{tot} for LECMPAU airway segregation.

There are five airways that could be segregated at different FLs for the integration of RPAS, see **Figure 1**. UQ400, UQ88 and UQ300 presented three FLs (260, 280 and 300) where RPAS could be integrated without any interaction with conventional aircraft. UM176 and UQ74 could be segregated at FL270 (see **Table 3**). ζ_{tot}^{FL} varied for each FL their value, which implied that it would be required to estimate a specific and independent value for ζ_{tot}. This independent value would remove inefficiencies for the integration of RPAS.

3.2 Operational phase

3.2.1 Base schedule with RPAS

To study the operational phase, a real one-hour schedule was selected from the rush hour of LECMPAU at FL290. **Table 4** shows the operational information of the schedule composed of four conventional aircraft and one RPAS. In this schedule, one RPAS is introduced by UM176 with a typical speed of 250 kts.

3.2.2 Temporary-blocking windows (TBWs)

The first step was to calculate the TBWs that will underline the airway indicator and conflict detection. **Table 5** provides de length or time span of the TBWs for the different aircraft that could interact between them.

The length of the TBWs increased with the RPAS due to its lower speed. The TBWs (i.e. the time exposed to conflict) almost doubled the value for conventional aircraft. **Table 6** provides the temporary limits (initial and final) for the TBWs between aircraft pairs.

3.2.3 Operational-phase indicators

According to the TBWs, aircraft with an entry time located inside the TBWs entailed a conflict between those aircraft pairs. In this example, there was no

Airway	ζ_{tot}^{250}	ζ_{tot}^{260}	ζ_{tot}^{270}	ζ_{tot}^{280}	ζ_{tot}^{290}	ζ_{tot}^{300}
UN858	0	0	0	0	0	0
UM190	0.4903	0.5911	1.0445	1.7939	2.3628	1.1805
UP181	0.5528	0	0	0	0	0
UL176	0.2512	0	0	0	0	0
UQ262	0.4382	1.0439	1.5495	3.0551	2.7039	2.5510
UQ148	0.5058	0.9344	1.4552	2.7312	2.8154	2.9160
UN10	0	0.7542	0	1.1512	0	1.6451
UN857	0	0	0	1.0887	0	0.9156
UL866	0.9234	0.4331	1.1965	1.0887	0	0.9156
UN995	0	0	0	0	0	0
UN976	0	0	0	0	0	0
UM601	0	0	0	0	0	0
UM176	0.2564	0.2888	0.4519	0.9624	2.2068	1.4878
UQ57	0.3028	0.2888	0.5137	0.9624	2.4138	1.4878
UQ73	0.2564	0.2888	0.4519	0.9624	2.2068	1.4878
UT430	0.5058	0.4726	1.0935	1.9611	2.4653	2.5284
UP152	0.4903	1.0529	0	0	2.7128	1.5682
UN725	0	0	0.5137	0	0	0
UQ400	0.2351	0.1690	0.5137	0.8999	2.2080	0.7584
UQ88	0.2351	0.1690	0.5137	0.8999	2.2080	0.7584
UL184	0.6088	0.3702	0.9449	0.8999	2.6966	0.7584
UQ424	0.6088	0.3702	0.9449	0.8999	2.6966	0.7584
UQ300	0.2351	0.1690	0.5137	0.8999	2.2080	0.7584
UQ268	0.8537	1.3565	1.0451	2.5607	3.3841	3.3381

Table 3.
Values of ζ_{tot}^{FL} for each airway and FL.

Aircraft	Airway	Entry time	*FL*	*V(kts)*
1	*UL*176	12:13:56	290	310.13
2	*UM*601	12:20:31	290	416.67
3	*UN*10	12:25:00	290	420.11
4	*UL*176	12:57:28	290	351.75
RPAS	*UM*176	12:30:00	290	250

Table 4.
Schedule of LECMPAU with one RPAS.

conflict between any aircraft. In the same way, there was no conflict; the indicator of conflict severity was zero.

However, airway availability was calculated for all airways taking into account base schedule, see **Table 7**.

The airway availability indicator decreased with the introduction of RPAS. In the case $\lambda_i = 0$ (UQ262 and UN857), it meant that there was no availability of this airway because the introduction of an RPAS through the airways could imply one

Aircraft	1	2	3	4	*RPAS*
1	—	206	—	—	—
2	206	—	177	192	310
3	—	177	—	—	641
4	—	192	—	—	—
RPAS	—	310	641	—	—

Table 5.
Temporary-blocking windows (sec) for the base schedule.

Aircraft	1	2	3	4	*RPAS*
1	—	[12:15:18, 12:18:44]	—	—	—
2	[12:15:43, 12:19:08]	—	[12:20:19, 12:23:16]	[12:16:25, 12:19:37]	[12:14:12, 12:19:22]
3	—	[12:22:15, 12:25:12]	—	—	[12:14:40, 12:25:21]
4	—	[12:58:22, 13:01:34]	—	—	—
RPAS	—	[12:51:09, 12:56:19]	[12:49:39, 13:00:20]	—	—
Entry time	12:13:56	12:20:31	12:25:00	12:57:28	12:30:00

Table 6.
Initial and final time of the TBWs.

Airway	λ_{AWYj}
UN858	0.8932
UM190	1
UP181	0.1488
UL176	0.8917
UQ262	0
UQ148	0.2907
UN10	0.8901
UN857	0
UL866	0.6741
UN995	0.7024
UN976	0.7093
UM601	0.7007
UM176	0.5572
UQ57	0.3298
UQ73	0.6176
UT430	0.8931
UP152	0.4501

Airway	λ_{AWYj}
UN725	0.8911
UQ400	0.8890
UQ88	0.8736
UL184	1
UQ424	1
UQ300	1
UQ268	0.6802

Table 7.
Airway availability indicator for FL290.

conflict during the 1 hour. On the contrary, in the case $\lambda_i = 1$ (UM190, UL184, UQ424 and UQ300) there was full availability for the safe introduction of RPAS. In other words, those airways allowed the introduction of RPAS because no interaction with conventional aircraft would occur. Results of this indicator should provide similar results to the dynamic indicator of airway conflict. However, air traffic flows of the operational phase are not the same as the design phase because of the specific rush hour characteristics.

4. Conclusions

This research developed a new risk-based framework to evaluate the safe introduction of RPAS in non-segregated airspace. The risk-based framework tackled two temporal horizons for the introduction of RPAS based on a design phase (strategical horizon) and an operational phase (tactical horizon). This innovative approach allowed considering the different variables that affected the aircraft operation at both temporal horizons, which ensured a hierarchical assessment. The design phase covered different input variables as the morphology or geometry, and the main characteristics of the air traffic flow. Meanwhile, the operational phase was characterised by the disappearance of generic air traffic flows (modelled by airway density and average ground speed) and focused on a one-hour schedule (constituted by conventional aircraft and RPAS). Different indicators were modelled depending on the temporal horizon. The design phase considered static and dynamic indicators (based on the airspace structure and generic air traffic flows). The operational phase considered three indicators: number of conflicts, conflict severity and airway availability. The application of the methodology was to detect geographical restrictions (airways that favour or inhibit the integration of RPAS) and temporary restrictions (when the RPAS can pierce into the airspace without generating any conflict).

This methodology was applied to Spanish airspace LECMPAU at different FLs from FL250 to FL300, which were the most favourable for RPAS integration due to their low density. The different static indicators ordered airways considering their complexity. LECMPAU was a complex scenario because of the high number of airways and crossing points. The airway segregation analysis concluded that no full airway could be segregated for RPAS; however, different FLs could be used considering their segregation for RPAS. The segregation of FLs for RPAS implied that they could operate these FLs without being exposed to conflict with conventional aircraft. A one-hour schedule of conventional aircraft was analysed for the introduction of one RPAS. Operational-phase indicators were assessed and based on the temporary-blocking windows, no conflict arose. The temporary-blocking windows provided the temporary restrictions for the integration of RPAS. Moreover, the airway availability indicator ordered the airway providing information about the airways that favoured (or inhibited) the introduction of RPAS with the operational-phase specific schedule. Regarding future research lines, the calculation of an independent and fixed value for conflict probability is crucial for the assessment of different airspaces and FLs. A further goal will be the analysis of the whole process to introduce flight plans of RPAS in non-segregated airspace ensuring safe scenarios.

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Conflict of interest

The authors declare no conflict of interest.

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