U-space separation management service: concept definition and validation

BUBBLES Concept of Operations

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Abstract— **Over the last decade, the unmanned aircraft industry has attracted a great deal of interest due to its potential and multitude of applications, especially in urban environments. This has led authorities and the general public to raise different issues and concerns, among which safety is the most prevalent. Safety is one of the pillars of BUBBLES, an Exploratory Research (ER) project funded by SESAR Joint Undertaking (SJU) that aims to define a new concept of operations to provide separation management in U-space airspaces. The main contribution of BUBBLES is to provide guidelines for dealing with conflict management in tactical phase, i.e., the separation provision phase, in U-space airspaces. In the context of BUBBLES, this paper presents the concept of separation management service, which applies dynamic separation minima tailored to the traffic class, the operational environment, and the performance of the Communication, Navigation and Surveillance (CNS) system. This concept has been validated through test flights in a rural environment simulating operation in a U3 environment, including a basic Human Performance Assessment (HPA).**

Keywords- Separation management; U-space; separation minima; separation provision; BUBBLES; UAS (Unmanned Aircraft System).

I. INTRODUCTION

Safety has been paramount in air traffic transport since the dawn of aviation. Conflict management is one of the main enablers of safety in aviation. According to [1], conflict management encompasses activities meant *to limit, to an acceptable level, the risk of collision between aircraft and hazards*. Conflict management is distributed in three layers: strategic conflict management, separation provision, and collision avoidance. Separation provision corresponds to the tactical layer of conflict management, which should be used when strategic conflict management is not enough to guarantee the required level of risk.

Conflict management in manned aviation is characterized by the participation of human beings, the relatively low density of operations, and the centralized distribution of separation provision by ATC (Air Traffic Control). However, the U-space presents a much different scenario, characterized by high levels of automation, a higher density of operations, and the distribution of service provision among several USSPs (U-space Service Providers). Therefore, the direct application of traditional conflict management processes to U-space airspaces is not appropriate due to the differences between both scenarios.

In manned aviation, there are a set of separation minima defined according to standard procedures like those described in [4] and separation provision uses a few fixed separation minima for different scenarios. For instance, in [5], separations of 2, 2.5, 3, and 5 NM are used as reference separation minima to derive safety and performance requirements for generic surveillance sensors. Higher separations are used over oceanic or desert areas as they lack sufficient surveillance infrastructure. This is possible because manned aircraft have similar performances and fly rather simple trajectories. However, applying this approach to UAS operations, whose performance and mission types are more varied, leads to waste airspace capacity, as the airspace would have to be allocated considering that all aircraft are performing the operations that require the highest separation. Also, according to [1], as the environment and surveillance performance can change, separation minima can be dynamically adjusted to better suit the current status of the airspace.

Therefore, BUBBLES proposes a Concept of Operations (ConOps) for a Separation Management Service (SMS) provided by the U-space, whose objective is to fill these gaps by providing airspace users (i.e.: operators and USSPs) with the information required to guarantee that the separation provision layer of the conflict management process is performed homogeneously and according to specified criteria, within U-space airspaces in which SMS is provided. Although the ideas behind this ConOps may be applied to any of the hazards considered in [1] (other aircraft, terrain, fixed obstacles, etc.), it has been implemented and validated considering the hazard posed by other aircraft, manned or unmanned. Therefore, the terms 'hazard' and 'aircraft' are used interchangeably hereinafter.

BUBBLES ConOps is aligned with the tactical conflict management described in [1] for manned aviation, which aims to limit the risk of collision between aircraft and hazards to an agreed level considered acceptable, keeping aircraft away from hazards by at least the appropriate separation minima. The scope of this concept covers UAS operating in the open, specific and certified categories defined in [2]; therefore, large RPAS flying under Instrumental Flight Rules (IFR) are not considered. The baseline for the development of this concept is the concept of operations (ConOps) developed by CORUS project [3].

Thus, the main goal of this paper is to present the BUBBLES ConOps defining separation management in the U-space. Then, the platform/tool that was developed to provide such a service and the test flights that were carried out in a real environment to validate the ConOps are explained.

The present paper is organized as follows: section I sets up the framework where the concept is developed and justifies the need for such a concept; section II outlines the ConOps for separation management in U-space airspaces; section III details how this concept has been validated, including the description of the platform developed to monitor the UAS applying the separation management service, and the organization of the flight tests; section IV shows the results obtained from a technical point of view and from the Human Performance assessment; and section V contains the main conclusions.

II. BUBBLES SEPARATION MANAGEMENT CONCEPT

The separation management service focuses on defining how the separation provision at tactical level must be implemented in a given U-space airspace so that all the conflicts arising therein are solved applying the same rules and a particular Target Level of Safety (TLS) is achieved.

Separation provision is an iterative process consisting of four steps [1]: (1) conflict detection, (2) solution formulation, (3) solution implementation, and (4) solution monitoring. To understand the information that need to be covered by the separation management service, a description of the separation provision process is explained next.

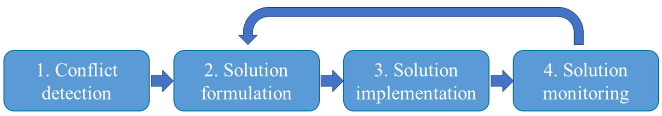

Figure 1. Separation provision process.

The *detection of a conflict* is based on the latest known position of the involved aircraft and its predicted trajectory. This step consists of predicting the expected distance at the closest point of approach (CPA) and the remaining time to the CPA within a given conflict horizon. A tactical conflict will be triggered if the distance at the CPA is less than the corresponding separation minima and the time to the CPA is lower than a pre-established threshold.

Solution formulation involves the identification of a separator, the definition of separation modes and the selection of separation minima and methods to be used. The solution formulation strongly depends on the intervention capability, which is the capability of humans and/or systems to detect and solve a conflict.

- *The designation of a separator.* The separator is the agent (either a human being optionally supported by an electronic system or a fully autonomous system) responsible for separation management when a conflict is detected. It can be either the airspace users or a USSP.
- *The selection of a separation mode.* The separation mode consists of an approved set of rules, procedures and conditions of application associated with separation minima and methods.
  - Separation minima are the distances aircraft must be kept away from the considered hazards so that an agreed Target Level of Safety (TLS) can be achieved.
  - Separation methods are specific maneuvers that need to be executed to maintain the separation minima.
  - Separation rules and conditions specify how the separator agent must apply the separation minima and methods.

The *solution implementation* is a three-fold process: (1) the solution defined in step 2 is notified to the agent who controls the UAS; (2) the agent executes the maneuvers needed to avoid the hazard; AND (3) the UAS performs the maneuvers executed by the agent in control. How the solution is implemented strongly depends on the automation level.

The *monitoring of the execution of the solution*. BUBBLES considers different agents in charge of monitoring the implementation of the formulated solution and warning the separator agent in case it is ineffective.

To properly conduct the separation provision process, the definition of what a tactical conflict is, as well as the applicable separation minima, are required. In addition, the applicable rules for solution formulation and implementation shall be clearly defined and published, so that all involved agents are able to follow the same set of rules. Finally, the responsibilities of the involved agents shall also be clearly defined.

Therefore, the SMS goal is to make available all the information required for U-space airspace users to guarantee that all tactical conflicts occurring within the U-space airspace in which such a service is provided are solved according to a pre-established set of rules and procedures, and a target effectiveness of the separation provision is achieved so that a particular TLS can be attained.

To ensure the harmonization of the conflict management process among all involved stakeholders, the separation management service is required to be centrally provided, acting as the single point of truth from which all airspace users collect the data required to execute the separation provision phase.

In particular, the SMS is in charge of providing all the U-space users involved in the management of tactical conflicts with all the information that is needed so that conflicts are solved applying the same set of rules and the same separation minima in order to achieve a predefined TLS. The separation management process must provide information about:

- The conflict horizon.
- The separator.
- The separation mode.
- The separation method.

- The separation minima.
- The required SPR/HPR (Safety and Performance Requirements/Human Performance Requirements).

To this purpose, the separation management concept is structured in 5 blocks, each of them charged with the responsibility of providing one particular piece of information so that the service can be provided by assembling them. Figure 2 shows the conceptual architecture of the BUBBLES separation management, where the green boxes correspond to static information defined at pre-operational level and the dark blue one stands for information which is dynamically updated at operational level.

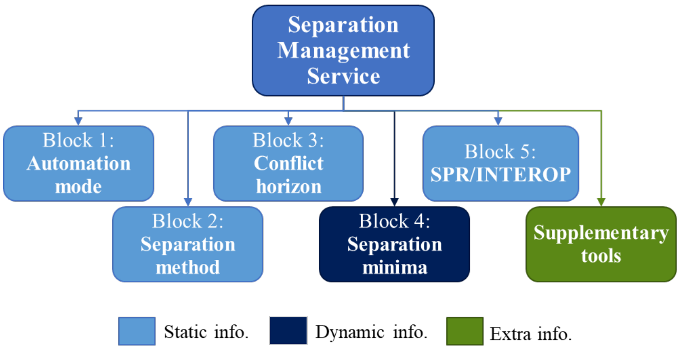

Figure 2. Conceptual architecture of the BUBBLES separation management service.

The *first block* is in charge of the definition of the available options regarding the level of automation to be used for tactical deconfliction processes. This block also defines the agents responsible to execute any of the four steps of tactical deconfliction (conflict detection, solution formulation, solution implementation, and monitorization of the solution), according to the used level of automation.

The *second block* is focused on the description of the possible maneuvers and/or actions that UAS operators and USSPs can use during the solution formulation step of the tactical deconfliction process.

The *third block* defines the Conflict horizon[1] to be considered during the solution formulation step of the tactical deconfliction process. The conflict horizon defined by the separation management service is related to the probability that the proposed separation maneuvers will lead to additional conflicts with nearby aircraft.

The *fourth block* consists of the publication of the applicable separation minima in the pre-operational and operational phases. In the operational phase, the separation minima are a dynamic value that are updated in real time depending on the CNS performance.

The *fifth block* consists in the publication of the SPR/INTEROP (Interoperability requirements) related to separation management that are required UAS operators and USSPs to operate in a U-space airspace.

To produce the information needed to support the solution of tactical conflicts, the SMS uses a set of supplementary tools, namely: (1) BUBBLES reference scenarios; (2) Accident Incident Model (AIM); (3) Target Level of Safety that must be attained; (4) tools to estimate the risk of mid-air collision; and (5) tools to compute the airspace capacity limit due to mitigated mid-air collision risk.

The separation management service could be considered as a U-space supporting service: it provides data to be used by other services as Tactical Conflict Resolution service, Common Information service or Drone Operation Plan Processing.

III. Concept Validation Plan

In order to validate the concept of separation management service described above, BUBBLES project developed a U-space platform, called BUBBLES Separation Management Environment (SME). This platform, as well as the BUBBLES concept, were tested in an experimental exercise by means of test flights.

A. Exercise description

The validation exercise consisted of test flights involving 14 drones from different operators performing their missions simultaneously in a real scenario near the city of Valencia (Spain).

During the validation exercise, conflicts were induced in a controlled way to validate the safety assessment and CNS performance degradation was manually induced to simulate abnormal conditions. In particular, GPS (Global Positioning System) positioning errors, packet losses and communication channel latencies were injected to simulate degradation. Performance of the platform in terms of conflict detection and alert declaration was assessed post-flight.

During the operations, traffic information regarding drone positioning data was sent to SME platform, which detected any conflicts and provided the required alerts to the pilots, including relevant information to solve them. And after the flights, an elementary Human Performance (HP) assessment was carried out by means of questionnaires with the aim of receiving feedback from the pilots on the different factors affecting conflict management and the operational feasibility and acceptability of the SME platform.

Finally, all telemetry data were recorded and carefully analyzed after the test flight campaign in order to detect that the alerts were triggered at the appropriate distance and that separation minima were correctly updated according to the CNS performance status.

Thus, the expected achievements of the validation exercise are: (1) to detect conflicts by SME platform and solve them by giving alerts with suggestive maneuvers to pilots; (2) to check if

[1] The extent to which hazards along the future trajectory of an aircraft are considered for separation provision [1].

the separation minima are properly adapted to the environment according to the CNS services performance; and (3) to receive feedback from pilots regarding the separation management and the SME through questionnaires.

B. Separation Management Environment (SME) platform description

The BUBBLES SME platform is an environment developed to monitor drones in real-time that provides the concept of U-space separation management described above and in [6]. This platform includes the basic U-space services required for the good functioning of the test flights and the enhancements necessary to test the dynamic separation minima concept. It is also aligned with the Conflict management and separation service defined by [7].

Figure 3 shows the high-level architecture of the SME platform.

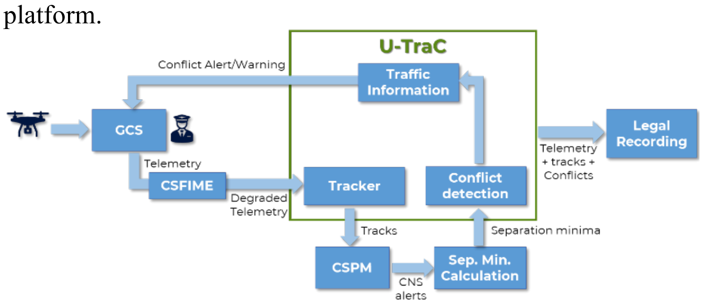

Figure 3. Architecture of SME platform.

Next, each of the components of the SME is described:

- *GCS (Ground Control Station).* This refers to the Android application developed by BUBBLES team based on de DJI Mobile SDK (Software Development Kit), which connects the drones with the SME platform. This app. allows the pilot to fly the drone while sending telemetry data to the U-TraC, via 4G connection, and receiving relevant information from it, such as tactical conflict alerts or nearby traffic.
- *CSFIME (Communication and Surveillance Fault Injector and Monitoring Environment).* This component adds degradation in the down link to the telemetry data sent by the drone to the U-TraC. The degradation includes GPS position errors, latencies, and loss of packages.
- *U-TraC (U-space tracking & Conflict detection)* provides separation management and some other needed U-space services for the test flights. The U-TraC is composed of a tracker, a conflict detection component, and a pseudo-traffic information service.
- *CSPM (Communication and Surveillance Performance Monitoring)* tool is used for two purposes: (1) to compute performance metrics to assess and evaluate the effects in the surveillance performance due to degradation of surveillance data; and (2) to measure and assess the communications performance evaluating the quality of the communication channel.
- *SMC (Separation Minima Calculation).* It consists of a service that, given a CNS performance, sends to the U-TraC the separation minima adapted to the situation. This component includes AI algorithms to compute the separation minima in real-time.
- *Legal recording.* Component to save the telemetry data, the tracks, and the conflict alerts for post-processing purposes.

When operating, the SME platform:

1. Receives telemetry and registration information that the drones GCS transmits to the tracker.
2. The CSFIME adds degradation into the telemetry data.
3. The tracker, built-in in the U-TraC component, processes the received UAS degraded reports and generates drone tracks using Kalman filters.
4. The CSPM component compute performance metrics to assess and evaluate the effects due to degradation on the communication and surveillance data. When degradation is detected, it sends a message to the Separation Minima Calculation (SMC) component.
5. The SMC component computes the separation minima applicable to each aircraft according to the operational environment, the type of traffic, and the CNS performance status, applying AI algorithms.
6. The Conflict detection components detects conflicts of different severity (up to 4 types of separation events as it is defined in the BUBBLES AIM) computing the pairwise separation between UAS.
7. When a conflict is detected, it transmits an alarm/warning to the GCS through the Traffic Information component. The message includes the position of the conflicting UAS and a suggested maneuver in the vertical dimension to solve the conflict.
8. Then, telemetry data, tracks, conflicts, and the information about the involved UAS is recorded for post-processing.

The SME platform has also a graphical interface (see Figure 4) where tracks, relevant traffic information and conflict messages generated in an operational volume can be viewed in real-time.

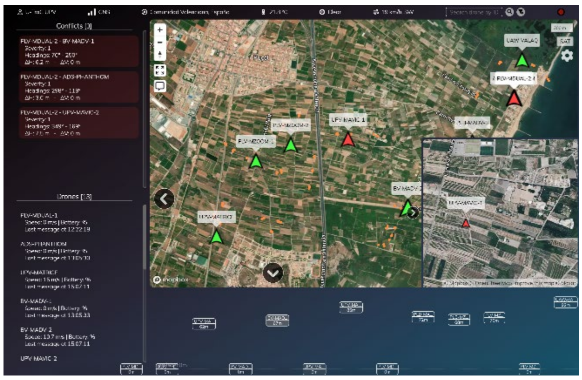

Figure 4. BUBBLES SME platform interface.

To connect the drones to the SME platform, an Android application has been developed for the pilot controllers (see its graphical interface in Figure 5), named GCS in Figure 3. The app. sends the UAS telemetry data and receives conflict alerts, suggestive maneuvers and other traffic information as nearby traffic or CNS status.

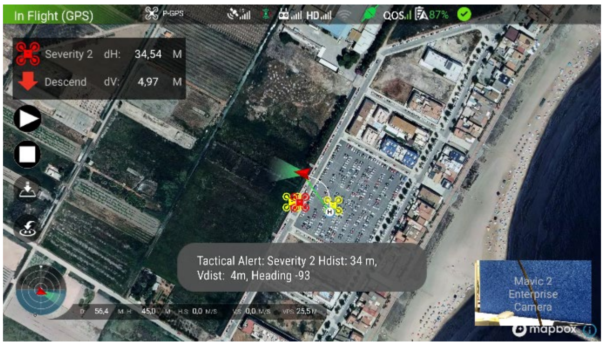

Figure 5. Pilots App interface.

C. *Organisation of test flights*

The test-flights were performed in a rural scenario of 15km^2, in an uncontrolled airspace in a medium-sized village in the north of Valencia (Spain). The flights involved 7 different experienced operators, including companies, security forces, fire brigades and professional pilots; with 14 different drones. The traffic density of this scenario would represent a future medium/high density scenario.

For each drone, a representative mission and operational category was assigned (see Table 1). Operations were representative of what could be a future scenario in an area close to the city, combining surveillance activities, delivery, or agricultural tasks.

TABLE 1. MISSIONS TO BE CONDUCTED DURING THE TEST-FLIGHTS.

iD	Mission	Operator	Operational category	Drone
1	Railway inspection	UPV	STS-ES-02	DJI Matrice 300 RTK
2	Road inspection	Police of Valencia	STS-ES-02	DJI Mavic Enterp. Dual
3	Agricultural tasks	UPV	A3	DJI Mavic Enterp. Zoom
4	Surveillance tasks	Police of Valencia	A3	DJI Mavic Enterp. Zoom
5	Delivery-Town	UPV	STS-ES-02	DJI Mavic Enterp. Zoom
6	Delivery-Industrial Park	Police of Valencia	STS-ES-02	DJI Mavic Enterprise Dual
7	Beach surveillance	Police of Benidorm	A3	DJI Mavic Enterp. Zoom
8	Precision agriculture	Police of Valencia	STS-ES-02	DJI Mavic Enterp. Zoom
9	Surveillance of orchards for fire risk	Firefighters of Valencia	STS-ES-02	DJI Mavic Enterp. Advance
10	Rescue of a trapped animal	Firefighters of Valencia	STS-ES-02	DJI Mavic Enterp. Advance
11	Precision agriculture	AsDrón Spain	A3	DJI Phantom 4 PRO
12	Surveillance tasks	UAV works	A3	Valaq Patrol
13	Agricultural tasks	ASD drones	A3	DJI Mavic Enterp. Advance
14	Photogrammetry	Police of Benidorm	A3	DJI Mavic Enterp. Advance

Most of the drones were DJI multi-rotors between 1 and 9 kg MTOW, and there was also a fixed-wing UAS. The operations were conducted in Open Category, and in Specific Category under Spanish National Standard Scenarios, named STS-ES.

Figure 6 shows the area where flights were performed and the reference trajectories planned for each drone.

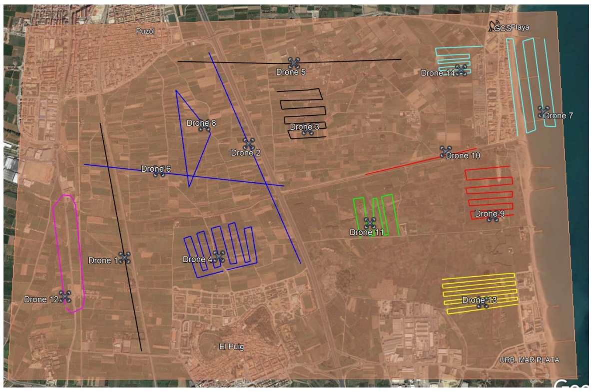

Figure 6. Operational volume and trajectories of test-flights.

For better representativeness, each mission was flown several times with different configurations, one of them flying the reference trajectories (trajectories shown in Figure 6) and other ones with deviations, changing their trajectories and causing conflicts. In addition, at certain instants of time, the CNS performance were degraded via the CSFIME component to simulate abnormal conditions.

So, a total of 4 tests were carried out:

- *Test 1:* Flights with autopilot. Each drone was assigned a flight plan and flew at a certain altitude, so that all flight plans were strategically deconflicted.
- *Test 2:* Manual flights following the reference trajectory. Each drone had their mission defined, as well as its flight level (separated in 3 layers at 30, 70 and 110m).
- *Test 3:* Manual flights following the reference trajectory. Each drone had their mission defined, but in this case all UAS flew in the same flight layer (between 65 and 75m altitude).
- *Test 4:* Manual flights following the reference trajectory. Each drone had their mission defined, and in this case, flight levels were completely free.

As mentioned above, in case of conflict, pilots were shown an alert on the controller indicating the other drone in conflict, the horizontal and vertical distance to it and a simple suggestion of a maneuver to solve it (ascend or descend). In case of multiple conflicts, the alert of the most severe conflict was displayed, i.e., the closest and the most urgent to solve.

Due to the lack of Right-of-way rules for unmanned aircraft, the proposed resolution maneuver was simple: when two drones came into conflict, the one above would ascend and the one below would descend. In addition, the structured layered airspace concept facilitated conflict resolution by vertical maneuvers. So, in all cases, pilots had to solve conflicts with vertical maneuvers. They had to give priority to the proposed maneuver, unless there was a setback such as the conflicting drone doing the same maneuver (e.g. pilot 1 was told to descend and pilot 2 also descended because he misinterpreted the information, so the conflict was not solved in a short period of time, in which case pilot 1 was free to solve the conflict as he considered to avoid an imminent collision).

The reference separation minima applicable during the flights is shown in Table 2. These distances were recalculated in real time depending on the CNS performance degradation. It should be noted that MAC (Mid-Air Collision), NMAC (Near Mid-Air Collision), IC/CA (Imminent Collision/Collision Avoidance), Loss of Separation and TC (Tactical Conflict) are the different protection volumes and separation events defined by BUBBLES in its collision model [6]. The first volume corresponds to conflict severity 0 and the last volume to severity 4. The traffic class in the tables is also based on BUBBLES' classification of aircraft according to their category of operation and sorted by level of risk.

TABLE 2. SEPARATION MINIMA FOR TEST-FLIGHTS.

Traffic Class	HORIZONTAL Separation Minima (m)				
	MAC	NMAC	IC / CA	Loss Sep	TC
A1	0.25	7.62	35.33	54.73	145.44
A2	0.5	7.62	35.33	54.73	145.44
A3	1	7.62	58.79	95.59	277.01
SAIL I-II	0.5	7.62	68.18	111.94	329.64
SAIL III-IV	1	7.62	72.30	123.02	366.52
SAIL V-VI	1	7.62	76.62	130.82	391.72
No pass.	2	7.62	119.79	208.79	643.62
Passenger	2.5	7.62	146.12	235.12	722.34

Traffic Class	VERTICAL Separation Minima (m)				
	MAC	NMAC	IC / CA	Loss Sep	TC
A1	0.125	2.286	8.176	11.786	22.867
A2	0.25	2.286	8.176	11.786	22.867
A3	0.5	2.286	8.176	11.786	22.867
SAIL I-II	0.25	2.286	8.176	11.786	22.867
SAIL III-IV	0.5	2.286	8.176	11.786	22.867
SAIL V-VI	0.5	2.286	8.176	11.786	22.867
No pass.	1	2.286	8.176	11.786	22.867
Passenger	1.25	2.286	8.176	11.786	22.867

IV. VALIDATION RESULTS

A. *Technical results*

After the flights, a post-analysis of the results obtained with the BUBBLES SME platform was made. Figure 7 shows the conflict distribution during all flight tests for each time instant, i.e. number of unique conflicts detected per minute.

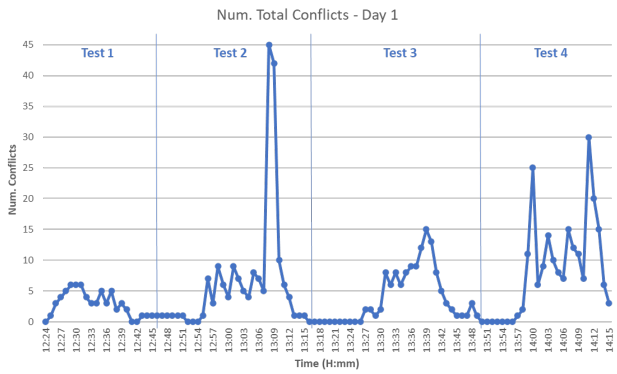

Figure 7. Number of conflicts per instant time and test.

In Figure 7, it is highlighted the peak of conflicts in test 2 due to a tracker stop, simulating a fault condition. Due to this failure, the separation minima increased significantly (see Figure 11, the increase in the tactical conflict separation threshold between 13:00 and 13:15) to preserve the level of safety, thus increasing the number of conflicts.

Table 3 summarizes the total number of conflicts in each of the tests performed and the average duration of conflicts, as well as the percentage of the conflicts solved.

TABLE 3. BUBBLES SME PLATFORM RESULTS.

Test	Conflicts detected	Mean conflicts duration (s)	Conflicts solved (%)
1	27	82.92	96
2	109	47.52	99
3	76	37.70	99
4	158	21.75	97

As can be seen, test 4, in which the drones flew at free altitudes, had the highest number of conflicts. In contrast, flying in assigned flight layers reduced the number of conflicts by half. Test 1 had the lowest number of conflicts, as they flew on autopilot and all flight plans were deconflicted in the pre-operational phase.

In tests 2 and 3 there are approximately the same number of conflicts, although when flying in the same layer the conflicts were shorter, because they were easier to solve, as there was no other drone above or below the drones in conflict and were quickly solved with a vertical maneuver. Thus, flying in structured airspace is arguably safer in terms of number of conflicts, although solving them requires a few seconds more on average. When layers are separated by at least 3 times the height of the aircraft protection volume, there is enough distance to solve conflicts without causing new ones, thus allowing a more efficient and safer use of airspace compared to unstructured airspace.

Looking at the last column of Table 3, almost all the conflicts were successfully solved thanks to the alerts sent to the pilots, except for some specific cases where the tests ended before they could be solved and in the post-processing exact times have been taken, leaving out the resolution times. Another small percentage of cases were momentary MQTT server crashes or loss of signal.

Analyzing the conflicts per severity, i.e. depending on what protection volume (as defined by BUBBLES [6]) is infringed, more than 95% of the conflicts were of severity 4, which are tactical conflicts (TC), and only 2.97% reached the loss of separation (see TABLE 4).

TABLE 4. NUMBER OF CONFLICTS PER SEVERITY

	Num. Conflicts	Percentage
Severity 1	2	0.54%
Severity 2	5	1.35%
Severity 3	11	2.97%
Severity 4	352	95.14%
Total	370	

This demonstrates that issuing an alert to pilots is very useful to solve potential conflicts and that the tactical mitigation barrier prevented more than 95% of tactical conflicts (severity 4) from evolving into imminent collisions (severity 3), at which point Collision Avoidance would come into play.

Below are two graphs showing the CPA distance of each of the detected higher severity safety events (severity 1 and 2) versus the collision threshold. That is, they show the minimum distance at which the conflicting drone pair stayed (green dot) compared to the distance considered as collision (blue line). The gray line shows the margin in meters between the CPA and the collision threshold (also named Mid-Air Collision - MAC).

The first graph (Figure 8) shows the two Severity 1 conflicts, considered Near-Mid-Air Collisions (NMAC), in which the innermost protection volume had been violated, according to the collision model developed by BUBBLES [6]. The second graph (Figure 9) shows the five Severity 2 conflicts, considered Imminent Collisions, in which the minimum distance of the second innermost protection volume was violated.

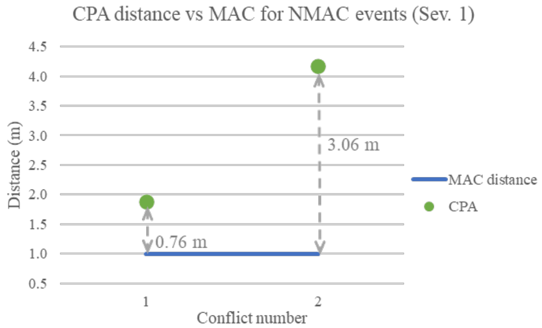

Figure 8. Severity 1 safety events detected vs collision threshold.

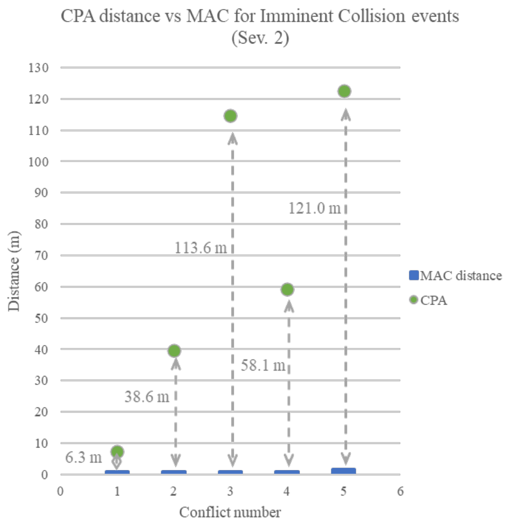

Figure 9. Severity 2 safety events detected vs collision threshold.

As can be seen in Figure 8, in the second conflict the distance between drones was more than 3 times the distance of the threshold considered as MAC. The case of the first conflict is due to the fact that the takeoff point of that pair of drones was the same, so at the time of starting the test they were already in conflict, and this was solved by ascending with a time delay.

In the case of Figure 9, the MAC distance of conflict 5 stands out, which is greater than the rest due to the fact that the pair of drones involved were of different category (A3 and SAIL I-II). The case of the first conflict has the same explanation as conflict 1 in the previous graph.

As can be seen, from severity 2 (imminent collisions) onwards, the CPA distances are already quite large and there is enough margin to resolve conflicts without reaching a collision. Moreover, since the pilot was alerted in case of conflict, few cases reached this severity, as most of them were resolved earlier.

Then, other technical analysis was made to check if separation minima were properly updated according to the CNS performance degradation. Figure 10 shows the injected degradations by hours, and Figure 11 depicts how this has affected the separation minima.

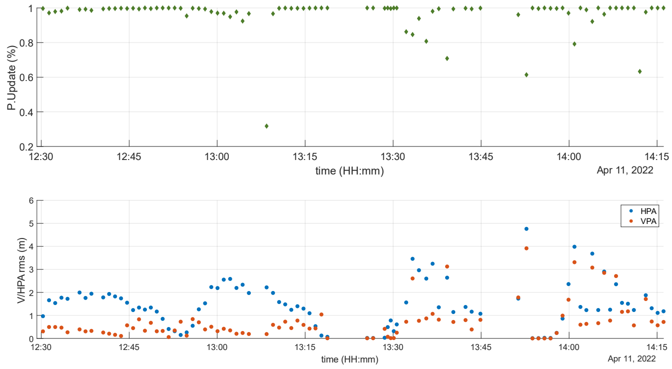

Figure 10. CNS performance per instant time.

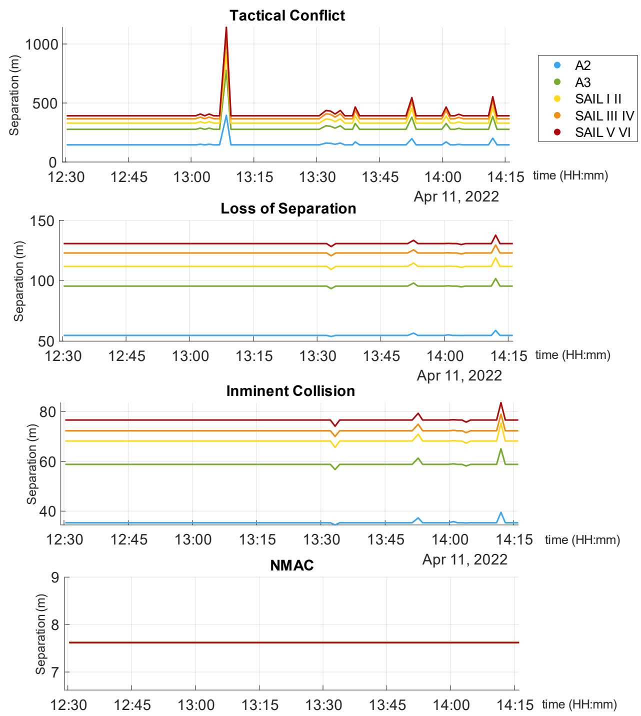

Figure 11. Separation Minima per instant time.

As it can be seen, NMAC distance is not affected by the CNS performance. This is because is an aircraft size-dependent parameter and is a fixed value [8]. In contrast, the other 3 distances are affected when performance is degraded. The GPS degradation affects the Vertical and Horizontal Positioning Accuracy (VPA/HPA) and packet loss affects to the message update probability (P_U), i.e. the % of drone telemetry reports that have arrived at the tracker.

When VPA/HPA worsens with respect to the predefined threshold, which has been set at 3m for Horizontal dimension and 3.5m for Vertical dimension, the Imminent Collision distance is affected and therefore the other two external distances are affected as well. In the case of the P_U, when this went below 95% it meant that the tracker had not received as many messages as it should have, causing the tactical conflict distance, to increase, as this parameter adds a time buffer.

So, dynamic separation minima were properly applied during test flights.

B. Human Performance assessment

After the test-flights, pilots were questioned about their views on the SME platform (in particular, the pilot APP) and the need of a separation management service, as well as the information they need to operate safely.

First, pilots were asked how they would rate the impact of the U-space simulated services provided by the platform on the success of their mission, their workload and their situational awareness.

As it can be seen in Figure 11, more than 96% consider the impact of the services provided to be positive on the success of their mission. Then, around 85% rate positively the impact on their workload. Regarding the impact on their situation awareness, 80% rate it positively and 20% remain neutral. It is important to highlight that the pilots were not familiar with the interface nor the layout of the pilot app and improvements both in workload and awareness are expected as the pilots become familiar with the platform.

Figure 12. Overall assessment results.

Then, pilots were asked how they would rate the usability/usefulness of the SME on a high-level assessment (Figure 11).

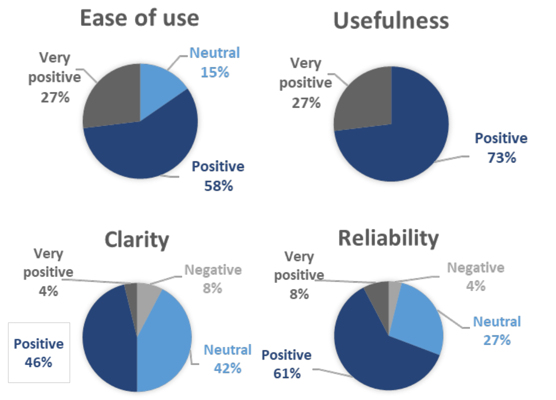

Figure 13. High-level assessment results.

The 85% consider the ease of use of the SME platform (in particular, the controller app) to be positive and the 100% rate positively its usefulness. In terms of the clarity of the information provided by the app interface, the 50% rate it positively but 8% consider it negative, due to the proposed vertical deconfliction maneuver creating pilot confusion. Finally, around 70% answer positively about the reliability of data (availability, accuracy…). Some pilots complained about the alerts lasting very little time on the controls, not giving them time to interpret the message well in some cases.

Next, the pilots were asked whether the SME platform has been useful in solving the conflict (see Figure 12), to which 100% answered Yes. Then, also 100% said that it is useful to know the severity of the conflict, i.e. the protection volume that is infringed, and 96% consider that they had enough time to react when they received a conflict alert.

Figure 14. Alerts assessment results.

Regarding the need of additional information, pilots suggested that it would be interesting to receive the position of the other drone in conflict on the controller map as well as its heading and speed. They also stated that a more understandable and direct maneuver recommendation would be needed, as well as audible warnings according to severity so that they are alerted when they are looking at the drone in VLOS. In the event of a conflict with a drone in priority (e.g. a drone with a rescue or medical emergency operation), pilots also commented that it would be interesting to display this information on the app interface, so that the non-priority drone pilot would know about it and act without disturbing the other operation.

Finally, the pilots were questioned about the separation minima distances proposed by BUBBLES.

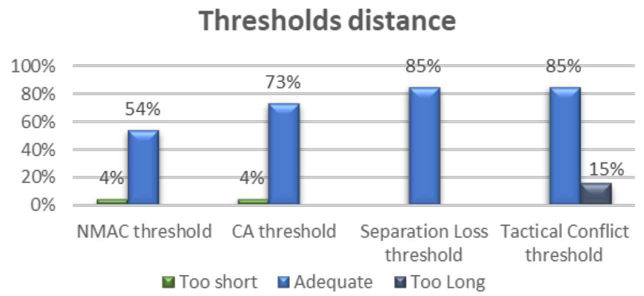

Figure 15. Separation minima assessment results.

In general, pilots consider all separation distances to be adequate (Near Mid-Air Collision, Imminent Collision, Separation Loss, and Tactical Conflict thresholds). Only 15% considered the tactical conflict distance to be too long, because at the time of CNS degradation, this distance was substantially increased, and the pilot was not able to locate the other conflicting drone with the naked eye.

V. CONCLUSIONS

This paper presents the separation management concept and its prototypical implementation supporting the separation provision in U-space airspaces proposed by BUBBLES, and the test-flights conducted to validate it, specially to validate the CNS performance monitoring and the dynamic separation minima computation.

Regarding the BUBBLES concept, this has been the first European project, funded by SESAR, to address the problem of how to deal with the separation provision in U-space airspaces and what information would need to be provided to U-space users or U-space Service Providers (USSPs) to manage separation between aircraft, including manned aviation.

As for the test flights, it was the first time that so many drones were flown simultaneously, controlled by different pilots, in a relatively small area of 15 km^2, and all of them connected to a platform providing U-space pseudo-services. Thus, the flights have been a representation of what could be the future of drones in urban and rural environments, and to see how necessary it is to provide U-space services to increase the safety and efficiency of the airspace.

Then, the pilot's feedback was very useful to draw conclusions and continue improving the platform to provide separation management service with the information they would need to enhance drone operations in terms of safety and efficiency. It is worth noting that regarding the BUBBLES concept, all the pilots found it very interesting and necessary to guarantee a safe operation among all users. After analyzing the questionnaires, the next conclusions can be drawn:

- Pilots express the need for the deployment of U-space services to manage airspace, specifically they value the separation management between all aircraft so that they do not collide and can operate safely.
- Pilots find the conflict alerts very useful as well as the suggestion of an evasive maneuver. It is also very useful for them to know the position, speed and heading of the aircraft in conflict in order to improve their situational awareness.
- Most pilots commented that when operating in VLOS, it is very difficult to detect conflicts with the naked eye since it is not possible to appreciate well the distances between the drones.
- As for BVLOS users, if VLOS drones were not provided with the separation management service and the BVLOSs were the ones in charge of solving conflicts, they stated that this would increase their workload and make it more difficult for them to solve conflicts, or at least to do it quickly. So, the separation management service should be provided to all U-space users. The need to integrate also other types of non-UAS aircraft into U-space can be highlighted here, as they can pose a safety hazard, especially training aircrafts or helicopters than operates in lower levels.
- From a workload point of view, by giving them the information in a simple and comfortable way at the controls, the pilots did not see increased difficulty in the operation.
- Finally, it is important to highlight the need for a common altitude reference system (CARS) since drones show the AGL (Above Ground Level) altitude referred to the take-off point, but different terrain elevations cause problems in knowing whether two drones are at the same altitude or not.

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