Impact of USSPs performance in shared U-space volumes

Munoz-Gamarra, J.L; Ramos, J.J; Liu, ZQ.
Aeronautics and Logistics department unit
University Autonomous of Barcelona
Barcelona (Spain)
JoseLuis.Munoz.Gamarra@uab.cat
JuanJose.Ramos@uab.es

Sobejano, A.
Aslogic U-space/ATM unit
Barcelona
(Spain)
asobejano@aslogic.es

***Abstract*—This work analyzes how different USSPs managing a shared U-space volume could impact on the other's performance. As it will be demonstrated, the representation of the trajectory and uncertainty associated with each mission will be key to optimize the use of this common resource in terms of effective airspace capacity. Based on a CORUS-XUAM VLL scenario, a simulation-based analysis will characterize the impact that USSPs capabilities to handle the mission' representation will have on the acceptance ratios, impacting not just on own performance but also to the other airspace users.**

Keywords-component; U-space; Airspace efficiency; flight trajectory representation; strategic conflict resolution; CISP-USSPs architecture

I. Introduction

U-space [1] was born as the framework to ensure the creation of safe, efficient and secure Very Low Level (VLL) airspace, accommodating a very large variety of new aircrafts: Unmanned Aerial Vehicles (UAVs). It is composed of a set of new services and specific procedures designed to support access to airspace. These new services are provided by U-space service providers (USSPs) in an open market that tries to encourage a high quality and competitive market that leads to safe and sustainable operations in the European U-space. Once certified, USSP will be able to offer their services in any U-space volume. A scenario in which more than one USSPs are providing services in the same volume under the coordination of a Common Information Service Provider [2] (CISP) could be possible according to existing legislation (see Figure 1, each USSP will offer their operators safe access to a shared airspace).

However, it will be key to ensure that all USSPs using the VLL volume will show comparable efficiency managing its shared airspace capacity, taking into account the uncertainty inherent to each mission. A set of questions raise in this shared airspace scenarios: Could a mission be accepted or cancelled due to a non-optimal performance of a different USSP capabilities in a shared airspace? Can a USSP jeopardize the level of service of another USSP offering their services in a shared airspace? Should a minimum performance level be required from USSPs and their services according to the complexity of the airspace where the service is provided? Should USSP certification requirements be adapted to the airspace complexity?

In order to answer these relevant questions, this work proposes a simulation-based analysis to assess how the planning process carried out by several USSP impacts each other from the airspace capacity utilization perspective. Specifically, focused on the way flight intents (or mission plans) are defined depending on the USSP capabilities to process them and deconflict the airspace. The paper is organized as follows: section 2 introduces the scenario (based on CORUS-XUAM Spanish demo) that will be the airspace structure based of our simulations; section 3 will introduce the main concepts of the strategic conflict management that will be used in the simulation study. Section 4 will present the methodology used in the simulation study and section 5 its main result. To finish off, the impact of the result obtained in a future shared USSPs deployment will be discussed.

II. SCENARIO DESCRIPTION

The simulated scenario is based on the CORUS-XUAM [3] Spanish demo performed in Castelldefels (Barcelona). The Spanish demonstration exercise was aimed at demonstrating the U-space system capabilities of managing UAS logistic operations within mid-size urban and suburban areas within controlled airspace.

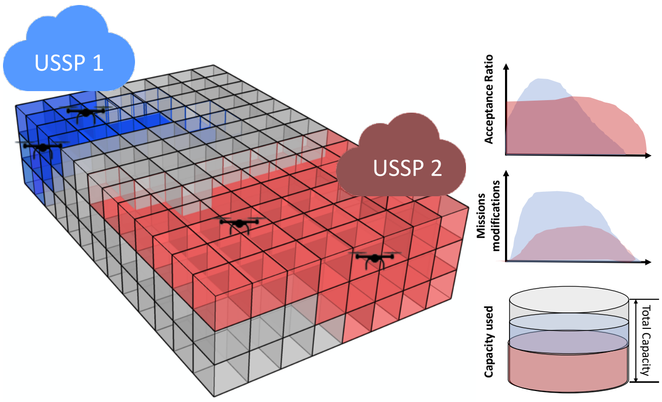

Figure 1. Schematic representation of several USSPs sharing a U-space volume and their performance and capacity used

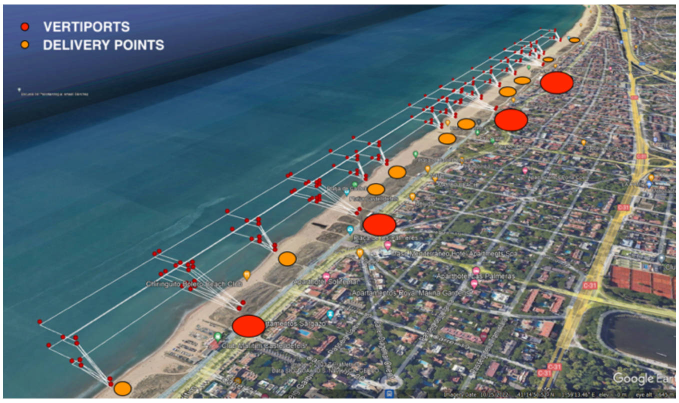

Figure 2. Corridor-based airspace structure used in the Spanish demonstrations in the CORUS-XUAM project

The exercise recreated a network of vertiports (4 in total, each one assigned to a specific operator) from which four different Drone Operators managed the take-offs and landings of their flights, executing last-mile delivery missions (see Figure 2). The vertiports (Points of Departure – PODs) also represented logistic hubs where drones were loaded with cargo received via other transport means to be delivered to one of the thirteen delivery points distributed along the 3 km. Two USSP, interoperating through the CISP, were deployed to support two drone operators each.

The flights were channeled through an airspace structure designed explicitly for serving last-mile delivery missions, where multirotors were continuously executing deliveries in the area and using the vertiports for the turnaround. The airspace structure was articulated around four air corridors, two in the west direction and two in the east direction. The corridors are aligned parallel. Each corridor is assigned a different altitude within the available envelope for safety. West corridors operate at both 30 and 70 meters altitude, while the East corridors operate at both 40 and 80 meters altitude (see Figure 3). The selection of different altitudes allowed for a safe crossing of corridors from/to vertiports and delivery points. Moreover, corridors have an additional horizontal offset added to them. This offset is intended to increase the safety of any vertical climb occurring on any corridor. In that way, unplanned vertical climbs, generally associated with loss-link RTL maneuvers, can be executed without interfering with other vehicles that are coincidentally operating at higher altitudes.

In this work the same type of operation is emulated, but with a much higher traffic density compared with the real flown scenario. For the experimentation goals, three USSP will be used in this case, each of them showing different capabilities in terms of the flight intent description.

III. Strategic Management of U-space Volumes

The safe and efficient deployment of U-space will be based on the safe arrangement of U-space volumes. The U-space regulation introduces the concept of U-space airspace as a

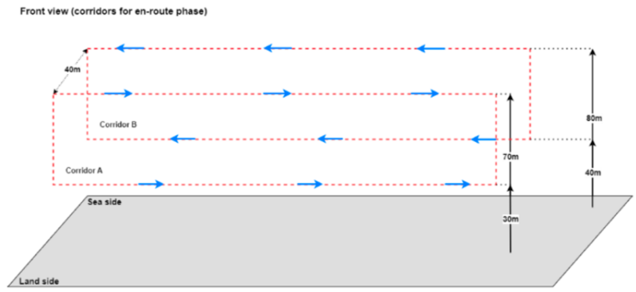

Figure 3. Concept view of the four corridors to be used in the simulation scenario.

geographical zone [4] where UAS operations are not allowed unless they are supported by several U-space services.

U-space volumes will be "equipped" with a set of U-space services to ensure the safe and efficient deployment of the U-space in these specific volumes [5]. It will be mandatory to provide Network identification, Geo-awareness, UAS flight authorization service and traffic information. Optionally, the entities providing these services (USSPs) may offer weather information and conformance monitoring services. It is expected that more than one USSP will offer its services in U-space volumes. They will coordinate their interactions through CISP, that will oversee spreading the common information required to enable the operation and provision of the U-space services. The Figure 4 illustrates the deployed U-space architecture.

In this work, the USSP platform DronAs by Aslogic[1] will be used. DronAs was one of the USSPs at CORUS-XUAM demonstrations. In addition to providing U-space services in real scenarios, DronAs has simulation capabilities for the analysis of demand-capacity balance. For the paper experimentation purposes, it will be used to emulate the three USSP interoperating through the CISP, each of them showing different capabilities for the strategic planning in managing the flight plan representation, as it is described next. Each USSP will receive the flight plan authorization requests from their drone operators. The USSP gets the geoawareness information from the CISP, as well as the operations that have been already approved, in order to check for conformance and deconflict the received request or reject otherwise. So it is clear that all USSPs will manage a common resource of the U-space: the capacity of the airspace volume. The performance of each USSP managing this resource will have a deep impact on the other entities providing services. A USSP that produces high latent capacity (airspace booked but not used) will reduce the capacity available for the other USSP, which could be translated in less operator missions accepted, or more missions' modifications, to ensure that the approved flight plans are free of conflict. While this may not be a problem in rural environment where a low traffic density is expected, it could become a bottleneck in urban areas with high density

[1] Aslogic is a Universitat Autònoma de Barcelona spinoff company

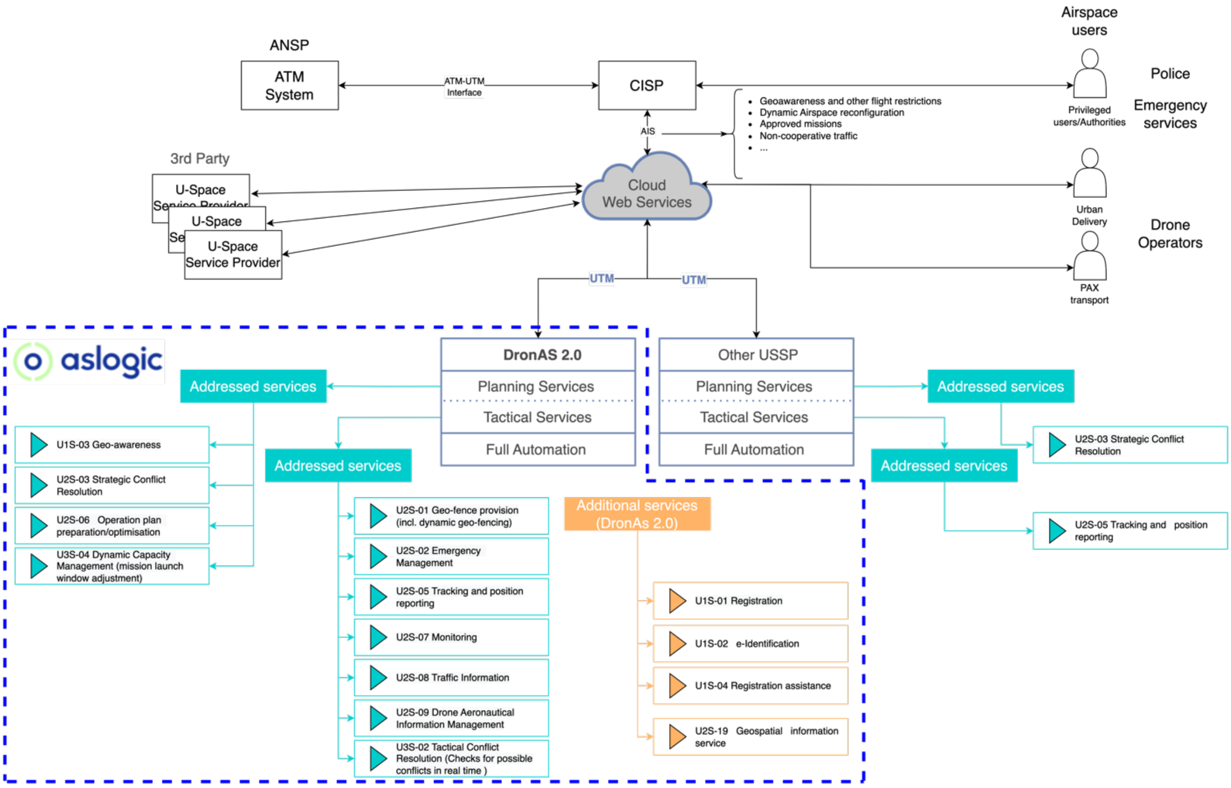

Figure 4. Cloud based architecture of USSP interoperating through the CISP.

scenarios. The urban scenarios will have additional restrictions due to the ground obstacles, so it would be mandatory to get the maximum of the available airspace.

To tackle this point, three main topics need to be covered: flight intent description, strategic conflict service and a seamless operator-USSP and CISP interoperability.

A. Flight trajectory description

The flight trajectory representation will be the building block, the non-indivisible unit of information, on which the strategic management of our airspace will be built (see Figure 5 where different mission uncertainty level is showed). The more detailed the information provided, the more efficient and advanced functionalities could be provided by USSPs and more efficient use of the airspace might be done.

In the scope of the Risk Assessment Model for UAS operations, the European Regulation defines the operational volume as the composition of the flight trajectory (missions) and the contingency volume [6][2].The flight trajectory means the volume(s) of airspace defined spatially and temporally in which the UAS operator plans to conduct the operation under normal procedures and the contingency volume means the volume of airspace outside the flight trajectory where contingency procedures defined will be applied.

Furthermore, the operational volume shall be characterized by the position-keeping capabilities of the UAS in 4D space (latitude, longitude, height and time), in particular:

- Navigation performance
- Flight technical error (the flight technical error is the error between the actual track and the desire track) of the UAS
- Path definition error (e.g. map errors)
- Latencies

Generally, UAV missions are provided using three different formats (or a combination of them), schematically represented in Figure 5:

- Volume format: specifying the airspace volume that contains the mission, without providing any additional details, and booking this volume for the entire time interval in which it is expected to be flying.
- Polyline format: as specified in Commission implementing regulation 2021/664[5], flight trajectory as a series of one or more 4D volumes expressed in height (base, ceiling), longitudinal and lateral limits, and duration (entry and exit times). Each dimension includes the uncertainty of the flight, considering the UAS operational performance, and the assumptions on the operator proficiency and weather conditions. The discretization of these polyline volume can vary considerably, changing the level of mission description (see Figure 5).

[2] EASA (2020a): Easy Access Rules for Unmanned Aircraft Systems (Regulations (EU) 2019/947 and (EU) 2019/945)

- 4D format: a set of 4D points providing the latitude, longitude, altitude, and time of all the waypoints making up the trajectory. Associated to each of these points there is an uncertainty value that models its temporal and position uncertainty.

In some circumstances it will be the nature of the mission itself that will set the level of description of the mission. For example, surveillance mission characterizing a crop will require a high flexibility that will make them suitable for a volume mission format. However logistic missions, where the origin, destination and trajectory are known since the planning phase, could be described in 4D format. Note that the 4D format is also aligned with the 2021/664 regulation. It provides an uncertainty volume attached to the envisioned 4D position of the aircraft with a time interval in which it is expected to be inside. However big differences are found between polyline and 4D format. As it will be demonstrated in results section, it deeply impacts the efficiency of the airspace as increases the volume (used or not) that a mission needs in its definition phase. 4D format mission strictly reserve the uncertainty envelop of the position and time uncertainty, while polyline representation occupies one segment of the mission for a time interval.

Note that mission description also impacts some main functionalities of U-space services:

- DACUS project [8] focused on the DCB U-space service, that it based on developing a “consolidated demand picture” considering mission planned and forecasting future demand, will strongly depend on the mission resolution (they define missions as “their single point of truth”) to increase operational capacity. The quantification of uncertainty will be an essential component of the service and the effectiveness of the DCB measures.
- BUBBLES [9] defines a protection volume around each aircraft, so that a breach of separation minima is triggered by the overlap of these volumes. During the strategic phase a probabilistic 4D trajectory is extracted from the operation plan, when the probability of a bubble intersection exceeds some predefined value then a conflict is declared. It is clear that high uncertainty values could reach to the detection of false conflicts.

Though it might seem obvious, operations described as volumes will have a higher negative impact on airspace occupancy compared with polyline description, and even more with 4DT description. This work will assess this impact quantitatively by focusing on the airspace occupancy in terms of the mission accepted/rejected ratio as a metric of efficiency. For this purpose, each of the USSPs will show different capabilities for processing the operator’s flight intent. USSP named A will be able to work with 4DT trajectories, as illustrated by the top image in Figure 6. USSP named B will be able to work with polyline trajectories, as illustrated by the middle image in Figure 6. USSP named C will be able to work with volume trajectories, as illustrated by the middle image in Figure 6.

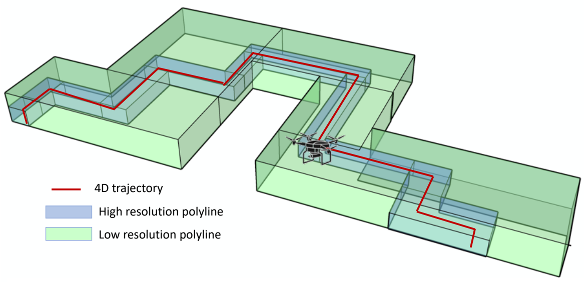

Figure 5. Schematic representation of 4D and polyline mission format.

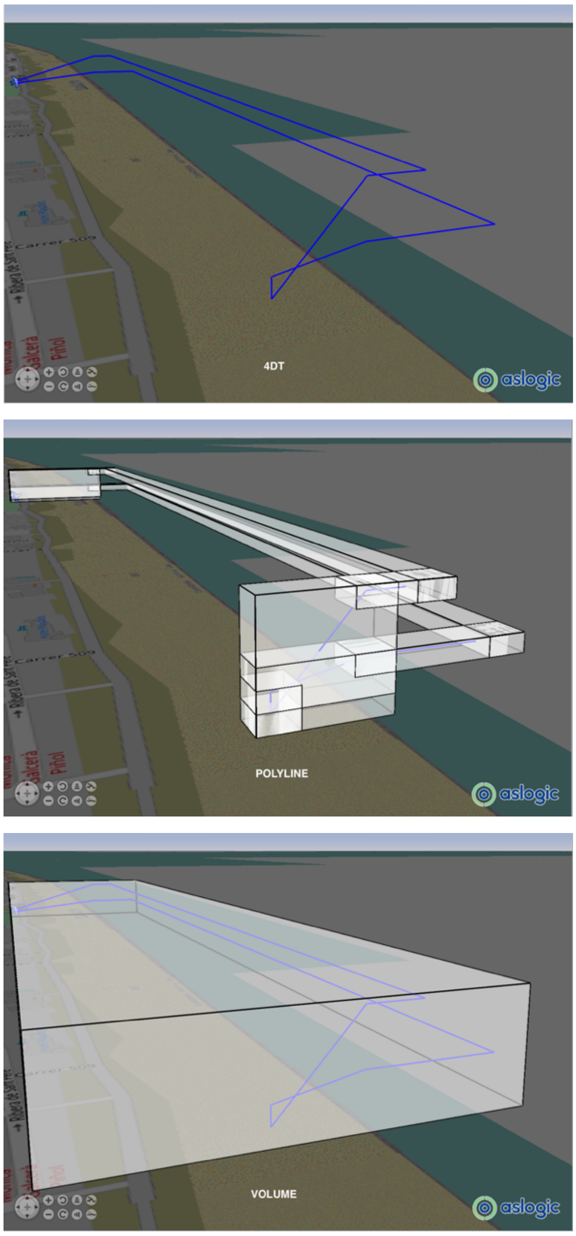

Figure 6. The three flight trajectory representations to be evaluated

B. *Strategic deconfliction service*

The strategic deconfliction service is part of the UAS flight authorization service. The EASA U-space regulation relies on the pre-flight strategic conflict resolution by the Flight authorization service in the pre-flight phase [4]. To get a flight

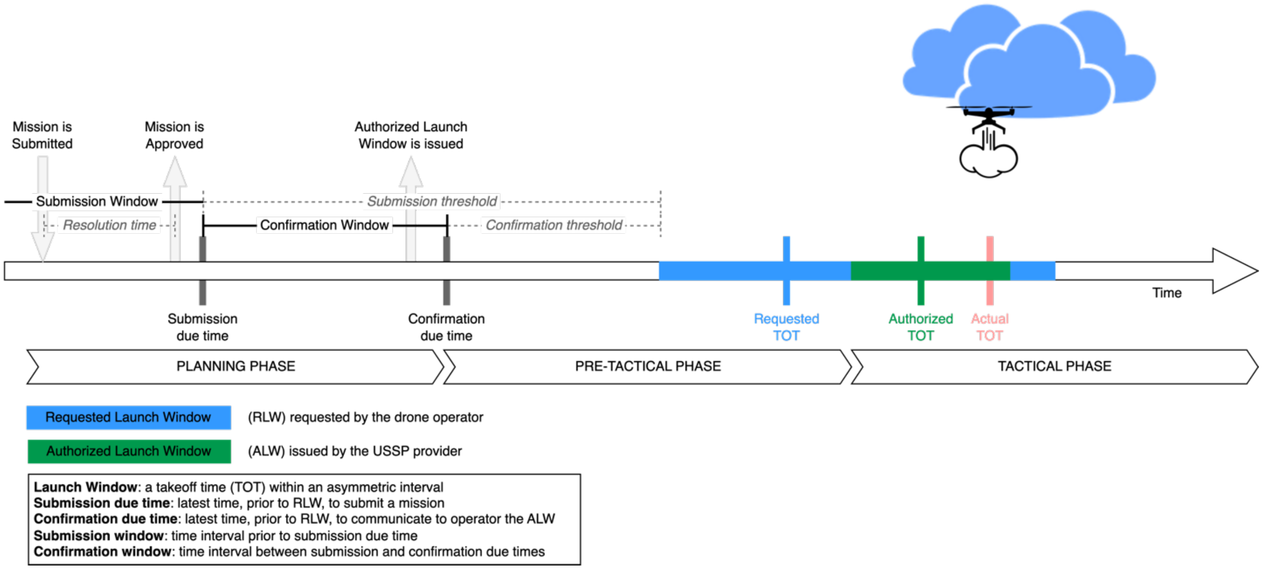

Figure 7. Timeline for planning and executing a mission.

authorization, a flight plan must be strategically deconflicted from any other conflicting flight plan. Strategic conflict resolution services are based on predictions of conflicts. Conflict resolution compares the submitted operation plan with the already approved ones. It is triggered when the probability of loss of separation is above threshold, based on the most likely predicted trajectory for each aircraft, proposing a set of solutions. These solutions go from changing a portion of the planned trajectory to avoid the volume in conflict up to modify the time interval in which the mission will be executed to ensure that the aircraft respect the separation minima values. Simpler strategic conflict resolution service just rejects the last submitted mission if it conflicts with the previous ones.

In this work a time-based separation mitigation strategy will be used. This separation strategy basically consists in adjusting the takeoff time of the missions in conflict. The main reason for using this mitigation strategy is to propose a suitable solution for the drone operator (DO) without additional modifications on the requested flight trajectory. DronAs implements an optimization set of algorithms to coordinate the takeoff time windows for deconflicting the different missions in conflict. This method was first developed for ATM traffic in the PARTAKE project [14]. A detailed view of the methods can be found in [8], [11] and [12].

The Figure 7 illustrates the timeline from the planning phase until the tactical phase (when approved mission departs). The drone operator (DO) issues the Flight Plan (FP) including the flight trajectory and the *Requested Launch Window* (RLW). The start time of the RLW is the reference for the remaining milestones. The planning phase involves the following steps:

1. Authorization of the FP has to be requested to the strategic conflict resolution service prior to the so-called Submission Due Time (common to all airspace users).
2. The USSP applies the conflict detection & resolution algorithms to determine potentially existing conflicts and the existence of, at least, one *Authorized Launch Window* (ALW). The ALW time window defines the time interval when the takeoff of the mission can safely happen in the sense of not having conflicts with other missions already approved.
3. Almost instantaneously (response latency is negligible), the FP is either rejected (no strategic deconfliction measure exists) or approved (at least one ALW exists). Result is communicated to the DO. The ALW is shorter than, and contained by, the RLW to preserve DO preferences.
4. The ALW of an approved mission is not communicated to the DO until the *Confirmation Due Time (*This window is also named as *Reasonable Time to React* [7]*)*. This so-called *Confirmation Window* is used by the USSP strategic deconflicting algorithms to have the possibility to still recalculate new feasible ALW to accommodate new FP approval requests arriving before the expiration of the confirmation due time.

Once the ALW is issued to the DO, starts the pre-tactical phase for preparing the flight. The start of the ALW determines the tactical phase. DO is supposed to follow the rules and takeoff within the allocated ALW, being sure that the mission has no strategic conflicts (loss of separation minima) with other planned missions.

C. Operator-USSP-CISP interaction times

USSPs share a common picture of the missions under study or approved thanks to the CISP that holds a common database with this information. Nowadays, in the face of several missions of the same priority (thus eliminating any missions of state and law enforcement bodies), a policy of "first come first served" (FCFS) is used to accept the planned missions. Nevertheless, some strategic mitigation algorithms form a batch of missions under approval revision to be able to modify all of them, ensuring a maximum performance (number of missions accepted), before notifying the modification or acceptance of them. For instance, this is the case in DronAs.

Furthermore, all the time parameters described in previous section can be tuned by the airspace managers to optimize the use of the airspace capacity. Note that, for instance, the takeoff can happen at any moment within the ALW, so the longer the ALW the more airspace capacity is 'consumed' by the flight. In fact, the values of these parameters, some of them tightly related to the Safety Target Level [9], have a strong impact on airspace capacity as well as on the DO flexibility.

High performance USSP, i.e., those who implement a batch planning strategy instead of FCFS, who are able to process 4DT flight plans, and who have the capability to optimize the time parameters, will benefit all USSPs operating in a shared U-space volume. However, those high performance USSP operators, and the airspace efficiency at the end, will be penalized by other service providers who have lower capabilities in terms of planning strategies, trajectory representation and less flexibility in the planning milestones (e.g., how far in advance the planned missions need to be reported? Are they going to be accepted/cancelled or modified at that exact time? or they will be confirmed after a certain time).

A deeper discussion on these efficiency concerns can be found in [13] For this paper experimentation goals, the planning strategy will be set to FCFS, and the planning milestone values will be fixed and shared by all three USSPs in order to focus de discussion on the flight trajectory representation concerns.

IV. SIMULATION STUDY

The DronAs USSP platform by Aslogic[1] will be used for the experimentation purposes. A part of the provision of U-space services, DronAs has a set of tools for designing the airspace architecture including different simulation capabilities. For this work goals, the demand-capacity balance (DCB) analysis tool has been used.

This tool emulates the strategic planning process to assess how a particular operation's demand will be accommodated considering the different variables related to the safety target level (focused on separation criteria), trajectory representation (as described in section A), and planning milestones (as described in section B).

For the sake of a fair comparative analysis, the operation demand for each USSP will be the same in all cases, and just the representation of the trajectory submitted to the strategic deconflicting service will be different (see Figure 6): 4DT for USSP A, Polyline for USSP B and Volume for USSP C.

The traffic is randomly generated by DronAs for a given simulation time (one hour of operation in this case). The DronAs traffic generator uses the airspace corridor-based structure shown in Figure 2 to define 4DT closed trajectories departing from one of the vertiports, delivering the parcel at one of the stablished delivery points and returning to the launching point. All these points, as well as the requested takeoff time, are randomly selected. A traffic set of 3.000 4DT trajectories is generated for the later stochastic simulation. To emulate the USSP that do not have capabilities to deal with 4DT trajectories, the DronAs mission design tool is used to transform this traffic set into the polyline and volume versions of the 4DT trajectories. The three images in Figure 6 show the 3D representation of this wrapping transformation process. All three traffic sets, with 3.000 trajectories each, are loaded into the DCB Analyzer. As mentioned before, the simulation study will focus just on the different trajectory representation capabilities of the three USSP, leaving separation criteria and planning milestones the same for each USSP.

The traffic density is one of the parameters to be set for the DCB analysis. It defines the number of missions to be randomly selected from the traffic set. For instance, a density of 100 operations during one hour of simulation will select 100 of missions out of the 3.000 in the traffic set. For the sake of experiment repeatability and fair comparison, the random generator seed is controlled. Thus, it can be ensured that the same missions will be selected for planning, regardless of the trajectory representation being used since the polyline and volume versions are just spatial transformations of the 4DT trajectories.

In order to improve the statistical significance of the results, each DCB analysis is composed by a set of traffic scenarios. In this work, 25 scenarios are defined and there are no changes on the scenario parameters, just the selected flights are randomly different from one scenario to the other, emulating this way 25 hours of operation. As it will be discussed in the next section, only the used traffic set must be changed from one DCB analysis to the other.

For better understanding the difference to be observed in the results, it is important to pay a look into the influence of the trajectory representation on the strategic deconflicting algorithms. This process is based on the detection of the spatiotemporal interactions between two or more trajectories (potential loss of separation or conflict). In a nutshell, a spatiotemporal interaction appears when one volume representing the location of an aircraft overlaps one or more

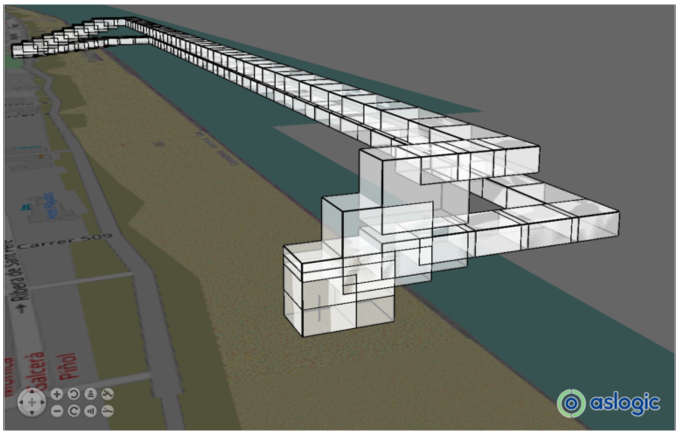

Figure 8. Illustration of the airspace digitalization performed by the DronAs U-space services to handle 4DT trajectories

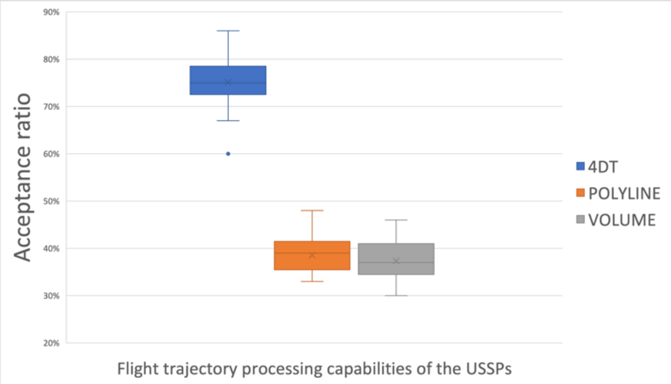

Figure 9. Average acceptance differences depending on the flight trajectory representation

volumes for other aircrafts during a given time interval. Two or more flights showing spatiotemporal interactions are considered as interdependent flights. The deconflict algorithms must determine if there exists a time shift for each interdependent flight that removes the spatiotemporal interactions.

The 4DT trajectories are digitalized into arrays of voxels, elements of volume that constitute a three-dimensional space (see Figure 8). The dimensions of the voxels are mainly determined by the vertical and horizontal separation criteria, as well as by the navigation performance. Each voxel is occupied during the time interval set as Authorized Launch Window (ALW). Hence, a spatiotemporal interaction exists when there exists a non-empty intersection, both spatial and temporal, amongst two or more voxels of different trajectories. In this case, the mitigation algorithm searches for a time shifting of the ALW of the interdependent flights subject to the rules described in section III.B. As this work limits the analysis to a FCFS policy, the strategic deconflicting is executed every time a new flight authorization is requested to the USSP. If no conflict exists, or the conflicts generated with already authorized flights can be mitigated, the new request is authorized.

For the airspace capacity impact assessment of the flight trajectory representation, USSP A will be able to process the 4DT trajectories as described, USSP B will be able to process high resolution polylines (see Figure 5), and USSP C will process volumes. The mitigation mechanism (strategic deconflicting) will be same in all three cases. Next section presents the results.

V. RESULTS

The first set of simulations aim to assess the differences in the average acceptance ratio (accepted vs requested missions) in the case that the airspace is not shared (one USSP at each simulated scenario). The traffic set is the same for each USSP and just the flight trajectory representation changes according to the USSP capabilities. The Figure 9 shows the statistical results.

As it could be expected, the USSP A acceptance ratio (75%) is much higher than others. However, there is no big difference between USSP B (39%) and C (37%). This is because of the corridor-based structure (see Figure 2). The time that a polyline representation will occupy the corridors on the way to the delivery point and the way back to the vertiport is similar to the time that the volume representation occupies the same segments of the corridor. This can be easily observed in the polyline and volume representations of the same flight shown in Figure 6. Therefore, the probability of having conflicts with other planned missions is also quite similar for both representations and, consequently, similar acceptance ratios can be expected.

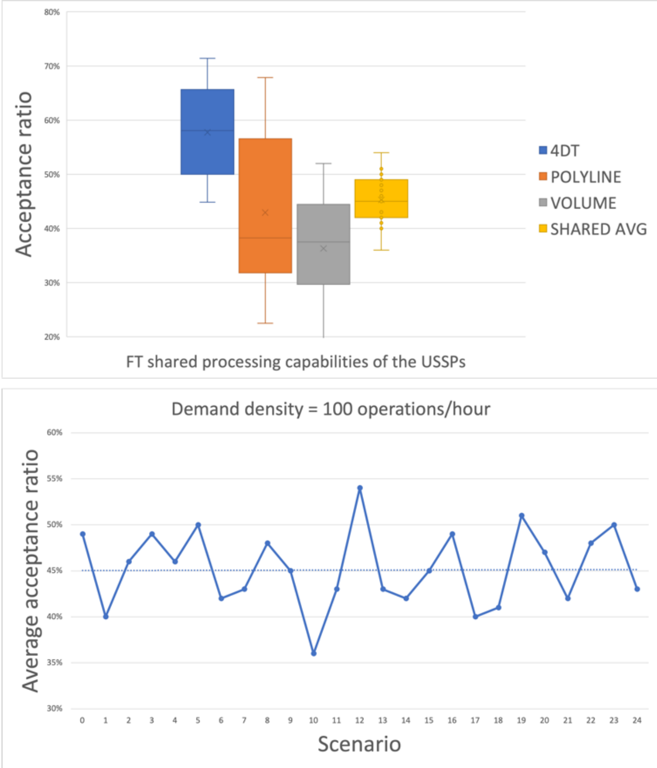

Figure 10. Acceptance ratio when the three USSPs are sharing the airspace

The second set of simulations aims to assess scenarios where the three USSP operate in shared airspace. In this analysis case, flights are randomly selected from the three traffic sets and the approval request is sent to the proper USSP according to the representation version (4DT, polyline or volume).

The Figure 10 shows the statistics of approved flight trajectories when all three USSPs operate on the shared airspace. In the top plot, it can be observed the degradation in the quality of service by USSP A (4DT) provided to their DOs, dropping from an acceptance ratio of 75% when standalone is the down to 58% when sharing the airspace with the other lower performance USSPs. In the case of USSP B and C, the average acceptance ratio remains the same. Worth to mention is the higher dispersion, which is a consequence of the FCFS policy during the random selection of the different trajectory representations. In the bottom plot, it can be observed that average acceptance ratio (45%) is higher compared with ratios from the polyline and volume representation standalone scenarios, but still far away from the acceptance ratios that can be obtained with the 4DT trajectory representation.

VI. DISCUSSION

This paper has presented a quantitative impact assessment of different flight trajectory representations on the effective airspace capacity. For this purpose, three USSP operating on a shared airspace have been emulated using the Demand-Capacity analysis tools provided by the DronAs U-space suite by Aslogic. Each emulated USSP have different capabilities for handling the flight trajectory representation: 4DT, Polyline and Volume. For the sake of a fair comparative analysis, the rules and strategies for planning, as well as the strategic conflict resolution measures, are the same for all USSPs.

First set of simulations were aimed to assess the differences of the airspace usage efficiency measured in terms of the acceptance ratio for highly dense scenarios (demand of 100 operations/hour). Under the same conditions, i.e., the same flight operations but with three different trajectory representations, the USSP capable of dealing with 4DT clearly outperforms the other USSPs (acceptance ratio almost doubles the others). However, there is no big difference between polyline and volume representations from airspace efficiency perspective, although the former is expected to be higher than the latter. The second set of simulations puts in place the three USSP operating simultaneously in a shared airspace. Interoperation is using the CISP model to share the relevant information between the three USSPs. In this case, the achieved acceptance ratio is a bit higher compared with the polyline and volume scenarios, but still far away of the airspace usage efficiency that can be achieved when flight trajectories can be handled as a 4DT representation.

Although these results may seem obvious, the simulations performed in this work provide a quantitative assessment about how the flight trajectory representation impacts on the airspace usage efficiency. It is worthy to note that all the U-space services and systems provided by the DronAs suite that have been used for the stochastic simulations are the same services and systems that are used in real flight operations. Furthermore, a set of questions were formulated at the beginning of the paper and the observed results enable their answer.

Could a mission be accepted or cancelled due to a non-optimal performance of a different USSP capabilities in a shared airspace? Clearly yes, the highest performance achieved with 4DT representation (75%) drops down to 45% when less accurate trajectory representations are in place simultaneously. Therefore, 30 operations in average are not approved because of the co-existence with USSP performing worse. *Can a USSP jeopardize the level of service of another USSP offering their services in a shared volume?* Yes, provided that the FCFS policy without any kind of prioritization mechanism are in place. The DO contracting the USSP A (with 4DT trajectory representation capabilities) will notice the rate of acceptance of its operations requests will drastically drop when USSP B and C are also providing services to other DO in the shared airspace. However, the DO will hardly understand the reason for receiving a clearly lower level of service. *Should a minimum performance level be required from USSPs and their services according to the complexity of the airspace where the service is provided?* In author's opinion, the answer is clearly yes. As the DCB analysis shows, lowest performance USSP (e.g., those who can only handle flight trajectories represented as volume) jeopardizes the overall airspace capacity, which penalizes higher performance USSP and the airspace users. However, some DO still might choose to contract lower performance USSP because of different reasons, for instance lower service fares. In this case, the fair USSP competition may not be enough to discriminate which USSP will survive, and which ones will disappear, and the overall performance will be negatively impacted.

Finally, the experimentation framework defined in this paper opens a set of open question to be explored in the future such as, for instance, could other planning policies compensate the trajectory representation impact on airspace efficiency? e.g., batch planning instead of FCFS planning. Which type of mechanisms can mitigate the performance loss due to trajectory representation? (e.g. prioritization, negotiation, etc.)

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