U-space Contingency Management Service: Enhancing U-space Volumes Safety

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***Abstract*—This work proposes an advanced U-space contingency management based on a new U-space strategic service that enhances mission description with a set of alternatives vertiports to be occupied in case of contingency. The new service, closely linked to demand-capacity balance and strategic deconfliction services, assigns safe alternative landing spots by analyzing the planned missions. Two potential solutions are outlined, primarily distinguished by the number of contingency vertiports assigned: contingency management based on assigning a single alternative vertiport to each mission (static) or assigning multiple contingency vertiports that are valid during specific time intervals. It is demonstrated that this improved mission planning can ensure that U-space volumes operate under ultra-safe conditions when encountering unforeseen events, highlighting its importance in high-risk scenarios such as urban air mobility deployments.**

Keywords-component; Advanced U-space service, contingency management, enhanced misssion description

I. Introduction

CORUS-XUAM Spanish demo activities were focused on the creation of high-density traffic scenarios with different U-space Service Providers (USSPs) sharing the management of U-space volume [1]. In one of the demo activities, 6 Unmanned Aerial Vehicles (UAVs) were flying simultaneously when one of the aircraft briefly lost its communication capabilities. As a consequence, the UAV executed and autonomous Return To Launch (RTL) point procedure. During the execution of this unexpected maneuver, the aircraft autonomously returned to its departure vertiport at a constant speed, following a straight path from the point where the contingency event occurred. During this autonomous maneuver, the pilot has no control over the aircraft. On its way to its starting position, USSPs were able to observe how the distance between the ongoing flights was reduced below the planned values, without resulting in a conflict. However, this situation had the potential to cause downstream conflicts, relying solely on tactical scenario management to prevent loss of separation. Since U-space tactical conflict resolution services are still under development and the UAV pilot had no control over the aircraft under contingency, the scenario's safety depended entirely on tactical interactions between surrounding USSPs and pilots, as well as the pilots' skills, to manage aircraft separation.

It is evident that in low density traffic scenarios, RTL procedure does not pose a problem, but at what traffic density would it begin to create conflicts with other UAVs?. Can we rely on tactical management of contingency events in high-density traffic scenarios? Which safety levels can be achieved with this approach? And what about Urban Air Mobility (UAM), characterized by elevated risks both on the ground and air?

This work proposes a contingency management based on a new strategic U-space service. First, the integration of this new service within the strategic U-space service framework will be outlined. This U-space contingency planning service will assign specific vertiport of the airspace network to each aircraft for use in case of a contingency. In this way, the mission plan will be enhanced with a set of pre-assigned contingency procedures determined by the position of the other aircraft simultaneously occupying the airspace volume. Once introduced, it will be characterized at what traffic density a contingency event, based on current RTL procedures, could result in a potential loss of separation with another aircraft, characterizing its dependency with airspace structure and demand traffic pattern. Next, the proposed contingency service will be integrated in the strategic planning of the characterized scenarios to assess its safety impact. In the final section, the results obtained will be discussed.

II. U-space Contingency Management Service

A. *State of the Art*

NASA [2] and Europe (CORUS-XUAM [3]) have already highlighted the need for a structured approach to contingency management, envisioning an increased level of automation in this process. Toward this goal, enhanced reliability and survivability of mission-critical systems are driving the development of health monitoring and Automated Contingency Management (ACM) systems. These systems, relying on onboard safety monitors, detect potential off-nominal situations and initiate contingency procedures. Once the contingency is triggered, the State of the Art (SoA) can be divided into two different approaches: pre-flight and in-flight management, depending on whether the mission was planned before takeoff or adjusted during flight.

In Pre-flight management approach, UPC team [4][5] proposes the development of a contingency manager that develops strategic contingency plans for each section of the mission (legs) according to the particular threat that the aircraft is facing. Other studies have focused on the emergency flight planning of UAVs to a safe landing zone during an emergency situation by using Voronoi diagrams and selecting the most suitable path with dynamic programming [6] and avoiding nonflying zones and weather conditions [7]. However, any of these approaches does not consider other planned traffic.

Using the tactical approach, flight management relies on onboard capabilities to manage the threat. Atkins [8], Boskovic [9] addressed the development of search-based trajectory optimization to identify feasible emergency landing path in real time. This search for potential trajectories can be based on computer vision techniques [10][11], and advanced machine learning methods [12]. Other in-flight approaches are based on a dynamic reconfiguration of the airspace [13] or pre-define flight rules to deal with unforeseen traffic [14].

B. *U-space stratetic contingency management planning.*

The proposed new U-space contingency service will play a central role in the strategic planning process together with the deconfliction service, as it is shown in Figure 1. As illustrated, operators will get information of the strategic context using geo-awareness service (that will inform about the restrictions of the VLL airspace volume where the mission is going to planned). Additionally, other U-space services, such the weather or CNS coverage service, will supplement the available information for mission planning. Next, during the mission preparation (Flight plan generation), the operator will proceed to specify the details of the mission. The specified mission will be the input to the strategic conflict resolution service that will verify if there is any other mission planning to use the same airspace, at the same time (considering the uncertainty volume of the mission that will fix the separation minima values). If the strategic conflict resolution service does not find any interdependency with other mission or can be solved shifting the take-off time or some points of the trajectory, the mission will be accepted [15].

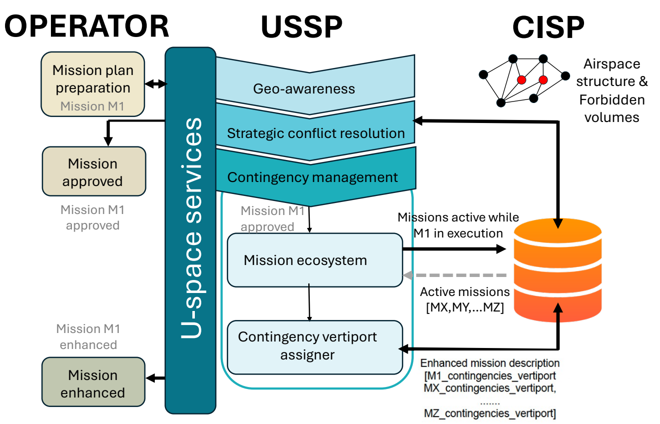

Figure 1. Interaction diagram of the U-space contingency service and other strategic USSP services. The figure also highlights the interactions between airspace user, USSP and CISP during the planning process.

Once it is confirmed that the mission is free of conflict, the new contingency service acts. As previously mentioned, traditional RTL protocols rely on coming back to the initial take-off point. However, these unforeseen maneuvers can impact the safety of the VLL airspace volume, as this new trajectory has not been cross-checked with the planned trajectories and initiation time is unpredictable. It is highly probable that an RTL may cause a conflict in high-traffic conditions. To avoid this downstream effect, the continency U-space service will assign teach mission a designated RTL vertiport, different to the departure one, called contingency vertiport. The schematic blocks in the contingency service in Figure 1 represent the procedure followed to assign the contingency vertiports.

Once a mission (called M1 in this example) is approved by the strategic conflict resolution service, the contingency service explores the missions that will be active while M1 will be in execution. The set of active missions (retrieved from the CISP database), that will conduct flights simultaneously, will form the ecosystem of the mission under study, in this specific example [MX,MY,..,MZ]. Next, this list of simultaneous missions then serves as input to the contingency vertiport assigner that will assigns a specific, and distinct, contingency vertiport to each member of the ecosystem. This procedure is expected to reduce the probability of conflict if any ecosystem missions require a RTL, even if the contingency event impacts two aircraft at the same time, as the contingency vertiports assigned to the members of the ecosystem are different. In this way, the selected contingency vertiport assignment algorithm enhances the mission description of each flight. Each time a new mission is approved by the strategic conflict resolution service, this process is repeated, resulting in an updated list of enhanced mission description [M1, MX, MY,…MZ contingency vertiports] that is provided to the CISP and the operators/U-space Service Providers (USSP). Once the mission is in execution the assigned contingency vertiport does not change.

Two alternative approaches have been explored for the algorithm that assigns a contingency vertiport to each ecosystem member:

- Static vertiport assigner provides each mission in the ecosystem with a single, fixed contingency vertiport for the entire flight duration.
- Dynamic vertiport assigner provides a list of contingency vertiports, each valid during a specific time interval of the flight. In that way, the assigned contingency vertiport evolves and changes while the mission is in progress.

III. SCENARIO DESCRIPTION

A. *Scenario definition*

The scenario that will be used for the contingency service validation process, will be inspired in a logistic activity. The flights are channeled through an airspace structure designed explicitly for serving last-mile delivery missions, where multirotor aircraft are continuously executing deliveries and using the vertiports for the turnaround. It is composed by a set of nodes (15), that represent the vertiports, linked by two different altitude and direction corridors, as it can be seen in Figure 2 A). The distance between vertiports (graph nodes) is 150m and they are connected following a straight line. In the cross-section view of the airspace structure, it can be observed that UAVs will reach first a reference node at the corridors altitude and then, following a constant altitude flight will reach the entry point of the corridor. The airspace structure was articulated around two air corridors, one oriented west and the other east. The corridors are aligned parallel. Each corridor has assigned a different altitude within the available envelope for safety. West corridor operate at 30m of altitude, while the East corridor operate at 50m altitude. 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 (see Figure 2 B top view). This offset is intended to increase the safety of any vertical climb occurring on any corridor.

Additionally, attached to each node of the graph there is a depart and landing probability (see Figure 2 B) to model different demand pattern. Thanks to this feature it is possible to study how the results depend on the potential definition of hotspot in the airspace structure.

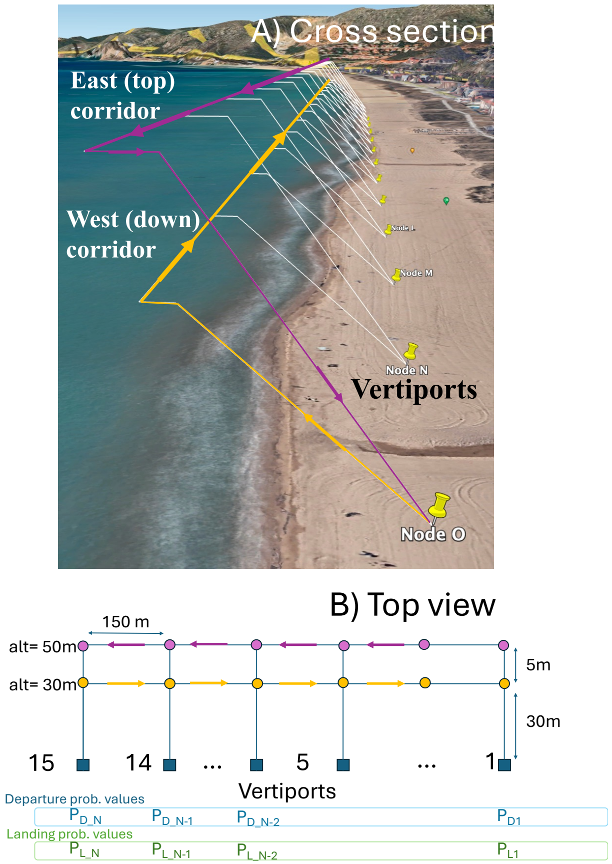

Figure 2 A) Cross section of the corrider based airspace structure and its top view (B).

B. *Methodology*

This work utilizes DronAs platform, from the University Autonomous of Barcelona, as the U-space service provider (USSP) solution. This platform has a set of strategic and tactical U-space services (strategic and tactical conflict resolution, demand capacity balance, conformance monitoring or traffic information among others) and simulation capabilities, for the analysis of demand-capacity balance. DronAs has also a set of tools for designing the airspace structure. In this work, the traffic is randomly generated for a specified simulation duration (one hour of scenario in this case) based on a traffic demand pattern. The traffic generator utilizes 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. All these points, as well as the requested take-off time, are randomly selected.

Once a traffic density is selected, the traffic generator will generate the defined number of missions (within a one-hour scenario), according to the specified airspace structure. Note that this traffic will use the strategic conflict resolution service to ensure a free of conflict traffic and avoid any potential loss of separation (a horizontal separation of 30m and a vertical separation of 5m has been established).

Once the conflict-free traffic has been generated, a contingency probability (P_C), is applied to determine the likelihood that any aircraft in the traffic set may be affected by an event triggering a contingency procedure. As a result, a certain number of the planned missions will execute a Return-to-Launch (RTL). It is assumed that the event that triggers the contingency maneuver does not impact the capabilities of the aircraft to fly. Additionally, it is also presumed that aircraft have a on board control system that allows the predefinition and execution of an alternative trajectory, if there is an event that trigger the contingency maneuver. It will be characterized if the RTL procedure will produce a conflict (loss of separation) with other missions (with and without the new U-space contingency service).

To ensure the statically significant of each simulation, 40 randomly generated scenarios are generated for each parametrization, getting the mean value of each relevant parameter (number of conflicts).

IV. SIMULATION STUDY

The first study in this work aims to assess the impact of current Return-to-Launch (RTL) contingency procedures across various spatial traffic pattern and traffic density values. With this objective two different scenarios have been defined (see Figure *3* A):

- Scenario A: probability to start/end a mission is equal at each node of the graph.
- Scenario B: the nodes located at the ends of the graph feed the traffic network.

Traffic density is swept in each scenario, feeding the strategic conflict resolution service with the missions generated. Once the potential conflicts are mitigated, a set of mission is

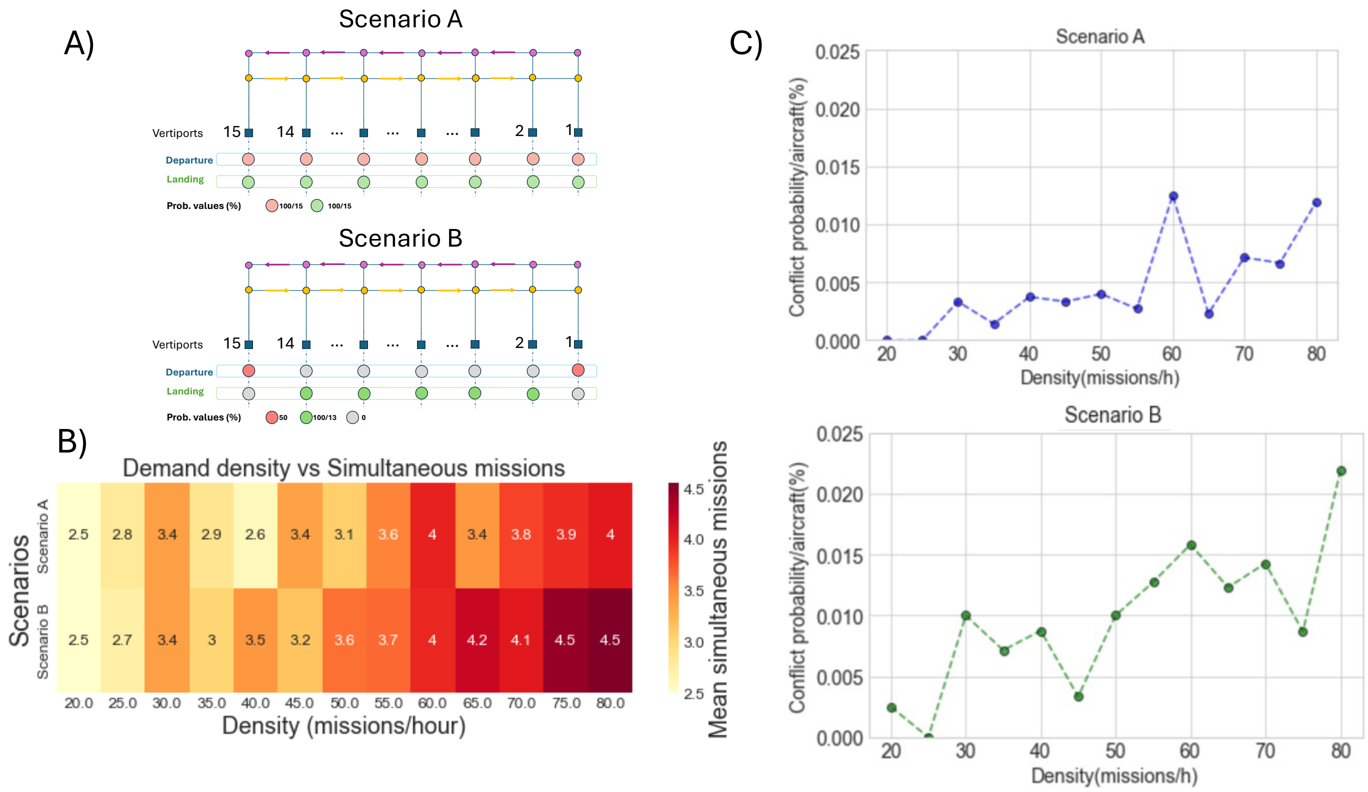

Figure 3 A) Schematic representation of the scenarios traffic demand pattern, specifying start/end probability. B) Heatmap showing the number of simultaneous missions vs traffic demand. C) Conflict probability per aircraft evolution with increasing traffic.

selected randomly, according to contingency probability value, and a RTL event is trigger at a random time of the planned flight. The contingency probability to have a contingency procedure in this initial simulation has been fixed to 0.05. Since the probability of generating a conflict, due to contingency, strongly depends on the number of flights that simultaneously sharing the airspace with the aircraft under threat, this parameter (number of members in the ecosystem) has also been characterized. The results are shown in Figure *3* B). As observed, scenario B present a higher number of simultaneous missions, ecosystem members, compared to scenario A. This slight difference (0.5) is due to demand pattern, which results in longer average mission durations in Scenario B. Consequently, with the same traffic density, there are more simultaneous flights. Note that the traffic generated and analyzed in Figure *3* B is conflict-free as it corresponds to the output of the strategic conflict resolution service.

To test the hypothesis that scenarios with the highest number of simultaneous missions will experience more conflicts during a contingency, 40 scenarios are generated (for each specified parametrization) in which a set of random contingency procedures are triggered in a conflict-free traffic. Once the contingency occurs, the aircraft executes the described RTL trajectory to its origin vertiport, and it is verified if there is any loss of separation with other aircraft. The results of this analysis are presented in Figure *3* C that shows the probability of conflict per aircraft when the RTL procedure is triggered. The probability of conflict per aircraft is calculated dividing the number of conflicts obtained in each scenario by 40 simulations (that are executed under the same conditions) and by the traffic density value. As it can be observed scenario B (the one with a higher number of simultaneous missions) presents the higher level of conflict probability. Also note that this scenario has the end nodes of the airspace structure as the feeders of the network. Consequently, when the RTL is triggered the missions in progress must return to the "origin vertiport" of the mission, potentially generating a conflict along its returning trajectory or even during the descent to ground level. As there are just two vertiports where the aircraft depart the probability of conflict is higher.

Note that the probability of conflict per aircraft, will be used to characterize of the Target Level of Safety (TLS) of the described scenarios managed with the described U-space services. The goal of the TLS is to set an upper bound on the aspired level of risk. This goal has been used in manned aviation for more than 40 years and several statistics have been performed by organizations [16] like International Civil Aviation Organization (ICAO) or EASA [17]. The notional values for the TLS of different types of systems are usually based on statistics. Systems in general can be categorized into three different types according to their accident rates [18]:

- Dangerous systems: the risk of accident is greater than one accident per 1000 operations (i.e 1.10^{-3}).
- Regulated systems: the risk of accident is between 1.10^{-3} and 1.10^{-5} per operation.

- Ultra-safe system: the risk of accident is set between 1.10^{-5} and 1.10^{-7} per operation. Examples of these systems are nuclear industry or ATM.

As observed, U-space deployments can be considered dangerous systems when executing current RTL contingency procedures, under high density traffic. To increase the safety level, the proposed contingency management U-space service is deployed.

A. Static U-space contingency management service

Analyzing the origin of the conflicts in the described scenarios, it was found that conflicts generated during the RTL occurred during the descent maneuver to the contingency vertiport, or in the portion of the trajectory guiding the aircraft to the vertiport where it will land. To mitigate conflicts with the departing vertiport, the static contingency vertiport assigner was developed.

In this new procedure, once the mission is submitted to the USSP, and the mission plan is processed to ensure the safety of the mission and the airspace, the mission description is enhanced by assigning a new contingency vertiport, different from the departure origin. Decoupling contingency vertiports from the departure ones, avoids conflicts generated by high demand vertiports, when a high volume of departures also need to accommodate contingency missions.

The procedure for assigning a new vertiport is divided into the following stages:

- **Step 1:** Once the mission is updated and approved by the strategic conflict resolution service, the new contingency service collects all the mission planned for the same timeframe, when the new planned mission will be executed. The set of missions sharing execution time with the mission under study forms “an ecosystem”.
- **Step 2**: The origin and destination vertiports of the ecosystem members are collected and removed form the potential contingency vertiports that could be assigned to the ecosystem flights.
- **Step 3:** Using the list of remaining network vertiports not utilized (for departure and arrival) by the ecosystem under study, a different contingency vertiport is assigned to each aircraft, satisfying proximity conditions (the nearest vertiport to each aircraft departure vertiport). Each aircraft will be assigned a different vertiport to avoid conflicts if a contingency threat arises for more than one aircraft in the ecosystem.

The new service is expected to reduce the number of conflicts generated by a contingency, thereby increasing safety levels in the airspace by avoiding any interaction during the descent phase to the vertiport with other flights initiating their mission. It is termed ‘static’ because the assigned contingency vertiport remains the same for the entire mission. To verify the hypothesis that the enriched mission description, resulting from the integration of the static contingency U-space service, will increase the safety level of the U-space volume, the service is integrated into the planning process of each mission and its impact in the baseline scenarios presented is characterized. Figure 4 shows the conflict probability per aircraft in the scenario A and B when a contingency probability of 0.05 and 0.10 is fixed and the traffic density is increased.

As observed in the scenario B, the integration of the static contingency service prevents any collateral conflict caused by any contingency procedure at traffic density values below 60 mission/hour (with a contingency probability of 0.05). It is also noteworthy that the conflict probability remains below the 0.0040 threshold even at higher densities (130mission/hour). The static contingency management reduces conflict probability by a factor of 6.6, approximately. These results remain valid even when the contingency probability in the scenario is increased to 0.10.

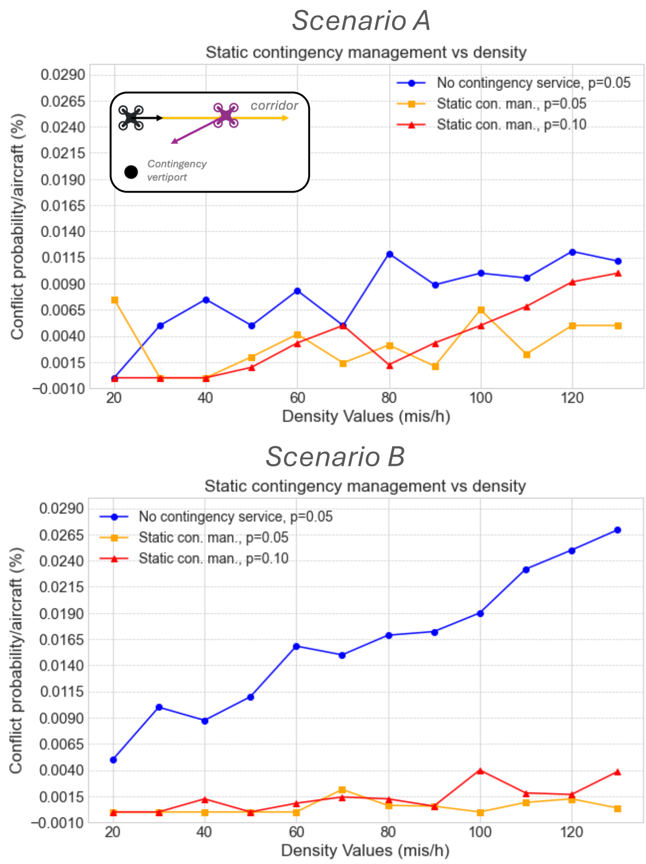

Figure 4. Conflict probability evolution with the integration of the static contingency service (with a contingency probability of 0.05/0.10) as a function of traffic density increase.

However, the new service does not increase significantly the safety levels of the scenario A, which has high traffic density at the end nodes of the airspace network. Two main potential reasons were identified after analyzing the conflicts configuration:

- Most of these conflicts occur during the execution of the RTL trajectory to the assigned vertiport, prior to starting the descent maneuver, as shown in the inset of Figure 4 scenario A. The problem arises when an aircraft in contingency has an assigned contingency vertiport that has already passed in its trajectory. Consequently, when it begins the maneuver to reach this vertiport, the aircraft must change direction (opposite to the way of the corridor) to approach it following a straight-line trajectory. This will cause the aircraft to conflict with all other aircraft following their planned trajectories within the corridor.

- The mean duration of the mission in Scenario A is shorter than Scenario B (90 seconds in Scenario A and 120 seconds in Scenario B) while the number of ecosystem members is similar (0.5 greater, as demonstrated in Figure 3 B). This indicates that, due to the reduced number of alternatives contingency vertiports along shorter paths, and having approximately equal number of ecosystem members, it is difficult to assign different alterative contingency vertiport to all members.

To address these issues, particularly the first one, a dynamic contingency vertiport assigner has been developed.

B. *Dynamic U-space contingency management service.*

The main difference between the dynamic contingency service and the static one is that the assigned contingency vertiport varies throughout the execution of each planned trajectory.

To avoid any UAV needing to change its direction and return to a point that has already been overtaken, a valid interval is attached to each potential contingency vertiport and mission under study. Since all the potential contingency vertiports for a specific mission are those to be overflown during its mission execution, a valid interval can be defined that extends from the mission starting time to the time when the potential contingency vertiport will be reached according to the planned mission. The selection of contingency vertiports assigned to the member of the ecosystem follows the same procedure that the static service: obtaining the ecosystem members, creating a potential list of contingency vertiports without the origin/destination points and assigning to each ecosystem member a different contingency vertiport close to its departure point. However, this process also considers the expiration time (valid time) of each of the assigned vertiport. When the valid interval of one of the ecosystems assigned vertiport is reached, the assignment process is repeated to allocate a new valid solution. In this way, each mission will have a set of assigned contingency vertiports, each with an attached valid interval. If a contingency event is triggered, the onboard control system needs to verify which vertiport to approach based on the mission progress and the valid interval of the assigned contingency vertiport list.

With this new service the results shown in Figure 5 are obtained. As can be observed, the use of dynamic contingency management has a significant impact on system safety. In scenario A, it was found that the static contingency service could not prevent contingency downstream conflicts at any traffic density, whereas using this approach, conflicts begin at approximately 80 mission/hour (for 0.05 and 0.10 contingency probability values). In the scenario B, the use of the dynamic service prevents any downstream conflict produced by a contingency, at any traffic density below 130mission/hour, when the probability of contingency is 0.05. Note that the static solution is valid for traffic densities lower than 60mission/hours (with higher contingency probability). When the probability is increased to 0.10, the solution remains valid until a traffic density of 100 mission/hour is reached.

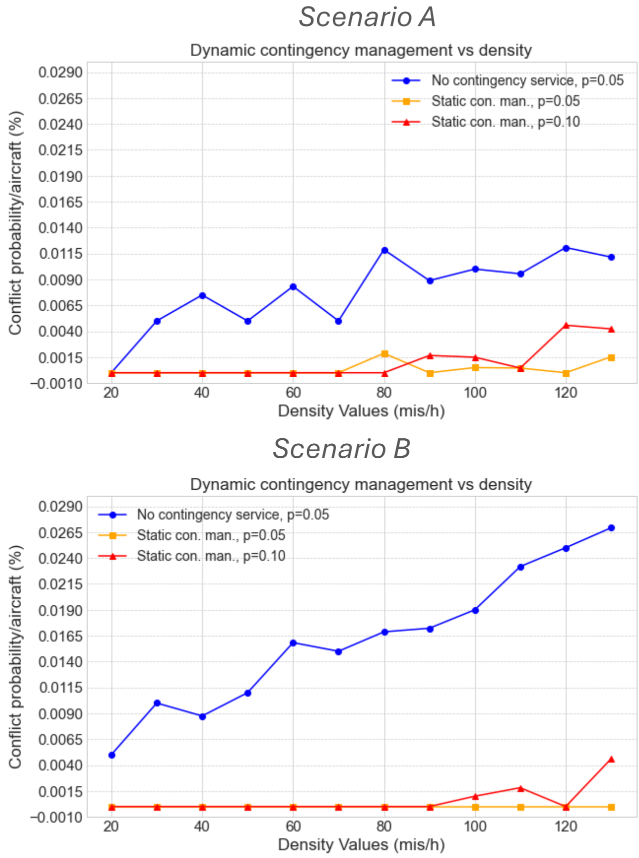

Figure 5. Conflict probability evolution with the integration of the dynamic contingency service (with a contingency probability of 0.05/0.10) as a function of traffic density increase.

V. RESULTS

Table 1 summarizes the safety level reached in the characterized scenarios by integrating the two different contingency U-space services with varying contingency probability. As observed, the Target Safety Level of Ultra Safe Systems (USS) is reached in both scenarios under different conditions. In scenario A, which presents a traffic pattern without any ordered spatial distribution (the probability to start/end in each node is equally distributed), USS condition is met with the static contingency service at 40 mission/hour (with a contingency probability of 0.10). However, this limit is extended when the dynamic contingency service is integrated, reaching 70 missions/h for a probability of 0.05 and 80 mission/hour when the contingency probability is increased to 0.10.

Regarding scenario B, that presents two spatial hotspots in the last nodes of the corridors, the integration of the contingency service has a deep impact. The static contingency service ensures the safety management of RTL procedures at 60 mission/h under low probability conditions. The dynamic contingency service extends the USS conditions to high traffic

TABLE I. ULTRA SAFE SYSTEM TARGET SAFETY LEVEL EVOLUTION DEPENDING ON CONTINGENCY MANAGEMENT SERVICE AND TRAFFIC DENSITY.

Scenario	Contingency service	Contingency probability	USS density threshold
A	Static	0.05	-
		0.10	40 missions/h
A	Dynamic	0.05	70 missions/h
		0.10	80 missions/h
B	Static	0.05	60 missions/h
		0.10	30 mission/h
B	Dynamic	0.05	130mission/h
		0.10	90mission/h

density, 130 missions/hour with contingency probability of 0.05 and 90 mission/hour when the contingency probability is 0.10.

VI. RESULTS

After analyzing the scenarios, the following points can be highlighted:

- Current RTL procedures that rely on returning to the departure vertiport are not a valid solution, from a safety perspective, when the U-space volume is based on a predefined fixed number of departure/landing points, specially as traffic density increases. As demonstrated in corridor-based scenarios, the contingency procedure is executed without accounting for the potential surrounding traffic and its downstream effect can generate conflicts. This suggests that the predefined contingency measurements to adopt, need to be linked to the Demand Capacity Balance (DCB) service and strategic conflict resolution service, particularly after characterizing how density impacts safety when a RTL procedure is triggered in a specific airspace structure.
- The static contingency service, which assigns a single contingency vertiport for each specific mission, has also proven to be a good alternative for scenarios that exhibit moderate traffic densities (lower than 40 mission/h and 60mision/h in the characterized scenarios with a contingency probability of 0.1 and 0.05 respectively).
- The dynamic contingency U-space service has proven to be an excellent solution for increasing U-space volumes safety in high density scenarios. As summarized in
- Table *1*, the integration of this new service creates USS airspaces at low contingency probabilities. Since the event that triggers the contingency procedures do not impact the aircraft capabilities to fly (such as CNS coverage issues or low battery state) airspaces that provide robust and detailed characterization (CNS coverage map or weather information) will be good candidates for integrating the dynamic contingency service to enhance system safety.
- An alternative approach to managing contingencies procedure is to develop a dedicated network of contingency vertiports that provide no additional service beyond a safe landing spot in case of contingency. The cartography of the contingency vertiports network would need to be thoroughly characterized to ensure compliance with the design rules and technical requirements [19][20]. The dimensions required for placing the infrastructure according to aircraft dimensions, obstacle free volume (OFV) and Final Approach and Take- Off Area (FATO) dimensions will constraint the potential locations where the vertiport could be placed. Additionally, it is important to note that this additional infrastructure will have a significant economic impact. What additional investments will be necessary to establish a safe, dedicated network of contingency vertiports? Alternatively, the implementation, and integration of the defined contingency service will only require an onboard control system (already available in commercial UAV) capable of managing alternative landing points, reducing the economic barrier to U-space implementation in urban scenarios.

VII. CONCLUSSIONS

This work has demonstrated how the integration of a dedicated contingency management U-space service could become U-space volumes in Ultra Safe System deployments, even in high traffic density scenarios. The proposed approach advocates for an enhanced mission description and planning process, based on the assignment of a set of alternative vertiports that evolves as the mission progresses. It has been shown that a deep characterization of airspace structure, traffic patterns, and density (DCB), combined with a detailed mission description (strategic deconfliction service), can eliminate the need for additional infrastructure to ensure safe landings during unforeseen events. This enriched planning process will be critical in high-risk deployment scenarios, such as Urban Air Mobility operations.

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