Assessing Safety for U-space Airspace: A Simulation Study of UAS Impact on Low-Altitude Helicopter Operations in Zurich

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***Abstract*—This paper proposes a quantitative methodology to use fast-time simulation to support the assessment of collision risk between Uncrewed Aircraft Systems (UAS) and crewed aircraft in the context of U-space airspace risk assessment. Airspace risk assessment is specifically required of European Union member states by the U-space regulation in order to designate U-space airspace for UAS operations. To illustrate the proposed methodology, a use case provided by the Swiss Federal Office of Civil Aviation (FOCA), was simulated. In this use case, UAS operations within a volume of airspace selected to represent U-space airspace interact with Helicopter Emergency Medical Services (HEMS) on historical HEMS routes in the city of Zurich, without mitigations to prevent collision. Using Monte Carlo methods in fast-time simulation and a four step quantitative methodology, we demonstrate that the probability of mid-air collision (MAC) between uncrewed and crewed aircraft can be estimated efficiently without historical UAS track data.**

***Keywords*—U-space airspace risk assessment, drones, UAS, safety assessment, air risk, HEMS, helicopter, simulation**

I. INTRODUCTION

On January 26, 2023, the U-space regulation [1, 2, 3] was enacted into law in the European Union, designed to ensure safe, efficient and secure access for large-scale UAS operations in European airspace. This U-space regulation requires the use of digital services for uncrewed aircraft system (UAS) traffic management (UTM). Differences in the UTM concept of operations between Europe and the United States is described in Ref. [4]. Acceptable Means of Compliance and Guidance Material (AMC/GM) [5] have also been published by the European Union Aviation Safety Agency (EASA) to provide guidance to European Union (EU) member states on how to comply with the U-space regulation.

As per Article 3 of the U-space Regulation [1], "where Member States designate U-space airspace for safety, security, privacy or environmental reasons, such designation shall be supported by an airspace risk assessment". Meeting this requirement is likely to need significant effort and resources, e.g., as described in the first volume of the U-space Airspace Risk Assessment Method and Guidelines [6], published by EUROCONTROL, which is summarized in Figure 1. In addition to safety risks, which are distinguished into air and ground risk, security risks, privacy risks, and environmental risks must be identified. Depending on the individual operating environment, the U-space airspace risk assessment (ARA) is unique for each U-space designation.

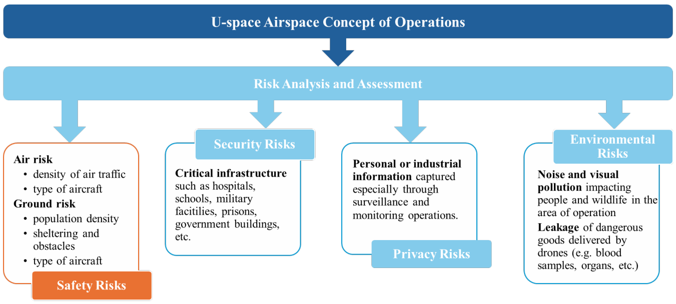

Figure 1. Summary of risks considered during a U-space ARA. Safety risks, in particular air risk, is the focus of this paper. Own depiction based on Ref. [6].

In the context of ARA, hazards inherent to aviation, particularly those resulting in mid-air collisions (MAC), are of significant concern.[1] Currently, however, there is no U-space airspace in place from which data can be processed to assess collision risk. Although there is a regulatory framework for U-space, research, development, implementation and validation of U-space airspace are occurring simultaneously. Hence a number of challenges exist to meet the ARA requirements for designation of U-space airspace, such as where and "how much" U-space airspace to designate; what volume of UAS traffic U-space must accommodate; where crewed aircraft and UAS operations might interact; and when, how much and for how long U-space airspace must be delegated to air traffic control (ATC) when crewed aircraft that are provided with an

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[1] Enforcing a zero probability of MAC is not practical. Instead, regulatory requirements specify acceptable levels of safety, which can be translated into allowable collision risk or MAC rates.

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ATC service have to cross or operate in U-space airspace.[2] Fast-time simulation, however, can provide a valuable tool for evaluating different U-space settings in a cost-effective and risk-free manner. This may include evaluating when specific services or actions are required to ensure safety.

One of the services mandated by the U-space regulation [1] for UAS operations in U-space airspace is a traffic information service (Article 11), which "shall contain information on any other conspicuous air traffic, that may be in proximity to the position or intended route of the UAS flight." Provision of this information is intended to allow UAS operators to "take the relevant action to avoid any collision hazard." The U-space regulation [1] (Article 4) also includes requirements for dynamic airspace reconfiguration (DAR) "in order to make sure that manned aircraft[3] which are provided with an air traffic control service and UAS remain segregated." Per the regulation, this refers to "the temporary modification of the U-space airspace in order to accommodate short-term changes in manned traffic demand, by adjusting the geographical limits of that U-space airspace." (Article 2) However, it is up to the EU member state - through their ARA - to identify where and when traffic information services or DAR are required to ensure safe operations.

The AURA ("Atm U-space inteRfAce") project, funded by Single European Sky ATM Research (SESAR) [7] and completed in 2023, studied a concept of operations for U-space information exchange with ATM systems. One of its pillars was the research of DAR behaviour, reaching technology readiness level (TRL) 4 with fast-time simulation used to achieve relevant results [8]. The SESAR funded ENSURE ("atm-uspacE iNterface and airSpace reconfigURation sErvice") [9] project is now seeking to refine and complete the definition of a common ATM U-space interface, with a particular focus on the development of a DAR service to TRL7. To enable the use of such a service, however, it is essential for the National Aviation Authority to identify where DAR services are needed. The most critical of these needs is when the risk of collision between UAS and crewed traffic within U-space airspace exceeds specified safety thresholds, as identified in an ARA.

This paper seeks to propose and demonstrate a quantitative methodology using fast-time simulation that can be used to assess unmitigated collision risk between UAS and crewed traffic in a realistic operational environment, informing ARA and the need for U-space services, such as traffic information services, and DAR. In the future this methodology could be expanded to assess the impact of traffic information services and DAR to mitigate collision risk, but this is left for future work. After the general introduction in Section I, Section II describes prior relevant literature, followed by Section III, which describes the objectives of the paper. Section IV introduces the proposed methodology, followed by Section V, which describes the use case examined in the paper, and Section VI, which describes the simulation setup used to illustrate the proposed methodology. The illustration results are presented in Section VII, while a discussion of the results and the final conclusions are presented in Section VIII. This final section also highlights the lessons learned in using the proposed methodology to support U-space airspace risk assessment and discusses potential next steps.

II. LITERATURE REVIEW

System level risk analysis has been used extensively in the assessment of traditional ATM systems [10, 11]. However, only more recently has simulation been used to support such analysis. One example of this is for the verification of onboard and remote collision avoidance systems like the Airborne Collision Avoidance System (ACAS X) [12, 13] and ACAS sXu for small UAS [14]. In both of these cases, simulation contributed to the certification of these systems [15].

A number of works in the literature have explored the assessment of UAS collision risk using Monte Carlo simulation methods. Much of this work has focused on collision risk associated with tactical deconfliction [16, 17, 18]. Ref. [16] developed and tested a collision risk model to identify airspace capacity based on risk thresholds, while Ref. [17] applied a modified Reich collision risk model to determine the separation needed to prevent mid-air collision for the simplified case of UAS traveling along the same track. Ref. [18] used Monte Carlo simulation to quantify the impact of uncertainties in tracking system behavior on UAS safety. Other prior work has focused on the impact of strategic deconfliction on reducing collision risk between UAS [19, 20, 21], including using Monte Carlo methods in the analysis of realistic operational use cases [22], and in realistic operational environments with airspace constraints [23]. These works did not, however, focus on collision risk between crewed and uncrewed aircraft. This topic has been explored by the prediction of collision risk between UAS and crewed aircraft within restricted areas around an airport [24], and through the study of DARs [25, 8].

A gap still remains in the literature on the use of simulation to explicitly quantify the safety impact of crewed and uncrewed aircraft operating in the same airspace, in the context of an ARA, as required of EU member states by the U-space regulation. In this paper we build on the work from Refs. [21, 22, 23] to take steps to fill this gap.

III. OBJECTIVES

The objective of this paper is to propose a quantitative methodology to use fast-time simulation to support the assessment of collision risk between UAS and crewed aircraft in the context of an ARA, and to illustrate its use. The use case used to illustrate the methodology was provided by FOCA, and is associated with helicopter emergency and medical service (HEMS) flights in low-level urban airspace that intersects a volume of airspace selected in the analysis to represent U-space airspace. The use case specifically does not include

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[2] UAS operations in U-space airspace do not require services from ATC by default. Crewed aircraft require ATC services when operating in controlled airspace.

[3] In the paper referred to as crewed aircraft.

any mitigation measures to prevent mid-air collisions between UAS and HEMS. The methodology was applied to obtain an indication of the unmitigated collision risk in this use case prior to establishing any mitigations such as U-space services or DAR. This assessment was conducted as a joint collaboration between FOCA, Airbus and EUROCONTROL.

The quantitative methodology proposed in this paper is described in detail in the next section, followed by the description of the U-space airspace use case, used as an illustration, and the simulation setup to apply this methodology.

IV. METHODOLOGY

The quantitative methodology that we propose to support the assessment of collision risk between UAS and crewed aircraft in the context of an ARA uses methods similar to those employed in our previous work assessing the impact of strategic deconfliction on UAS to UAS collision risk [21, 22, 23], and of dynamic airspace reconfiguration [8] on UAS operations. These studies applied Monte Carlo methods to simulate the behavior of aircraft under realistic operational uncertainties, and processed the resulting aircraft position data to generate statistics that quantify safety.

The quantitative methodology we propose here, and which we illustrate by quantifying collision risk associated with HEMS flights in low-level urban airspace and UAS in intersecting U-space airspace, is made up of four steps: (see Figure 2)

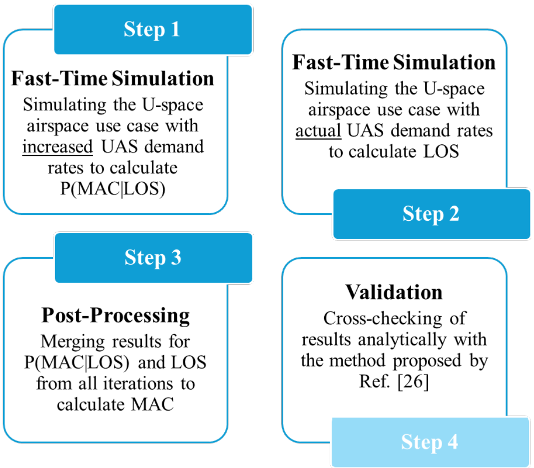

Figure 2. Quantitative methodology proposed to support the assessment of collision risk between UAS and crewed aircraft in the context of an ARA.

First, in **step 1**, we propose using fast-time simulation to estimate the probability of a MAC given a loss of separation (LOS), i.e., $P(MAC \mid LOS)$. Note that, for this study, MAC and LOS are defined specifically as losses of horizontal separation between UAS and HEMS, and not between UAS and UAS (or HEMS and HEMS), since it is specifically the collision risk between UAS and HEMS that are of interest in this study. The reason for estimating $P(MAC \mid LOS)$ is that MAC events are rare, while LOS events (as defined here) are more common. Estimation of MAC probability based on observed LOS events therefore produces more reliable results than observing MAC events directly, without an impractically large number of simulation runs. As in Ref. [22, 23], we assume $P(MAC, LOS) = P(MAC \mid LOS) \times P(LOS)$. Because a MAC is always accompanied by a LOS event, $P(MAC, LOS) = P(MAC)$, so $P(MAC) = P(MAC \mid LOS) \times P(LOS)$. Rearranging:

$$P(MAC \mid LOS) = MAC/LOS \tag{1}$$

where MAC and LOS are the observed MAC and LOS counts. We propose assuming that $P(MAC \mid LOS)$ is approximately constant, which was confirmed for the use case used as an illustration in this paper by running a large number of simulation runs using demand rates at which both MAC and LOS events were observed, as shown in Figure 6. To make sure that this result was not dependent on the demand density rates simulated, we also simulated across a range of demand rates.

Next, in **step 2**, we propose using fast-time simulation to quantify the probability of LOS - between UAS and HEMS per HEMS flight hour for this study - at the reference UAS and HEMS demand rates specified.

In **step 3**, we propose using the $P(MAC \mid LOS)$ from step 1 and observed LOS counts from step 2 to estimate the probability of MAC - between UAS and HEMS per HEMS flight hour for this study - using equation 2. Rearranging equation 1 and using a Maximum Likelihood Estimate for MAC count:

$$MAC = P(MAC \mid LOS) \times LOS \tag{2}$$

where MAC is the estimated MAC count, and LOS is the observed LOS count.

Finally, in an optional **step 4**, we propose validating the simulation results from step 3 using analytical methods, such as the analytical approach described in Ref. [26]. This approach uses a volumetric collision risk model to predict encounters between aircraft and the ideal gas molecules collision frequency theory to estimate the order of magnitude of the probability of MAC between aircraft. The likelihood of a collision depends on the representative dimensions of the aircraft, their speeds and the traffic density. The approach does not, however, account for the impact of the traffic spatial distribution to route around airspace constraints. This approach has been validated against historical data from aviation accident records, displaying accurate albeit conservative results. Besides the parameters described in Tables III and IV in Section VI, additional parameters needed for the calculation are shown in Table I. For this study, the collision avoidance parameter ϵ is defined for both the UAS and HEMS aircraft. If it is set to 100% effectiveness, the collision would be avoided at all times. To be consistent with the hypothesis of the analysis of unmitigated collision, $\epsilon_{UAS_{UAS-HEMS}} = \epsilon_{HEMS_{UAS-HEMS}} = 0$, so no collision avoidance is assumed for either HEMS or UAS.

To implement steps 1 and 2 of the methodology proposed in this paper, a simulator is required. The simulator used to illustrate the methodology in this paper has two key components: a simulation environment, and a set of digital services

TABLE I. ADDITIONAL PARAMETERS CONSIDERED FOR STEP 4 AND NEEDED FOR [26]

Parameter	Value
HEMS radius* (m)	3.86
HEMS area of operations (km^2)	94
HEMS aircraft in fleet** (aircraft)	1
UAS radius* (m)	0.41
UAS area of operations (km^2)	94
UAS aircraft in fleet** (aircraft)	48
UAS typical mission length (min)	20
Operational day length (hr)	12
$\epsilon_{HEMS_{HEMS-UAS}}$	0
$\epsilon_{UAS_{HEMS-UAS}}$	0

*aircraft size based on Ref. [27]
**maximum number of simultaneous flights

necessary to model the appropriate aircraft behavior. These are described below.

A. Simulation Environment

The simulation environment used in this paper models three key elements: demand for UAS and HEMS operations; path planning for those operations; and vehicle behaviour for those operations as they fly their missions.

In each simulation run, the total number of operations simulated was fixed based on the demand rate and simulation duration for the specific scenario being run. Individual operation plans were generated for each simulated operation to meet its mission requirements (e.g., to fly from an origin to a destination). For the HEMS traffic, these origins and destinations were pre-defined by the scenario, while for the UAS traffic, the origins and destinations were sampled uniformly from the origin and destination regions defined for the scenario, which for this study were both the studied U-space airspace focus area (see Section V). The operation departure times for both UAS and HEMS flights were generated by sampling from probability distributions defining inter-departure time (modeled as a Poisson distribution), and associated parameters (the mean demand rate, defined separately for the UAS and HEMS traffic).

For the generation of the UAS operation plans, which had no pre-defined route, a path planner produced a series of four dimensional waypoints to reach the operation's mission goals, while complying with dynamic constraints such as turn radius and routing around any restricted airspace in the lateral plane, specific to the scenario being simulated. This path planning was done using the Rapidly-Exploring Random Tree Star (RRT*) algorithm [28], which is designed to provide an asymptotically-optimal, motion-based trajectory. HEMS operation plans were based on the pre-defined routes specified for the HEMS traffic.

Vehicle flight physics was modelled for both UAS and HEMS traffic assuming a point-mass model. Constraints on turn rate were applied via a Dubins model to match the dynamic constraints of the vehicle [29], and to simulate the vehicle control system response to unplanned disturbances, which were injected in the lateral, vertical and longitudinal directions to model effects such as guidance and navigation error and wind effects. These were applied as vehicle position error in every tick of the simulation environment, sampled from a Gaussian distribution.

B. Digital Services

In this paper, strategic deconfliction services were used in the simulation of both the UAS and HEMS traffic, to ensure that UAS were appropriately separated from each other, and that HEMS were appropriately separated from each other. Note that UAS and HEMS were not deconflicted from each other in any way.

Strategic deconfliction was based on scheduling, as in Ref. [21]. This service computed an optimal departure delay by solving a linear program formed by any overlaps between the operational intents that exist in the system and the operational intent proposed by the operation being planned.

No tactical deconfliction was simulated in this study.

The use case used as an illustration in this paper is presented in the next section.

V. USE CASE

The use case selected to illustrate the proposed methodology presented in this paper forms part of the FOCA ARA for the potential establishment of U-space operations in Zurich, Switzerland. With a population of more than $420,000$ inhabitants, Zurich is the largest city in Switzerland [30].

The volume of airspace selected in this analysis to represent a U-space airspace is shown in Figure 3.

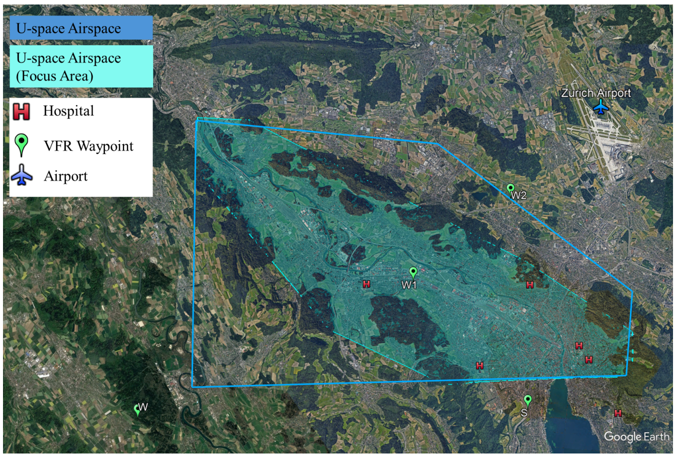

Figure 3. Full U-space airspace boundaries (dark blue) and urban U-space airspace focus area (light blue).

The studied U-space airspace (dark blue region in Figure 3) covers 158 km^2 and is centered on the Zurich city center. The city of Zurich is located in a valley, which concentrates the potential UAS traffic in the airspace to an area from the Northwest corner of the airspace to its Southeast corner (light blue region in Figure 3). Several hospitals with active helipads are located in this area, to and from which low-level HEMS operate. The studied U-space airspace is located approximately three kilometers from Zurich Airport (LSZH). Switzerland has a long-standing tradition of general aviation (GA) operations and flights conducted under visual flight rules (VFR) that can be observed frequently in the area. From 2014 to 2023, VFR flights represented on average 2.9% of the annual movements recorded in LSZH [31]. A summary of the key characteristics of the studied U-space airspace is provided in Table II.

TABLE II. STUDIED U-SPACE AIRSPACE: KEY FACTS.

Full Area	158 km^2
Focus Area	94 km^2
Altitude	0-150 m AGL
MAC (UAS-HEMS)	10 m horizontal separation
LOS (UAS-HEMS)	100 m horizontal separation

In order to illustrate the proposed methodology to use fast-time simulation to support the assessment of collision risk between UAS and crewed aircraft in the context of an ARA, collision risk was estimated for a specific scenario in the city of Zurich in which UAS and HEMS interact. This scenario was selected amongst others (including interactions between UAS and gliders, and interactions between UAS and GA aircraft). As there are no defined or community agreed separation minima between UAS and HEMS, for the study in this paper, and based on input from FOCA, a MAC is defined as a loss of 10 m of horizontal separation, and a LOS as a loss of 100 m of horizontal separation. The chosen scenario examines the air risk associated with multiple UAS operating in the studied U-space airspace focus area alongside HEMS flying on defined routes in low-level airspace. The corresponding simulation setup is introduced in the next section.

VI. SIMULATION SETUP

The process of establishing U-space airspace requires the development of a U-space airspace concept of operations (ConOps). This ConOps is the first step in the airspace risk assessment, as depicted in Figure 1. In collaboration with FOCA, we developed a simulation setup tailored to the HEMS use case from the FOCA ConOps. We applied the quantitative approach described in Section IV to this use case as an illustration of the approach proposed to support ARA with fast-time simulation. In order to configure this specific use case, the following characteristics were considered in the simulation: airspace structure and restrictions; UAS and HEMS demand densities; and UAS and HEMS flight profiles and performance.

A. *Airspace Structure and Restrictions*

The studied U-space airspace focus area, which is located entirely within the Zurich Airport Control Zone (LSZH CTR), may interact with various types of traffic. This includes GA and VFR traffic along the western VFR routes following the waypoints Whiskey (W), Whiskey 1 (W1), Whiskey 2 (W2) and Sierra (S). These waypoints are strategically placed to increase situational awareness and to structure inbound and outbound flights for LSZH. The studied U-space airspace is located below, from ground up to 150 m AGL (see Table II).

Five no-fly zones were selected around which UAS operations must be re-routed. These zones were established at critical infrastructure, such as prisons and electrical substations, to ensure safety and security of these sensitive areas. The exact location and dimensions of the no-fly zones were extracted from the Swiss Dronemap [32].

In addition to the no-fly zones, the studied U-space airspace accommodates several hospitals that are serviced by HEMS operations, providing critical medical services to the surrounding areas. The HEMS-VFR routes were defined based on two sources. First, VFR traffic data in the form of heat maps was provided by FOCA, which showed that VFR traffic predominantly follows published VFR routes at altitudes of 1,000-4,500 ft AGL. Only some outliers were recorded at 500-1,000ft AGL[4]. Second, hospital landing statistics from FOCA were used to identify hospitals of interest. For this paper, 32 bi-directional HEMS routes were defined in the U-space airspace. The routes serve the top five hospital destinations. A summary of the U-space airspace structure and restrictions simulated is shown in Figure 4.

B. *UAS and HEMS Demand Densities*

UAS flights were simulated to start and end at locations uniformly distributed throughout the studied U-space airspace focus area and represent a range of UAS use cases operating in the "specific" category. The reference UAS demand rate simulated, as specified by FOCA, was 48 operations per hour, which was chosen to illustrate a scenario with multiple companies performing aerial delivery and surveillance in the area, creating a large amount of operations per day.

In addition to the hospital landing statistics from FOCA, six weeks of historical radar data collected between 2021 and 2023 and provided by FOCA was used to define the reference HEMS demand rate. The data was specifically chosen to reflect seasonal and annual variations and shows that an average of $3,200$ aircraft movements per year operated from the selected hospitals. Assuming a 12-hour operating day, this corresponds to a HEMS demand rate of 0.7 operations per hour. Distributing the demand rate evenly across all simulated HEMS routes yields a reference demand rate of 0.011 operations per hour per route.

Table III summarizes the UAS and HEMS demand rates simulated.

TABLE III. UAS AND HEMS REFERENCE DEMAND RATES.

UAS demand rate (ops./hr)	48
HEMS demand rate (ops./hr/route)	0.011

C. *UAS and HEMS Flight Profile and Performance*

In this study, two different types of aircraft were simulated: UAS (reference: multicopter drone) operating in the "specific"

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[4] Preliminary study runs simulated crossing VFR traffic based on this historical data. However, no encounters were recorded between UAS and crossing VFR traffic because they were already segregated by cruise altitude. For this reason crossing VFR traffic was not considered in this study.

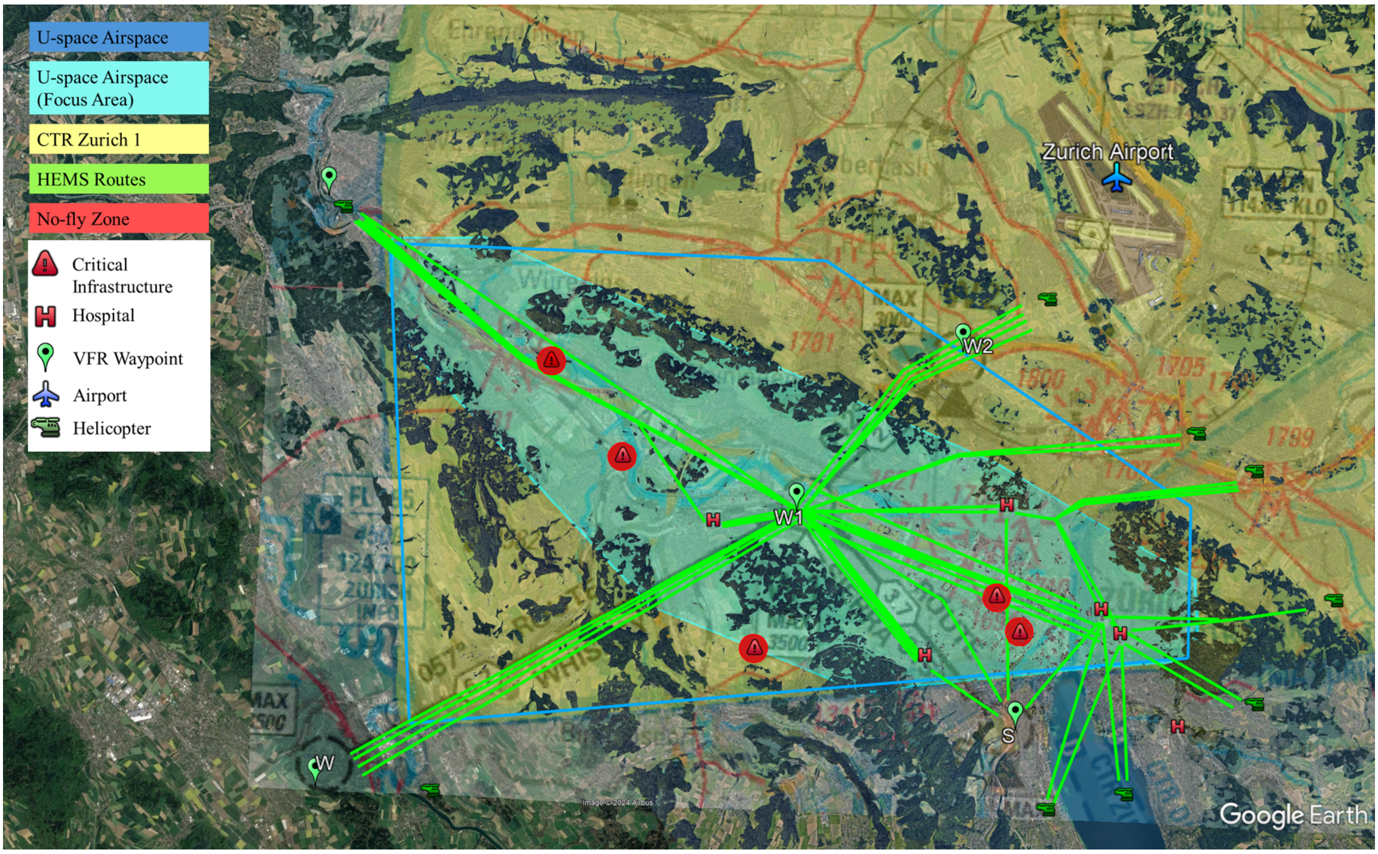

Figure 4. Studied U-space airspace structure and restrictions.

category; and HEMS (reference: Airbus H145 helicopter) operating VFR. Table IV summarizes the flight profile and flight performance assumptions for each type of operation. During the preparation of the simulation, three challenges were encountered. Firstly, there is a lack of real UAS traffic data to validate the simulation results, hence the use of another model for validation (as described in step 4 of the approach in Section IV). Secondly, as of now, there is no standardized UAS performance model as exists for traditional fixed-wing aircraft and rotorcraft (BADA and BADA-H) that can be used in simulation. Therefore, we set the UAS parameters in the simulation based on typical values for multicopter drone aircraft in the specific category, as used in our previous work [23, 22]. And thirdly, some of the HEMS performance parameters had to be adjusted due to the lack of a flight controller in the simulator that is tailored to rotorcraft. This resulted in a deviation from the BADA-H reference for some parameters, which is shown in Table IV.

Consistent with the use case defined by FOCA, the cruise altitude for the simulated UAS was sampled from a uniform distribution between 60 and 150 m, while for the HEMS traffic it was sampled from a normal distribution with average of 131 m, and standard deviation of 30 m.

TABLE IV. UAS AND HEMS: FLIGHT PROFILE AND FLIGHT PERFORMANCE. REFERENCE UAS: MULTICOPTER DRONE. REFERENCE HEMS: AIRBUS H145.

Parameter	Assumption for Simulation	
	UAS	HEMS
Vertical ascent/descent length (m)	10	150
Vertical ascent speed (m/s)	5	5 (BADA-H)
Vertical descent speed (m/s)	5	2.5 (BADA-H)
Max speed (m/s)	50	190
Min speed (m/s)	0	0 (BADA-H)
Cruise speed (m/s)	15	69.5 (BADA-H)
Max acceleration/deceleration (m/s^2)	9.8	150
Cruise altitude $(m$ AGL)	Uniform([60,150])	Normal(131,30)

VII. RESULTS

As described in Section III, the proposed approach to support ARA with fast-time simulation is illustrated with a use case that estimates the unmitigated collision risk between HEMS flights operating in low level airspace and UAS operating in U-space airspace. The results of this illustrative study are presented below and summarized in Figure 5.

The first step of the approach introduced in Section IV, was applied to the use case by estimating the probability of MAC given LOS between UAS and HEMS. This was done by simulating increased demand rates up to 200 UAS operations per hour and up to 3 HEMS operations per hour

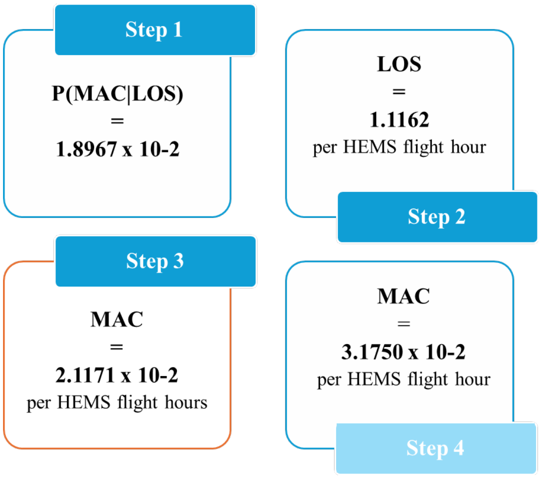

Figure 5. UAS-HEMS collision study results obtained through proposed quantitative methodology to support ARA.

per route, at which both MAC and LOS occur for the UAS-HEMS use case. For this step we completed 311 simulation runs of 2 hours each. This resulted in 18,988 aircraft flight hours being simulated, 6,660 hours of which were HEMS flights. $P(MAC|LOS)$ was calculated using equation 1. The behaviour of this metric through the simulation runs is shown in Figure 6, and demonstrates the approximately constant value expected in Section IV.

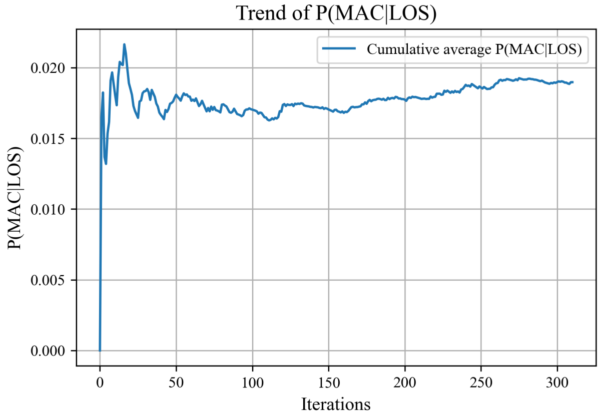

Figure 6. Trend of cumulative average $P(MAC|LOS)$ over 311 simulation runs.

In total, 27,028 LOS and 500 MACs were observed. This results in a cumulative average $P(MAC|LOS)$ equal to 1.8967×10^{-2}, with a standard deviation and standard error of 1.6×10^{-2}, and 0.09%, respectively.

For step 2, we simulated the FOCA specified demand rates of 48 UAS operations per hour and 0.011 HEMS operations per hour per route to observe LOS events. We completed 135 simulation runs of 12 hours each. This resulted in 10,580 aircraft flight hours being simulated, 87.8 hours of which were HEMS. A total of 98 LOS events were observed, resulting in an observed LOS rate of 1.1162 LOS per HEMS flight hour.

Using Equation 2 and the results from steps 1 and 2, the probability of MAC between UAS and HEMS was estimated in step 3 to be 2.1171×10^{-2} MAC per HEMS flight hour[5]. Note that this result is influenced by multiple factors and parameter choices, such as number of simulated hours; the number of UAS; the simulated fixed routes for HEMS; the UAS mission profiles simulated; assumptions about UAS flight altitudes; etc. For comparison, the JARUS Guidelines on Operations Risk Assessment (SORA 2.5) for UAS operating in the “specific” category, specify a target level of safety of 10^{-7} MAC per flight hour [33]. This, however, applies to operations conducted under self-separation and see-and-avoid, in contrast to the unmitigated use case simulated here.

To cross-check our results, the alternative analytical method described in step 4 of Section IV was applied, giving a probability of MAC between HEMS and UAS[6] of 3.17502×10^{-2} MAC per HEMS flight hour. This result is also influenced by multiple factors and parameter choices. While the results applying simulation are slightly lower than this result, they are within the same order of magnitude, increasing confidence in the simulation results obtained, and of the approach used to generate the results.

VIII. CONCLUSION

In this paper a quantitative methodology is presented to use fast-time simulation to support the assessment of collision risk between UAS and crewed aircraft in the context of an ARA. This approach is illustrated with a use case provided by FOCA that estimates the unmitigated collision risk between HEMS flights operating in low level airspace and UAS operating in an intersecting U-space airspace. The results indicate that the proposed methodology is effective at generating valuable quantitative results for an ARA very efficiently, with the potential to reduce the time needed for ARA. The value of the unmitigated probability of MAC between UAS and HEMS obtained in the illustration, however, requires further investigation.

The approach proposed and illustrated in this paper could also be appropriate to assess the impact of collision risk mitigations, such as the following:

- Traffic information provision to UAS operators using U-space traffic information services that provide positions of known traffic, allowing UAS operators to take relevant actions to avoid collisions.
- Collision avoidance systems such as onboard detect-and-avoid systems that allow UAS to avoid collisions directly.
- Strategic deconfliction of crewed and uncrewed operations by the U-space service provider, which would require crewed aircraft to be an active U-space service user.
- Demand capacity balancing to ensure that demand for constrained airspace resources does not exceed safe and socially acceptable levels.

[5] $1.8967 \times 10^{-2} \times 1.1162 = 2.1171 \times 10^{-2}$

[6] In Ref. [26] referred to as $F_{\text{transient}_{\text{UAS-HEMS}}}$

- Introducing airspace structure, such the declaration of crewed aircraft routes as static no-fly zones.
- The declaration of crewed aircraft routes in controlled airspace that intersect U-space airspace as temporary no-fly zones using DAR.[7]
- Constraining U-space airspace capacity to reduce the rate of simultaneous UAS operations.

The study presented in this paper has shown that fast-time simulation has the potential to assist U-space airspace risk assessment in validating the decisions made in the ConOps design phase and the assumptions used to elaborate it. This is done by enabling the estimation of collision risk for realistic traffic scenarios. However, since the U-space airspace ConOps relies on assumptions, so does the fast-time simulation. Currently, there is no historical data for UAS traffic, nor is there a standardised UAS performance model (multicopter, fixed wing, etc.) available for reference in simulation. EUROCONTROL is addressing these challenges through various initiatives, such as the ACUTE project [34], that, up to now, has collected data from more than 40,000 drone flights in Europe; and efforts of its BADA team to propose a consistent and pragmatic approach to UAS performance modelling. There is currently also no guidance on how to define loss of separation events between UAS and crewed traffic. This is a key requirement for calculating ground risk in the second part of the safety risk analysis and assessment described in Section I.

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