Enhancing the Safety of Multi-UAS Urban Operations with SORA

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***Abstract*—Unmanned Aircraft Systems (UAS) play a pivotal role in a variety of modern applications, with traffic monitoring emerging as a critical use case. This study presents the Specific Operations Risk Assessment (SORA) 2.0 framework as applied to UAS operations dedicated for traffic monitoring in urban environments. A comprehensive risk assessment is provided by incorporating real-world scenarios and addressing practical aspects of traffic monitoring missions. A fleet of semi-autonomous drones is employed to safely acquire video footage of traffic for further analysis, based on a detailed elaboration of SORA methodology steps. In this regard, enhancements are proposed for structuring the Air Risk Class assessment and corresponding mitigation measures, as well as recommendations concerning Multi-UAS and autonomous operations, aiming to improve the methodology. As the demand for UAS operations in urban environments, including efficient and secure traffic management solutions, constantly increases, this study aspires to contribute to the UAS operational safety and regulatory framework.**

***Index Terms*—Unmanned Aerial Vehicles, SORA, Multi-UAS, Semi-Autonomous, EASA, Traffic Monitoring, Ground Risk Class, Air Risk Class**

I. Introduction

UAS play a pivotal role in the integrity of critical infrastructure systems including applications for traffic monitoring [1]–[3], autonomous systems for power and telecommunication infrastructure inspection [4], [5], as well as for identifying locations of vegetation encroachment in the power network using Light Detection and Ranging (LiDAR) enabled UAS [6]–[8]. The range of applications is broad, with multiple UAS being employed for Search and Rescue missions in disaster management due to their versatility and ease of deployment [9]–[11], while algorithms have been developed to enable localization in Global Navigation Satellite Systems (GNNSs)-denied environments through cooperative relative positioning methodologies [12], [13]. With the demand for UAS operations being significantly increased in the recent years, inherent risks have been brought that require thorough risk assessment and mitigation. The European Union Aviation Safety Agency (EASA) introduced a comprehensive risk categorization in regulation 2019/947, providing a framework to ensure the safety of UAS operations. This framework divides the operations based on the weight of the UAS and the proximity to people not involved in the operation, as can be seen in Table I [14].

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Table I: EASA UAS Categories [14]

Open Category (Low Risk Operations)		
A1: Not over assemblies of people (UAS weight <900g)	A2: Fly close to people (UAS weight <4kg)	A3: Fly far from people (UAS weight <25kg)
Specific Category (Medium Risk Operations)		
Standard Scenarios (STS)	Pre-Defined Risk Assessment (PDRA)	Specific Operation Risk Assessment (SORA)
Certified Category (High Risk Operations)		
International flights of certified cargo drones	Operations of unmanned drones carrying passengers or cargo	Operations of a piloted aircraft carrying passengers or cargo

In this study, special focus is given in assessing and mitigating the risk of a traffic monitoring operation, based on Specific Operations Risk Assessment (SORA) 2.0 [14]. UAS-assisted traffic monitoring is beneficial since it allows for real-time data acquisition, i.e., video recordings, that is collected from high quality cameras that modern UAS are equipped with. Such capabilities are crucial for traffic management and emergency response in case of accidents. By also considering the ever increasing number of vehicles in urban environments, leading to increased congestion and accidents [15], the ability to immediately respond in cases of emergency is valuable. UAS are cost-effective compared to over-roadway based cameras, side-roadway vehicles that are equipped with LiDAR cameras and other piezoelectric and vibration sensors [16]. Also, they can cover large areas efficiently without disrupting the traffic and they can assess areas that are challenging for ground based monitoring systems [17]. Additionally, UAS offer flexibility due to ease of deployment in both urban and rural areas while adapting to the specific needs of each operation. In this context, the main contributions of this study are the following:

- Application of step-by-step SORA for Multi-UAS traffic monitoring and identification of limitations within the methodology.
- Structured approach for identifying the initial Air Risk Class (ARC), accompanied by a systematic procedure for applying corresponding mitigation measures and a revised version of the Safety Assurance Integrity Level (SAIL) determination matrix.
- Inclusion of Multi-UAS and autonomous operations to SORA methodology, by considering the risk of collision and the autonomy levels.

- Detailed Concept of Operations (ConOps) description that includes equations to calculate operational volume.

The rest of the paper is structured as follows: Section II, presents the related work while Section III describes the traffic monitoring process and the SORA methodology. Section IV, discusses the findings from this process, followed by Section V, which elaborates on the aforementioned contributions, while concluding remarks and future work are presented in Section VI.

II. Related Work

Previous work states the specific challenges that have been faced for various types of operations, also offering insights for future applications. Specifically, SORA has been applied to assess the risk for a UAS media production application, aiming to employ autonomous UAS for aerial cinematography in the countryside around rivers and mountains [18]. In another study, the SORA was applied for Multi-UAS missions in an airport, that is a particularly challenging environment for UAS operations [19]. The objective was to perform airspace inspection using two tethered Multi-rotor UAS in the airport of Luxembourg, that is classified as a controlled Very Low Level (VLL) airspace, aiming to acquire high quality images of an airplane to assess its condition. Both studies identified that the SORA methodology comes with limitations for supporting Multi-UAS and autonomous operations.

As mentioned in Section I, UAS are important for disaster management and previous work has identified the threats faced by the First Responders, also describing mitigation methods. These methods include the use of hexacopter UAS, weather monitoring, anti-collision lights, trained personnel and submission of Notice to Airmen (NOTAM) [20]. In this latter study, tests have been conducted to cover various use cases, including three different scenarios for earthquakes, industrial pilot accidents and terrorist attacks.

Other studies focused on automating the SORA methodology by defining the requirements that are needed to develop an application [21]. This was achieved through a structured approach to provide ConOps data to facilitate automatic determination of the Ground Risk Class (GRC), ARC, SAIL, and Operational Safety Objectives (OSOs). Consequently, the corresponding mitigation measures where derived based on the operation type. While this approach expedited SORA development, challenges and issues have been identified relating with the ConOps development. Specifically, it was observed that any adjustment to the ConOps during development of SORA resulted in the change of operational limitations and requirements which was time-consuming and required thorough revision. In a similar vein, a web-based tool has been developed to assess UAS compliance with the Joint Authorities for Rule making on Unmanned Systems (JARUS) SORA 2.0 guidelines [22]. This tool comes in the form of a questionnaire, an analysis is conducted for providing an evaluation report. Notably, three quad rotors failed the OSOs #10 and #12 requirements due lack of rotor redundancy.

The literature has also pinpointed the limited guidance for organizations acting as competent third parties in SORA [23]. For instance, third parties are organizations that can validate the maintenance program or training syllabus, procedures or audit another organization. In this context, guidance material is provided.

Recently, Urban Air Mobility (UAM) has attracted significant scientific attention for designing and developing passenger-grade autonomous aerial vehicles [24]. Although UAM envisions to revolutionize urban and suburban mobility, there are several technological and financial challenges, but most importantly the societal and legal aspects are crucial to drive success [25]. To this end, regulations must be appropriately amended and efforts have been directed in the implementation of the U-Space Airspace, that provides a safe sharing space between manned and unmanned aircraft. Currently, there are active efforts aiming to enable Beyond Visual Line of Sight (BVLOS) operations and UAM within U-Space [26].

In the field of large Remotely Piloted Aircraft System (RPAS) flights, major discussion points have been proposed for JARUS SORA. Such suggestions include coverage of operational scenarios over open ocean environments, ability to manipulate the geometry and dynamics of the operation, and assessing the possibility of near real-time airspace density data for operators [27]. Although, this was proposed in the Australian airspace, these suggestions could be a driver for improving EASA's SORA.

III. SORA for Traffic Monitoring

Road traffic monitoring utilizing drones as aerial data collection platforms as can be seen in Fig. 1 is a novel and promising area of research that has attracted considerable attention in the recent past [1], [28], [29]. In the following subsections we describe the process of implementing the SORA methodology for a case study scenario focused on urban traffic monitoring in Nicosia as part of our activities in the ERC, URANUS, No. 101088124.

Figure 1: Traffic Monitoring from HARPY-DATA dataset [2]

A. Step 1: ConOps Description

Multiple Unmanned Aerial Vehicles (UAVs) with specifications depicted in Table II [30] will be deployed for traffic monitoring of a 1.5km long arterial road in Nicosia city center,

Figure 2: Operation site includes a 1.5km long arterial road (blue) in Nicosia city center, Cyprus. Green, yellow and red regions correspond to the flight geography, contingency volume and ground risk buffer, respectively.

Cyprus (Fig. 2), from 07:00 to 19:00, for six days, including weekends. The UAVs will be guided to designated locations (black marks in Fig. 2) using an in-house built multi-agent control interface [31] to maximize efficiency. High-definition RGB video will be acquired at a height of $150m$ to maximize detection performance following a previous study [28]. The videos will be analyzed to detect and track moving vehicles for obtaining traffic-related features, i.e., velocity, direction, trajectory, distance to leading vehicles, number of vehicles crossing points on the road, and road-lane state estimation, i.e., average speed and vehicle density [32].

During the operation trained pilots and observers will be present to monitor and to take control of the UAVs when needed. Specifically, 7 UAVs will be used with an equal number of pilots and observers. The operation will continue throughout the day to capture a total of 7 hours of traffic per day, using an intermittent acquisition pattern, i.e., video will be acquired until the UAVs' batteries reach 25%. At this point, the pilots will navigate the UAVs back to control stations to change batteries and continue acquisition of data.

Table II: UAV and Parachute Specifications

Specifications of the selected UAV	
Model	MAVIC 2 Enterprise
MTOM	1100g
Diagonal Length	354mm
Flight Time	31min
Resolution	3840x2160 @30FPS
Operating Frequency	2.400 - 2.4835 GHz 5.725 - 5.850 GHz
Specifications of the selected Parachute	
Deploy Time	0.5 seconds
Battery	150mAh

B. Step 2: Determination of the Intrinsic UAS GRC

The intrinsic ground risk relates to the risk of a person on the ground being hit by the UAS and is depended on the area of operation, dimensions and weight of the UAS, as well as the type of flight, i.e., Visual Line of Sight (VLOS) or BVLOS. Additionally, the operational volume must be defined, that includes the flight geography (green), the contingency volume (yellow) and the ground risk buffer (red), as shown in Fig. 2.

Table III: GRC Determination

Intrinsic UAS GRC					
	Max UAS characteristics dimension	1m / approx. 3ft	3m / approx, 10ft	8m / approx. 25ft	8m / approx. 25ft
	Typical kinetic energy expected	700J (approx. 529ftlb)	34kJ (approx. 250 00ftlb)	1084kJ (approx. 800 000ftlb)	1084kJ (approx. 8000 00ftlb)
Operational Scenarios	VLOS/BVLOS over a controlled ground area	1	2	3	4
	VLOS over a sparsely populated area	2	3	4	5
	BVLOS over a sparsely populated area	3	4	5	6
	VLOS over a populated area	4	5	6	8
	BVLOS over a populated area	5	6	8	10
	VLOS over an assembly of people	7			
	BVLOS over an assembly of people	8			

To identify the components of the operational volume (Fig. 3) the parameters shown in Table IV have been calculated [33]. Gray boxes indicate the values for the specific operation conducted in this study. Also, to calculate the kinetic energy the terminal velocity must be determined, as shown in Eq. 1

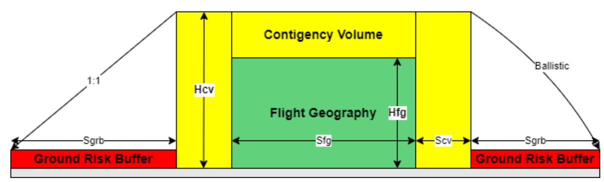

Figure 3: Operational Volume Diagram

$$V = \sqrt{\frac{2W}{C_d \cdot r \cdot A}}, \; KE = \frac{1}{2} m V^2, \tag{1}$$

where V is the terminal velocity, W and m is the maximum take of mass, C_d is the drag coefficient, r is the air density, A is the reference area and KE is the kinetic energy.

In this study, based on the UAV's characteristics (Table II) the terminal velocity was calculated as $V = 19.8m/s$ using $C_d = 0.47$, $r = 1.2985kg/m^3$, and $A = 0.009193m^2$, resulting in kinetic energy $KE = 215.6J$. By also considering that the mission will be conducted in VLOS over a populated area, the intrinsic GRC is 4, as illustrated in Table III.

C. Step 3: Determination of the Final GRC

Ground risk mitigations aim to reduce the danger of a person being struck by a UAS while on the ground. There are three type of ground risk mitigations as shown in Table V, each of which has robustness levels depending on the confidence level that the risk is mitigated, i.e., none, low, medium, high.

M1 mitigations suggest that a ground risk buffer is defined based on the 1:1 rule. However, since the chosen operation area consists of an urban environment with multiple UAVs, the application of the 1:1 rule is unattainable; thus, a low level of robustness is claimed, while monitoring of weather conditions

Table IV: Operational Volume Characteristics

Features	Definition	Results
g	Acceleration of the gravity	$9.81m/s^2$
S_{gps}	GPS horizontal inaccuracy	$3m$
H_{gps}	GPS vertical inaccuracy	$4m$
S_{pos}	Position holding error	$3m$
S_k	Map error	$1m$
V_z	Rate of descent	$5.5m/s$
t_{par}	Parachute deploy time	$0.5s$
CD	Characteristic dimensions of the drone	$0.35m$
V_0	Initial velocity	$13.89m/s$
V_{wind}	Speed of the wind	$5.55m/s$
Lateral Contingency Maneuvers without parachute	$S_{cm} = \frac{1}{2} \frac{V^2}{g \cdot \tan(\Theta)}$	$9.83m$
Lateral Contingency Maneuvers with parachute	$S_{cm} = V_0 \cdot t_{par}$	$6.95m$
Reaction Distance	$S_{rz} = V_0 \cdot 1s$	$13.89m$
Lateral Contingency Volume	$S_{cv} = S_{gps} + S_{pos} + S_k + S_{rz} + S_{cm}$	$27.84m$
Vertical Contingency Maneuvers without Parachute	$H_{cm} = \frac{1}{2} \frac{V}{g}$	$0.71m$
Vertical Contingency Maneuvers with Parachute	$H_{cm} = V_0 \cdot t_{par} \cdot 0.7$	$4.86m$
Response Height	$H_{rz} = V_0 \cdot 0.7 \cdot 1s$	$9.72m$
Vertical Contingency Volume	$H_{cv} = H_{fg} + H_{gps} + H_{rz} + H_{cm}$	$168.58m$
Termination of Flight using Parachute	$S_{grb} = V_0 t_{par} + V_{wind} \cdot \frac{H_{cv}}{V_z}$	$177.05m$
Calculation of Ground Risk Buffer (Ballistic Approach)	$S_{grb} = V_0 \cdot \sqrt{\frac{2H_{cv}}{g}} + \frac{1}{2}CD$	$81.61m$
Simplified approach 1:1 rule	$S_{grb} = H_{cv} + \frac{1}{2}CD$	$168.76m$
Lateral Flight Geography	S_{fg}	$1500m$
Vertical Flight Geography	H_{fg}	$150m$

Table V: GRC Mitigations

		Robustness		
Mitigation Sequence	Mitigations for Ground Risk	Low	Medium	High
1	M1 - Strategic mitigations for ground risk	0,-1	-2	-4
2	M2 - Effects of ground impact are reduced	0	-1	-2
3	M3 - An emergency response plan (ERP) is in place, the UAS operator is validated and effective	1	0	-1

and UAV performance will be performed. For the M2 mitigations, a parachute will be employed to reduce ground impact; thus, a medium robustness level is claimed, which is also the same for the M3 mitigations, i.e., an Emergency Response Plan is in place although not validated by a competent third-party entity. Consequently, the final GRC is 3.

D. Step 4: Determination of the Initial ARC

The initial ARC represents the aggregated collision risk prior to the implementation of any mitigating measures. It provides a qualitative assessment of the likelihood of a UAS encountering a manned aircraft within typical and generalized civil airspace. SORA employs the operational airspace outlined in the ConOps to establish the air risk category, taking into account the probability of mid-air collisions. By considering the operational requirements, the initial ARC is ARC-c, as shown in Table VI.

Table VI: ARC Determination

Operational environment, AEC and ARC			
Operations In	Initial generalized density rating	Corresponding AEC	Initial ARC
Airport/Heliport Environment			
OPS in an airport/heliport environment in class B,C or D airspace	5	AEC 1	ARC-d
OPS in an airport/heliport environment in class E airspace or in class F or G	3	AEC 6	ARC-c
Operations above 400ft AGL but below flight level 600			
OPS > 400ftAGL but < FL600 in a Mode-S Veil or transponder mandatory zone (TMZ)	5	AEC 2	ARC-d
OPS > 400ftAGL but < FL 600 in controlled airspace	5	AEC 3	ARC-d
OPS > 400ft AGL but < FL600 in uncontrolled airspace over an urban area	3	AEC 4	ARC-c
OPS > 400ft AGL but < FL 600 in uncontrolled airspace over a rural area	2	AEC 5	ARC-c
Operations below 400ft AGL			
OPS < 400ft AGL in a Mode-S Veil or TMZ	3	AEC 7	ARC-c
OPS < 400ft AGL in controlled airspace	3	AEC 8	ARC-c
OPS < 400ft AGL in uncontrolled airspace over an urban area	2	AEC 9	ARC-c
OPS < 400ftAGL in uncontrolled airspace over a rural area	1	AEC 10	ARC-b
Operations above flight level 600			
OPS > FL 600	1	AEC 11	ARC-b
Operations in atypical or segregated airspace			
OPS in atypical/segregated airspace	1	AEC 12	ARC-a

E. Step 5: Application of Strategic Mitigations to Determine the Residual ARC

The ARC can be reduced by using strategic or tactical mitigations measures [34]. There are two types of strategic mitigations: mitigations by operational restrictions, such as geographical boundaries, time limitations and time of exposure, and mitigations by common structures and rules. Determination of the ARC requires the National Aviation Authority (Department of Civil Aviation [DCA]) to approve the proposed mitigations for the given operation. In this study, the mitigations for ARC will be applied as shown in Table VII, aiming to a final ARC-b.

F. Step 6: Tactical Mitigation Requirement and Robustness (TMPR) Levels

TMPR is the amount of tactical mitigation that needs to be applied to mitigate the risk that could not be mitigated by strategic mitigations. Tactical mitigations are implemented while carrying out the operation and serve to address any remaining risk of a mid-air collision that persists even after applying strategic mitigations. This approach functions as a "mitigating feedback loop", aiming to actively reduce the incidence of collisions by dynamically adjusting the geometry and dynamics of conflicting aircraft in real-time based on current conflict information. It consists of the following five steps: *Detect, Decide, Command, Execute, Feedback Loop*.

Table VII: Strategic Mitigations for ARC

Strategic Mitigations by Operational Restrictions	Mitigation by boundary	Operation within VLL airspace
		VLOS Operation
	Mitigation by Chronology	Operation during the day
	Mitigation by time of exposure	Intervals of 25min
Strategic Mitigations by Structure and Rules	Mitigation by common flight rules	Anti-Collision Beacon
		Contact with DCA 5 days before the flight
		Verification of other traffic during the operation
		Meteorology Reports
	Mitigation by common airspace structure	Remote Identification Technology

G. Step 7: SAIL Determination

SAIL represents the level of confidence that the operation will remain under control and it is determined by combining the final GRC and ARC, as shown in Table VIII. Since the final GRC is 3 and the residual ARC is ARC-b, the SAIL value for the operation is II.

Table VIII: SAIL Determination

	Residual ARC			
Final GRC	a	b	c	d
≤ 2	I	II	IV	VI
3	II	II	IV	VI
4	III	III	IV	VI
5	IV	IV	IV	VI
6	V	V	V	VI
7	VI	VI	VI	VI
> 7	Certified Category			

H. Step 8: Identification of the OSOs

Using the determined SAIL value, the importance level of OSOs is identified, as shown in Table IX.

I. Step 9: Adjacent Area/Airspace Considerations

This section analyses the risk of a loss of control that may lead the UAV to operate outside of the operation area. The risk of the UAV flying away from the operational volume is very low, even though there will be multiple UAVs, since restrictions will be applied by the multi-agent control software used to conduct the operation. As mentioned in Section III-A, each UAV will have a designated pilot and an observer with the operation conducted in VLOS. Consequently, according to SORA instructions, the safety requirements for containment are: (a) the UAS will be equipped with parachutes, and (b) the control ground station software will restrict the operational volume of each drone.

J. Step 10: Comprehensive Safety Portfolio

Having determined the SAIL, the robustness levels of the OSOs have been identified according to the Table IX. Below the OSOs are mentioned excluding optional ones.

1) Ensure that the operator is competent and/or proven (OSO #1): The operation will be conducted by senior team members and experienced pilots who received special training for the operation. Flight logs and UAS maintenance procedures are well documented.
2) UAS Maintained by competent or proven entity (OSO #3): UAS maintenance is conducted using the guidelines provided by trained members of the team. Heavy maintenance is performed at a manufacturer's authorized service location and it is well documented.
3) C3 (Command/Control/Communication) link performance is appropriate for the operation (OSO #6): The radio-frequency (RF) spectrum use and environmental conditions for C3 links are adequate to safely conduct the operation.

Table IX: Operational Safety Objectives

O: Optional, L: Low Robustness, M: Medium Robustness, H: High Robustness

OSO Number		SAIL					
	Technical issue with the UAS	I	II	III	IV	V	VI
OSO #01	Ensure the operator is competent and/or proven	O	L	M	H	H	H
OSO #02	UAS manufactured by competent and/or proven authority	O	O	L	M	H	H
OSO #03	UAS maintained by competent and/or proven entity	L	L	M	M	H	H
OSO #04	UAS developed to authority recognized design standards	O	O	L	L	M	H
OSO #05	UAS is designed considering system safety and reliability	O	O	L	M	H	H
OSO #06	C3 link performance is appropriate for the operation	O	L	L	M	H	H
OSO #07	Inspection of the UAS (product inspection) to ensure consistency to the ConOps	L	L	M	M	H	H
OSO #08	Operational procedures are defined, validated and adhered to	L	M	H	H	H	H
OSO #09	Remote crew trained and current and able to control the abnormal situation	L	L	M	M	H	H
OSO #10	Safe recovery from technical issue	L	L	M	M	H	H
	Deterioration of external systems supporting UAS operations						
OSO #11	Procedures are in-place to handle the deterioration, of external systems supporting UAS operations	L	M	H	H	H	H
OSO #12	The UAS is designed to manage the deterioration of external systems supporting UAS operations	L	L	M	M	H	H
OSO #13	External services supporting UAS operations are adequate for the operation	L	L	M	H	H	H
	Human Error						
OSO #14	Operational procedures are defined, validated and adhered to	L	M	H	H	H	H
OSO #15	Remote crew trained and current and able to control the abnormal situation	L	L	M	M	H	H
OSO #16	Multi-crew coordination	L	L	M	M	H	H
OSO #17	Remote crew is fit to operate	L	L	M	M	H	H
OSO #18	Automatic protection of the flight, envelope from human error to	O	O	L	M	H	H
OSO #19	Safe recovery from human error	O	O	L	M	M	H
OSO #20	A human factors evaluation has been performed and the human machine interface (HMI) appropriate for the mission	O	L	L	M	M	H
	Adverse operating conditions						
OSO #21	Operational procedures are defined, validated and adhered to	L	M	H	H	H	H
OSO #22	The remote crew is trained to identify critical environmental conditions and to avoid them	L	L	M	M	M	H
OSO #23	Environmental conditions for safe operations are defined measurable and adhered to	L	L	M	M	H	H
OSO #24	UAS is designed and qualified for adverse environmental conditions	O	O	M	H	H	H

4) Inspection of the UAS (product inspection) to ensure consistency to the ConOps (OSO #7): Pre-flight and post-flight UAS inspection is performed using checklists.
5) OSOs related to Operational procedures (OSO #8, #11, #14, #21): Normal, Contigency and Emergency Procedures are covered in the Operations Manual.
6) OSOs related to the remote crew training (OSO #09, #15, #22): The team that will perform the operation is trained with the required theoretical knowledge for specific category and with practical experience as required by the Operations Manual.
7) OSOs related to safe design (OSO #10, OSO #12): Pre-flight checks will be conducted by experienced members of the team. The UAS will always operate within the operational volume. Contingency and emergency procedures are implemented.
8) External services supporting UAS operations are adequate to the operation (OSO #13): The operation will be conducted with assistance by the Cyprus Ministry of Transport, Communications and Works and the DCA.
9) Multi crew coordination (OSO #16): The operation will be conducted based on a meticulously-crafted plan, which will be tested through simulations and smaller scale flight tests. Constant communication between pilots will be maintained during the operation.
10) Remote crew is fit to operate (OSO #17): All pilots are responsible for informing the Accountable Manager of any changes in medical status prior to flying that may affect their ability to carry out their duties. In such case, they will be replaced.
11) Human factors evaluation has been performed and the Human-Machine Interface (HMI) found appropriate for the mission (OSO #20): A multi-agent control platform will be used to monitor and control the UAVs.
12) Environmental conditions for safe operations defined, measurable and adhered to (OSO #23): The operation will take place in days with no rain and wind according to the manufacturer's manual.

IV. Discussion

To effectively implement SORA, it's crucial to define operational parameters and mitigate associated risks. One of the primary risks encountered in this study is operating UAVs over busy urban roads, heightening the potential for accidents and disruptions. To tackle this, a comprehensive risk mitigation approach was applied, by using VLOS protocols to ensure direct visual observation of UAVs by trained personnel for prompt intervention in case of deviations. Additionally, timely communication with DCA facilitates coordination and compliance with regulations, to reduce collision risks with manned aircraft and other UAVs. Finally, integrating a parachute system into the UAV ensures fail-safe mechanisms for unforeseen malfunctions or loss of control, to prevent harm to bystanders or properties.

Ongoing work aims to improve GRC determination that is expected to be included in SORA 2.5. The new GRC model will consider the population density and the maximum UAS cruise speed, instead of the operational scenario and the expected kinetic energy. Additionally, there is the intention to introduce a new air model in SORA 3.0 [35].

In this study, during SORA implementation, it was observed that it lacks support for autonomous (and semi-autonomous) Multi-UAS operations. Consequently, individual assessments must be conducted for each UAS. Additionally, the determination of ARC can be structured similarly to the process for determining the GRC, to facilitate step-by-step guidance. To this end, in the following Section amendments are proposed to enhance the current SORA methodology.

V. Improvements for SORA

A. Methodology for Air Risk Assessment

The SORA methodology as previously mentioned, exhibits certain limitations. Specifically it was identified that there is a lack of clear structure for determining the ARC and applying corresponding mitigation measures. Addressing these limitations is crucial for enhancing the effectiveness and precision of the risk assessment process.

Table X: Proposed amendments for defining ARC

Initial UAS ARC						
	Height of Flight	Below 120m	Between 120m and 150m	Between 150m and FL600	Over FL600	Class E, F,G Airspace
Environment	Atypical Airspace	1	1	2	2	
	Uncontrolled Airspace Rural Areas	3	4	6	5	
	Uncontrolled Airspace Urban Areas	6	6	7	5	
	Controlled Airspace	6	7	10	5	
	Mode C Veil or TMZ	6	7	11	5	
	Airport/Heliport	9	10	11	5	8

For enhancing the structure of determining the initial ARC within SORA, an updated approach is proposed, consisting of the airspace environment which is classified in 6 categories, based on the expected aerial density (Table X). On the other hand, the flight's height is classified in 5 categories. The first category encompasses altitudes under $400ft$ ($120m$), marking the maximum allowable height for UAS in the open category. Hence, it is the safest due to its adherence to regulatory constraints. The next classification is flights between $120m - 150m$ (under $500ft$) which represents the maximum range for operations in VLL airspace. Airspace between $150m$ and $FL600$ is considered to be the most challenging category, since UAS face an elevated risk of manned aircraft encounters. Lastly flights over $FL600$ are considered relatively safe since manned aircraft do not operate over that height. However, it is important to note potential encounters with military aircrafts at this altitude. In airport environments, airspace classes E, F and G are considered safer compared to classes B, C, and D.

In order to systematically and effectively mitigate the ARC, a structured mitigation approach is proposed as shown in

Table XI: ARC Mitigations

		Robustness		
Mitigation Sequence	Mitigations for Air Risk	Low	Medium	High
1	Mitigations by Operational Restrictions	-1	-2	-3
2	Mitigations by Structures and Rules	0	-1	-2
3	VLOS Operation		-1	

Table XI, consisting of the following mitigations, akin to GRC mitigations as can be seen in Table XII.

Table XII: Proposed Mitigations for ARC

Mitigations by Operational Restrictions	Mitigations by Structures and Rules	VLOS Operation
Use of VLL airspace	Contact DCA before the operation and communication with air traffic controller	Visual Line Of Sight Flight
No-fly zones in operational volume to avoid busy areas	Procedure to verify the presence of other traffic	
Not flying near airports	Existence of collision avoidance system	
Demonstration of low air density rating	Procedure to notify other airspace users	
Flying at outer reaches of airspace	Remote Identification Technology	

Based on the aforementioned considerations, Table XIII showcases the determination of SAIL with an enhanced matrix.

Table XIII: Updated SAIL Determination

SAIL Determination									
	Residual ARC								
Final GRC	2	3	4	5	6	7	8	9	>9
≤ 2	I	II	II	III	III	IV	V	VI	Certified Category
3	II	II	III	III	IV	IV	V	VI	
4	III	III	III	IV	IV	IV	V	VI	
5	IV	IV	IV	IV	IV	IV	V	VI	
6	V	V	V	V	V	V	V	VI	
7	VI	VI	VI	VI	VI	VI	VI	VI	
>7	Certified Category								

B. Autonomous Operations

The integration of autonomous UAS operations necessitates an expansion of the SORA framework to incorporate varying degrees of automation. This adaptation is crucial, particularly in semi-automated or fully automated operations, where the level of autonomy significantly impacts safety considerations. While automation may enhance safety in less congested rural areas, its application in densely populated urban environments introduces unique challenges due to factors, such as building layout and airspace congestion. To ensure comprehensive risk mitigation, it is essential to evaluate automation levels across four distinct categories: No autonomy, semi-autonomous, autonomous with VLOS, and autonomous with BVLOS [36]. This classification allows for a nuanced understanding of the associated risks and informs targeted safety measures in diverse operational contexts.

C. Risk Of Collision in Multi-UAS Operations

To incorporate collision risk analysis in scenarios involving Multi-UAS operations, that inherently pose unique challenges, an enhancement is proposed building upon previously developed methodologies that classify each UAS as *dangerous*, *regulated*, or *ultra-safe*, as can be seen in Table XIV [37].

Table XIV: Risk Of Collision

System	Risk	ARC
Dangerous	Greater than 10^{-3}	+1
Regulated	Between 10^{-3} and 10^{-5}	0
Ultra-Safe	Between 10^{-5} and 10^{-7}	-1

In this context, the probability of human collision with a UAS that causes a fatal injury can be computed using Eq. 2, while the probability of a UAS colliding with another UAS can be determined through Eq. 3. This proposed extension not only contributes to the evolving field of UAS risk assessment, but also highlights the practical implications of incorporating collision risk analysis in Multi-UAS scenarios.

$$P_{collision} = \frac{P_{fatal\_injury}}{N \cdot P_{(fatal\_injury|struck)}} \quad (2)$$

where N is the average number of persons per struck, $P_{(fatal\_injury|struck)}$ is the conditional probability that a person suffers a fatal injury if struck.

$$\begin{aligned} P_{collision} &= f_{conflict} \cdot P_{(collision|conflict)} \\ f_{conflicts} &= f_0 \cdot (1 - \epsilon_{strategic}) \end{aligned} \quad (3)$$

where $f_{conflict}$ is the unmitigated frequency that two aircraft are exposed to potential risk when they close to each other, $\epsilon_{strategic}$ is the effectiveness of strategic mitigations, and $P_{(\text{collision}|\text{conflict})}$ is the conditional probability that a conflict becomes a collision.

VI. Conclusions and Future Work

This study has demonstrated the SORA methodology to UAS-assisted traffic monitoring in urban areas. It identified the operation's risk level as SAIL II; thus, meeting safety standards, but revealing limitations in the SORA framework. Challenges include defining and mitigating ARC, assessing collision risks in Multi-UAS operations, and evaluating autonomous-related risks. To address these limitations, enhancements have been proposed to advocate for structured ARC assessment, updated SAIL identification, and collision risk calculation for Multi-UAS operations. Emphasis has been also placed on assessing automation levels in future SORA iterations to improve UAS operations' safety and efficiency in urban settings.

As a part of future work, the proposed enhancements will be implemented to validate their efficacy, and focus will be given on assessing the risks associated with varying autonomous degrees. This could involve developing comprehensive frameworks or metrics to evaluate autonomous levels and its impact on operational safety. In the context of Multi-UAS operations, collision avoidance strategies will be essential for defining associated risks. Additionally, collaboration with regulatory authorities is crucial for gathering empirical data and practical insights to contribute to the development of safe and reliable autonomous Multi-UAS operations.

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