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SORA-BASED RISK ASSESSMENT FOR CARGO UNMANNED AERIAL VEHICLES IN THE UAM FRAMEWORK

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Abstract

The Specific Operations Risk Assessment (SORA) is a systematic approach proposed by the European Union Safety Agency (EASA) to conduct an operation-focused safety assessment on Unmanned Aerial Vehicles (UAVs). In the SORA approach, the risk that a UAV and the associated operations poses to individuals and infrastructures on-ground as well as the chance of mid-air collision with piloted aircraft are investigated. Through the study of the UAV aspects, such as dimension and weight, the population density of the overflown area and the manned traffic in the operating region, the UAV can be ranked with a risk class, namely Low, Medium or High. The risk class determines the robustness level of the safety requirements that the UAV must meet. If the safety requirements outlined via the application of SORA are satisfied, the UAV operator can present the request to obtain approval to fly from the authorities. In this paper, the SORA is applied to three scale-unlike UAVs involved in an aerial logistics chain. Each UAV is characterized by a different transportation purpose and thus, design requirements. This requires the UAV designer to deal concurrently with a variety of UAV concepts. For this reason, the SORA is implemented in a supporting tool that assists the designer throughout the safety assessment of the involved UAVs and automatically generates the risk categorization. The SORA approach classifies these UAVs within the highest risk class because of the operations intended to take place in densely populated regions and in fully autonomous mode. To reduce this risk classification, technical and/or operational mitigations are proposed and further explored. However, these mitigations still prove to be insufficient to ensure the compliance of the considered UAVs with today's UAV norms. By marking the current regulation deficiencies, a gap between the UAV systems and the UAV policy is identified. This permits to develop a roadmap to pave the way towards the integration of delivery services with UAVs into the civil airspace.

Keywords: *UAV, Safety Assessment, SORA, logistics chain, EASA, Roadmap*

1. Introduction, Motivation & Background

In recent years, Unmanned Aerial Vehicles (UAVs) are becoming increasingly popular worldwide in various sectors, such as agriculture, surveillance, and search & rescue. A significant driver of this growth constitutes the necessity of urban cargo transportation. First, this is attributable to the rising percentage of the population living in cities: this percentage will reach approximately 77.5 percent in Europe by 2030 in comparison to 56.2 percent in 2020 [1]. Second, the soar of the e-commerce market share contributes amply to the urgency of prompt freight delivery in the urban environment. Present on-ground vehicles, such as trucks, vans, or scooters, provide the conventional package delivery. This leads to traffic jam and road congestion, especially in the urban areas, which in turn provoke noise pollution, toxic emission load, delivery delays and customer dissatisfaction [2, 3]. The exploitation of airfreight logistics chains can be one key to circumventing this hurdle. Nowadays, such conventional air logistics systems only connect international cargo airports, and the air logistics chain ends there. The dispatching and delivering process continues afterwards using road transport. The development of

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innovative regional and urban airport/airfield-centric freight logistics systems is an encouraging strategy to relieve the traffic on the ground. In addition, the Urban/Advanced Air Mobility (UAM/AAM) concept is gaining high attention [4]. Hence, the aforementioned tendencies enable the extension of the urban airport/airfield-centric freight logistics chains to the third dimension by using flying units rather than relying on ground transportation. Emission-free Cargo Unmanned Aerial Vehicles (CUAV) are a promising solution to be deployed into an airfreight logistics chain to alleviate environmental and noise pollution along with the reduction of the delivery time. Various CUAV concepts are envisaged to enforce such airfreight logistics chains. However, the integration of (C)UAVs into the civil (manned) airspace is still enormously challenging [5]. This emerges particularly when dealing with operations in the urban scenario that call for a high level of autonomy (*i.e.* pursuing the pilotless capability). From a safety perspective, UAV operations might lead to serious hazards in-air and on the ground. Indeed, they constitute a threat due to potential air collisions with other UAVs or piloted aircraft. In addition to the fatalities in the air, they can also damage infrastructures and buildings as well as cause injury to people on the ground in case of failure. Therefore, it is essential to identify and manage the risk that UAVs might pose to in-air and on-ground third parties by considering it at the initial design phase. While the market development of UAVs is accelerating, UAV rulemaking might become a bottleneck. The European UAV legislation is partially enacted and still under investigation. Moreover, distinctive UAV-based aspects specifically on delivery services such as the flight in Beyond Visual Line of Sight (BVLOS) mode and the mission over urban or densely populated areas are still lacking sufficient details. Overall, these delays, limits and, in the worst case, undermines the market adoption of the UAM/AAM and thus, the entry into service of airfreight logistics chains. Nevertheless, the current UAV regulatory framework mandates that evidence of the fulfilment of a *satisfactory* state of flight safety is a prerequisite to obtaining approval to fly from the competent authorities [5]. This reinforces the importance of safety as a key factor driving the development of UAVs. For this reason, the Specific Operations Risk Assessment (SORA) proposed by the European Union Aviation Safety Agency (EASA) is exploited in this work [5, 6]. The SORA aids the UAV designer in defining the safety requirements and verifying the compliance with the UAV-based EASA regulations. Existing research and development show a deficiency in safety studies on UAVs. Firstly, it is mainly focused on small UAVs (MTOM less than 25 kg [7]) within the “Open” category, where the operations are harmless. Secondly, when it comes to larger UAVs in the AAM/UAM arena, the dominant attention is to the application to passenger transportation, for instance city taxis, airport shuttles, and inter-city connections [8]. Hence, this work is intended to contribute with a SORA-based safety study on the UAV *cargo* transportation field. The EU-funded project Urban and Regional Aerial Freight (URAF) is developing an aerial logistics chain by making use of different UAV concepts, such as a small aircraft, a compact heavy-cargo multicopter and a VTOL Lift & Cruise for time critical delivery. The aim is delivering packages from an international airport to the end customer within the city-centre targeting same-day delivery. This requires flying over densely populated areas, in Beyond Visual Line Of Sight (BVLOS) mode and fully-autonomously. Consequently, an accurate safety assessment is mandatory. First, this accompanies the design of sufficiently safe and reliable aerial vehicles pursuing the certification. Second, the results of a safety assessment of a specific use case - such as the delivery service - contribute to the EASA’s specification standardisation of that operating scenario.

This paper resumes the current UAV legal framework in Europe. To introduce the potential of SORA, a summary of the conventional aircraft safety assessment methodologies is provided. Also briefly highlighted is the implementation of the SORA approach into a build-in tool. Section 2 details all this. The main aspects of the considered logistics chain and the specifications of the vehicles are summarized is Section 3. The step-by-step application of SORA to the URAF case study is described in Section 4, whereas Section 5 discusses the results.

2. Methodology

2.1 Related Work

At the current state, a comprehensive Certification Specification (CS) for UAVs is being developed, analogous to the CS-23/25 and the CS-27/29 - standards for aviation and rotorcraft, respectively. An extensive overhaul of the UAV regulation provided by the EASA is the starting point for the study setting. In 2015, a risk-based operation-centric approach was postulated by the EASA as a baseline for the regulatory framework of commercial and non-commercial UAV applications [8]. Afterwards, the Joint Authorities for Rulemaking on Unmanned Systems (JARUS) published the first Requirements and Recommendations for a European Certification Standards in 2019 [6]. A first version of a systematic methodology to classify the risk of a UAV was incorporated in this documentation. Traditional risk assessment methodologies used in *manned* aviation focus on preserving passengers' safety (see Section 2.2) rather than the risk that the aircraft *operations* might cause to individuals and infrastructures on ground; therefore, developing a novel approach for *unmanned* aircraft was essential. The SORA 1.0 was issued in 2019 (see Section 2.4) [5]. Since 2019, the EASA consolidated the UAV legal framework in three main time steps:

1. with the Implementing Regulation and Delegated Rules in September 2019 [9],
2. with the amendments in Opinion No 01 in 2020 [10],
3. with the so-called Special Conditions (SC) for Light UAV for *Medium* and for *High* Risk along 2020-2021, namely in December 2020 and December 2021 [11, 12].

In addition to that, another class of aircraft with comparable flight characteristics to UAV was debated. In May 2020, a Proposed Means of Compliance for Vertical Take-Off and Landing aircraft (MOC-VTOL), which is fundamentally based on the CS-23/25 and CS-27/29, was published [13]. Furthermore, EASA's "Artificial Intelligence (AI) Roadmap - 2020" addresses the guidelines for flying with high level of automation, on which UAV operations strongly rely, and proposes a timeline for the finalisation of a fully autonomous, safe and effective ATM-integrated Unmanned Traffic Management (UTM) [14].

As soon as the EASA reactively has gained sufficient experience in UAV operation scenarios by closely cooperating with industry and research, the aforementioned SC for Medium and High Risk together with the MOC for VTOL and the AI-related directives are going to be transposed into a UAV-CS. The UAV-CS is envisaged as including both type certification directives and aspects peculiar to UAVs. For instance, the BVLOS, the lower flying altitude/greater proximity to the ground, the massive AI utilization for Detect and Avoidance – DAA, and many others associated with pilotless flight [5]. Although UAVs are not proportionate to aircraft size, the use of the standard CS as baseline for the type certification is currently appropriate. This facilitates achieving approval to fly from the authorities. In fact, it provides standards and a safe environment while leaving flexibility to certify various design concepts in a field where technology and design solutions rapidly evolve [9, 10, 14].

2.2 Risk-Safety assessment in Aviation

In civil aviation, the CS already incorporate risk and safety aspects among the technical aircraft characteristics for airworthiness certification. These aspects are usually associated to system architecture and equipment installation requirements [18]. Failure severity and hazard frequency are especially addressed. Aircraft and rotorcraft must comply with the requirements outlined by the EASA's CS to obtain approval to fly. Accurate safety assessments are conducted separately through safety-tailored Acceptable Means of Compliance (AMC).

Each CS is typically coupled with a set of AMC, which are derived from the Society of Automotive Engineers SAE's Aerospace Recommended Practice (ARP). The SAE ARP supports the airworthiness certification process and provides manuals for conducting manned aerial system safety studies. Numerous recommended practices are available: the ARP 4754A, the ARP 4761, the ARP 5150 and the ARP 5151 are the most used among many others [8]. Because the purpose of the safety assessment is to assure that the system architecture provides on-board humans with a careful level of protection against hazards in any operating condition, these approaches place the focus on the aircraft and its subsystems. On the one hand, the ARP 4754A specifies the guidelines to be followed throughout the whole aircraft development process (from the requirements to the aircraft functions verification and testing) [15]. It is based on risk minimization in the aircraft operating environment over the whole lifecycle to deploy a rigorously safe vehicle concept. On the other hand, the ARP 4761 discusses into further depth the safety assessment approach and the methodologies associated with it [16]. Instead, the ARP 5150 and ARP 5151 are concerned with the on-going safety assessment of already-in-service aerial vehicles; hence, they do not belong in the conceptual design phase [17, 18].

2.3 Risk-Safety assessment in UAVs

The core of the safety assessment in the UAV field is rather upon the operation that the UAV carries out along with the operational environment, where the operation occurs [8]. Today's UAV regulatory framework in Europe is also administrated by the EASA (see Section 2.1), which recommends a policy for a risk-based classification of the UAVs as detailed in [5]. This classification divides the UAVs into three categories: the "Open", the "Specific" and the "Certified".

- The "Open" category incorporates small UAVs – especially for leisure – that exhibit a low risk against people and infrastructures on-ground as well as no threat for other aerial vehicles. The UAVs within the "Open" category are always remotely piloted in Visual Line Of Sight (VLOS) and their weight is confined to 25 kg. They do constitute no harm for people and thus, no permit to fly is inquired [5].
- The "Specific" category contains all UAVs, which do not meet the directives of the "Open" category. The risk is higher and includes operations in BVLOS mode and UAVs with a Maximum Take-Off Mass (MTOM) of up to 600 kg [11, 12]. The BVLOS is allowed for a maximum of 2 km from the Remote Pilot (RP) and with the assistance of an observer located a kilometre away from the RP. Such vehicles need to be granted to fly by the competent authority.
- The "Certified" category involves the largest drones and/or the highest-risk operations, such as delivery service close to people (e.g., delivery upon the balcony, the building rooftop or onto the private garden) and air taxi. Therefore, these vehicles are treated like conventional aircraft, and they must be properly certified (i.e. obtain a type certification and a certification of airworthiness) [19].

According to the UAV regulations in [5, 6], a risk and safety assessment is inappropriate for the UAV undertaking low risk operations in the "Open" Category. Instead, obtaining approval to fly under the "Specific" category, which deals with "Medium" risk operations, is critical. As a result, a safety assessment turns out to be necessary involving, at this point, the application of SORA. The SORA examines not only the operation's risk, but also the pilot's skills and the features of the UAV. The generated kinetic energy in case of an impact, the size and the complexity of the UAV, the population density of the overflown area, and the airspace structure as well as the density of the traffic in the area are addressed as the main influencing criteria for the risk assessment. The result of the risk assessment yields a risk level - namely Low, Medium and High - that is allocated to the UAV and the related operation. This risk level is essential to assign the exact UAV certification basis to the UAV. To cope with this, the EASA issued the aforementioned SC for Light UAV with *Medium*-Risk [11] and the SC for Light UAV that shows *High*-Risk [12]. This way, the risk level expressed by the SC matches the SORA rank.

2.4 SORA Approach

The SORA is a qualitative and systematic approach to derive a set of safety requirements that a UAV is recommended to meet [5, 6]. It is performed to attest the UAV to an acceptable level of safety in air and on the ground. Figure 1 is a flowchart of the SORA process, which is detailed in Art. 11 of [5]. This approach assists the UAV designer in assessing the risk of the proposed mission by considering the UAV performance and the operating conditions. A Concept of Operation (ConOps) analysis constitutes the input for the SORA. A ConOps describes how a set of qualities and capabilities work together to achieve desired objectives. This set concerns the type of aircraft (*i.e.* main dimension and MTOM), the flight scenario (*e.g.* mission profile, airspace traffic, VLOS or BVLOS mode, etc.), and the population density within the overflown area. Given this information, a Ground Risk Class (GRC) and an Air Risk Class (ARC) can be logically extrapolated through the SORA criteria in [5]. The GRC indicates the level of danger - in a scale from one to ten - that a UAV and its operation pose to uninvolved people and infrastructure on the ground in case of failure. The ARC denotes the chance of mid-air collisions between the UAV and other piloted aircraft. ARC-a, ARC-b, ARC-c, and ARC-d are the four primary qualitative categories in the ARC classification. ARC-a assumes unmanned vehicles operate in locations where they have no (or minimal) occasion of coming across other aircraft, whereas ARC-d implies they fly in Class B, C, or D where a significant chance of encountering them arises. Operations in rural and urban areas encompass a low-medium and medium likelihood of colliding with manned aircraft, ARC-b and ARC-c, respectively. Ad-hoc mitigation measures can be used to alter the GRC and ARC. The combination of the adjusted (final) GRC and ARC determines the Specific Assurance and Integrity Level (SAIL). The SAIL value lays between SAIL I and SAIL VI. It also assigns a risk level to a UAV, such as *Low* (SAIL I and II), *Medium* (SAIL III and IV) or *High* (SAIL V and VI) [5, 11, 12]. The SAIL, on the one hand, denotes the level of confidence that a given operation takes place under control into the predefined operational volume. On the other hand, the SAIL also includes the Operational Safety Objectives (OSOs), i.e. the safety requirements, with which the UAV and its operation must comply to obtain flight approval.

As the value of the SAIL raises, the robustness of the safety objectives increases. For this reason, an UAV design driven by the safety requirements paves the way towards the development of an adequately safe vehicle, which yields to a smooth achievement of the airworthiness certification.

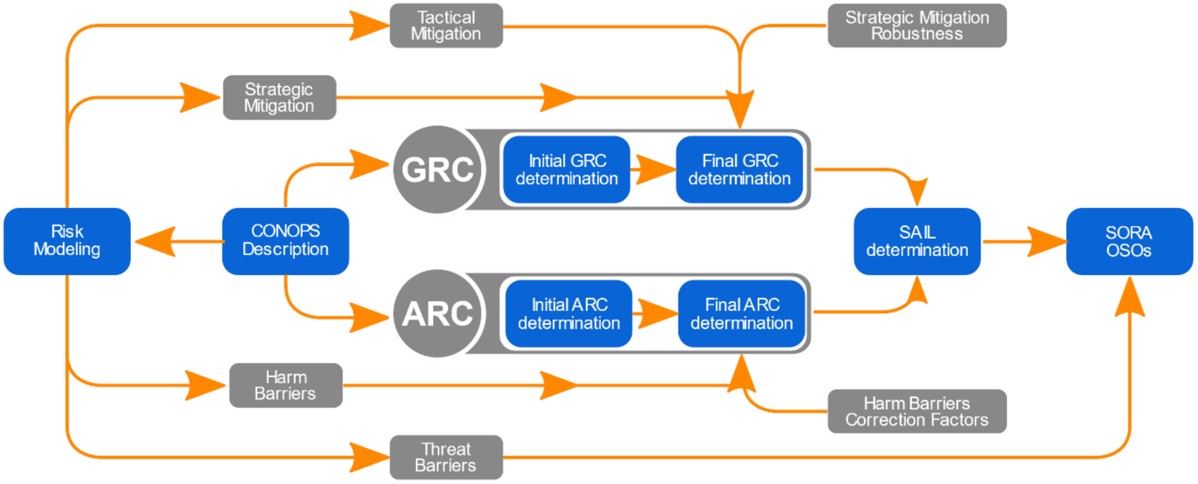

Figure 1 - SORA Flowchart.

2.5 SORA-based Supporting Tool

As part of this work, a software tool with a graphical user interface is realized to guide the UAV designer through the SORA process. Thereby, it mirrors the previously described sequence of SAIL and the subsequent OSO assessment based on GRC and ARC. The software tool automates workflows and hence, minimizes the workload of the user. In addition to the fundamentals of SORA, the implementation into the presented tool comprises the selection of initial mitigation measures tailored to the considered vehicle and its operating scenario. Moreover, the tool assists in one of the central points of SORA - the determination of GRC and ARC. While the identification of the appropriate ARC is carried out by using local airspace class maps (see Section 4.4 and 4.5), the GRC is classified based on the degree of urbanization (DEGURBA) – this is briefly outlined hereafter.

Once a proposed flight path has been specified, the program identifies DEBURGA[2] as the initial criterion for the GRC by considering the flight area under consideration along with the population density of the region overflown as deposited in DEBURGA. It differentiates among three area types, which are classified based on the proportion of the local population living in urban agglomerations and centres (Local Administrative Units):

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[2] According to "Notice of Proposed Amendment 2020-07" [20], DEGURBA may be used as first baseline measure either during the preliminary stage of risk assessment or if no local high-resolution information is available.

- Cities (densely populated areas)
- Smaller cities and suburbs (areas with medium population density)
- Rural areas (sparsely populated areas).

According to [21], it can be assumed that the area is “sparsely populated”, when it has already been categorized as thinly populated (also defined as “rural areas”) by DEGURBA. By means of the developed program, alternate routes providing a slighter initial GRC can be unveiled. The automated recommendation of the GRC, in certain cases, eliminates the need for a subsequent reduction of the GRC through appropriate mitigation measures. For instance, by avoiding the elevated risk associated with the overflight of highly populated areas. For this reason, it constitutes the most suitable initial mitigation measure.

3 Case Study: Aerial cargo logistics chain

The logistics chain described in this study covers the delivery of items from an international cargo airport to the end-customers in the city centre using three autonomous and emissions-free CUAVs. Moreover, it consists of various segments that are depicted in Figure 2. These spatial segments are correlated to different ranges resulting in various transportation purposes (e.g., inter-city, intra-city, time-critical delivery, etc.). Any CUAV involved in the proposed airfreight logistics chain is responsible for a separate spatial segment. Hence, each CUAV has its own set of design requirements, which leads to distinct configuration, size, and propulsion system [22].

The delivery services using UAVs are still evolving scenarios and they are temporarily allocated to the “Certified” category [19]. By 2035, the proposed delivery service is assumed to entry into service. Rulemaking for an autonomous and fully automated operating scenario - releasing the BVLOS constraint - as well as the safe integration with the manned air traffic is the major challenge for the next ten years [14]. Indeed, the documentation for this category is today unavailable. Because of this, the directives for the “Specific” category, including SORA, are exploited in a broad scale to conduct the preliminary risk assessment of the various CUAV concepts involved in this study [22, 23].

The North-Rhine Westphalia (NRW) region in Germany’s north-west is being evaluated within the URAF project. The international cargo airport under consideration is the Cologne-Bonn airport (CGN) and the end-customer resides in the city of Aachen. Stops over at the regional airfield of Aachen (Flugplatz Aachen-Merzbrueck – FAM) and city-hubs located nearby the city are assumed. The segment performed by cargo bikes is not considered in this work [22].

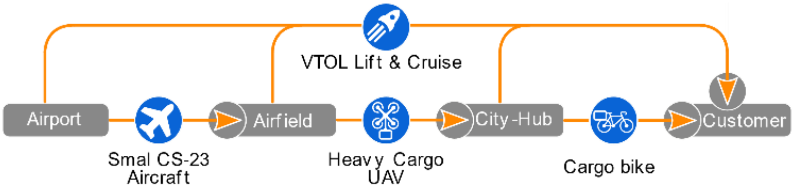


Figure 2 - Aerial cargo logistics chain.

3.1 Small CS-23 Aircraft

A small CO_2 – neutral aircraft provides the *inter-city* transport by travelling the distance between the international cargo airport and the regional airfield. High speed and high range characterize this aircraft. Short Take-Off and Landing (STOL) capability – targeting the 600 m – is a design requirement. The maximum cruise speed is 300 km/h to be competitive over the ground-based transport. The payload requirement is set to 500 kg of packages. A hybrid-electric hydrogen-powered fuel-cells system is the propulsion solution [22]. The main aspects of the small aircraft are summarized in Table 1.

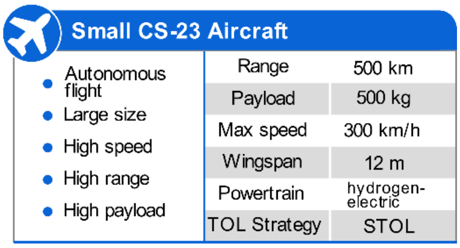
3.2 Heavy-Cargo UAV

An all-electric heavy-lift UAV transfers the freight from the regional airfield to the city-hubs located within the city (*intra-city* transport). It is characterized by a low speed (approx. 90km/h) and medium payload capacity. A low to medium range (25 km – 30 km) is the connection distance between the airfield and the city-hub [24]. The VTOL capability along with a compact size is necessary to operate in the urban environment due to the lack of accessible runways [22, 24]. Table 2 summarizes the features of the Heavy-lift UAV.

3.3 VTOL Lift & Cruise

The all-electric VTOL Lift & Cruise vehicle deals with high-urgency delivery. High speed, medium-range but low payload capability characterizes it. The VTOL capability is essential to carry the parcel directly to the end customer located in a radius of 50 km from any starting point - either the international cargo airport or the regional airfield. This allows avoiding waiting times caused by sorting, loading, dispatching, and other handling procedures. Thus, with a cruise speed of 130 km/h, this UAV can reach any place within its operational range in less than two hours. The wingspan is limited under three meters to allow the take-off and landing at the customer place (see Table 3) [22].

Table 1 Features of the small aircraft.

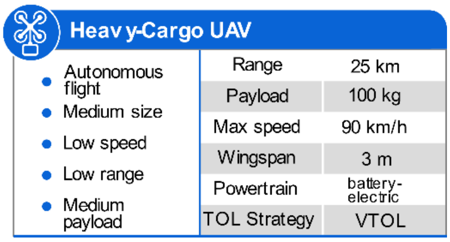


Small CS-23 Aircraft

- Autonomous flight
- Large size
- High speed
- High range
- High payload

Range	500 km
Payload	500 kg
Max speed	300 km/h
Wingspan	12 m
Powertrain	hydrogen-electric
TOL Strategy	STOL

Table 2 Features of the heavy-lift drone.

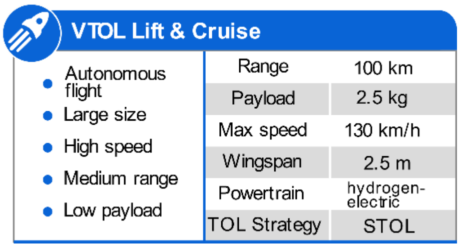


Heavy-Cargo UAV

- Autonomous flight
- Medium size
- Low speed
- Low range
- Medium payload

Range	25 km
Payload	100 kg
Max speed	90 km/h
Wingspan	3 m
Powertrain	battery-electric
TOL Strategy	VTOL

Table 3 Features of the VTOL-LC



VTOL Lift & Cruise

- Autonomous flight
- Large size
- High speed
- Medium range
- Low payload

Range	100 km
Payload	2.5 kg
Max speed	130 km/h
Wingspan	2.5 m
Powertrain	hydrogen-electric
TOL Strategy	STOL

4 SORA application to the case study

In this Section, the application of the SORA to the URAF case study (see Section 2 and Section 3) is described. The approach starts with the ConOps analysis, proceeds with the evaluation of the GRC and ARC and ends with the derivation of the SAIL and the discussion of the OSOs.

4.1 Step #1: ConOps Analysis

The international airport CGN serves as starting point of the logistics chain. Packages arrive daily and are sorted based on the destination. The small aircraft caters for the cargo transportation from the CGN to the FAM regional airfield. Here, the items are successively transferred onto the heavy-lift drone and are delivered to appropriate city-hubs. The infrastructures at the international airport, the regional airfield and the city-hubs are equipped with dedicated platforms for the VTOL and designated parking spaces or deposits [22].

To prepare the evaluation of the GRC, the population density of the overflown area is analysed. Figure 3 shows the population density distribution along a point-to-point path and an alternate route for the small aircraft as an example. When flying along the alternate pre-planned route, the flight share over sparsely populated areas is nearly fourfold in comparison to the point-to-point path, as Figure 4 displays. As a result, the average population density of the overflown area travelling via the alternate route is halved (Figure 4). A similar study is done for the heavy-lift drone and the VTOL Lift & Cruise. The numerical results are reported in Table 4 under "Operational Scenario".

Table 4 - ConOps results.

	VTOL LIFT&CRUISE	**HEAVY-LIFT DRONE**	**SMALL AIRCRAFT**
AIRSPACE	Class G	Class G	Class G
FLIGHT ALTITUDE	150 m	150 m	150 m[3]
IS A PILOT INVOLVED?	No, Autonomous	No, Autonomous	No, Autonomous
OVERFLOWN AREA	Populated area	Populated area	Populated area
OPERATIONAL SCENARIO (alternate route)	2% sparsely 33% suburbs 65% city	5% sparsely 42% suburbs 56% city	58% sparsely 23% suburbs 9% city
FLIGHT MODE (VLOS/BVLOS)	BVLOS	BVLOS	BVLOS
MAX SIZE	Wingspan: 3 m	Main dimension: 3 m	Wingspan: 12 m
MTOM	25 kg	280 kg	1650 kg
KINETIC ENERGY (classical calculation method)	42 kJ	480 kJ	5729 kJ
KINETIC ENERGY (alternate calculation method)	14 kJ	320 kJ	2172 kJ

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[3] A flight altitude of 150 m is temporarily assigned to the small aircraft.

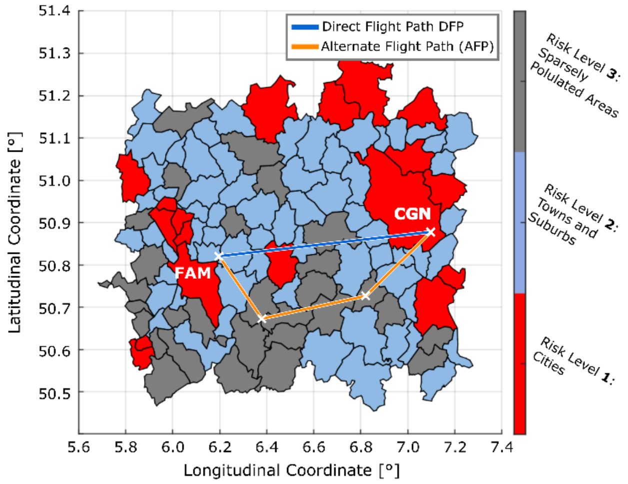

Figure 3 - Routes based on the overflown area for the small aircraft.

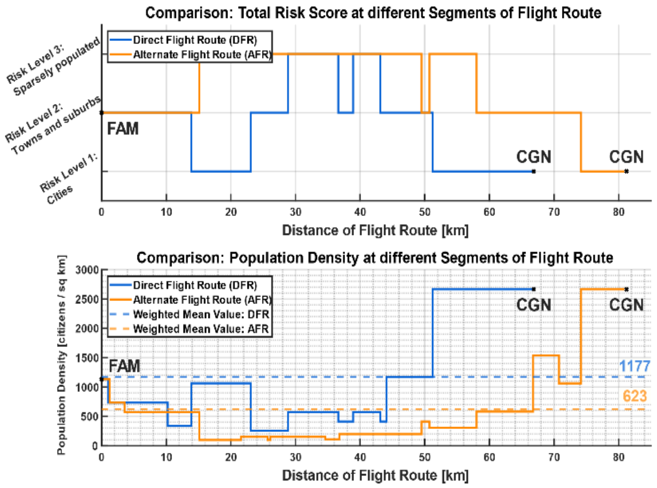

Figure 4 - Comparison of the population density P2P and alternate route of the small aircraft (CGN-FAM).

4.2 Step #2 Ground Risk Class (GRC)

The evaluation of the GRC (Section 2.4) requires first the vehicles' main size and the expected kinetic energy generated in case of impact on ground (see Table 4). Falling from the cruise altitude due to an unrecoverable failure is considered the most dangerous condition. The mass and the terminal velocity are the key term for the calculation of the kinetic energy. In this work, the kinetic energy is calculated via a Riccati type differential equation (Eq. 1) [23]:

$$V_i = -v_\infty * \tanh\left[arccosh\left(exp\left(\frac{z_{flight}*g}{v_\infty^2}\right)\right)\right] \qquad (1)$$

$$where\ v(t \to \infty) = v_\infty = -\sqrt{MTOM * \frac{g}{k}}$$

$$k = \frac{1}{2} * \rho * c_D * A_{cross}$$

$$\begin{cases} z_{flight} flight\ altitude \\ g\ gravitational\ constant \\ \rho\ air\ density\ at\ the\ flight\ altitude \\ c_D\ drag\ coefficient\ [23] \\ A_{cross} - sectional\ ares \end{cases}$$

As described in [23], the proposed categorisation of SORA, which couples the main dimension to the kinetic energy (see Section 2.4), might lead to GRC-related inconsistencies, when dealing with today's non-standard scenarios. For instance, heavy UAV with medium-compact size and flying at a low altitude might fall in different GRC classes.

For this reason, the application of Eq. 1 is preferable to obtain preliminary assumptions of the GRC more accurate, especially in realistic impact scenarios as detailed in [23].

The investigation of the GRC proceeds with the evaluation of the operational scenario. In the ideal envisaged scenario, the aerial vehicles fly autonomously in BVLOS mode - this entails that no pilot supports the process.

Hence, an initial GRC equals *six* for the VTOL Lift & Cruise and a GRC of *eight* for the Heavy-Lift UAV is determined. In both cases, the high kinetic energy causes the dominant casualty and drives the selection of a medium and medium-high class, respectively. Lastly, the small aircraft is characterized by a GRC equivalent to *ten*, i.e. the highest class [22].

4.3 Step #3 Mitigation of the GRC

SORA provides a predefined reference in [5] including numerous mitigation measures and associated GRC's reduction points. For instance, actions to decrease the number of uninvolved pedestrians on the ground, equipment to reduce the energy absorbed by people (e.g. parachute) and an extensive elaboration of an Emergency Response Plan (ERP) along with the setting-up of a Flight Terminator System (FTS) are proper countermeasures. The allocation of the GRC reduction points derived from the respective mitigations for this case study is detailed in [22].

The final GRC are:

- VTOL Lift & Cruise = 6 – 0 points = 6,
- Heavy-Lift drone = 8 – 2 points = 6,
- Small Aircraft = 10 – 3 points = 7.

4.4 Step #4 Air Risk Class (ARC)

The examination of the ARC starts with the determination of the Air Class in which the UAV are authorized to fly. Currently, there is no directive that rules the integration of the UTM within the manned traffic. Thus, the CUAVs are temporarily assigned to the uncontrolled airspace Class G because their operations are still uncertainly classified due to the lack of information [22]. The Class G has a 500 ft altitude limit (equal 150 m). Besides, small UAVs should not fly below 120 meters, as this is the "Open" category's altitude limit.

As a result, the CUAV are assumed flying at 150 m of cruise altitude, resulting in a downwards margin of 30 m with the “Open” category and a 150 m upwards gap with the civil airspace[4].

This allocation within the Class G reduces the chance of encountering other vehicles throughout the trip but it does not fully eliminate the risk. For this reason, the ARC, prior to any collision mitigations, is qualitative hypothesized as ARC-c (see Section 2.4 and [5]).

4.5 Step #5 Mitigation of the ARC

As the assumed initial ARC is a qualitative hypothesis, a reduction of the ARC is feasible only if the designer proposes and proves the reliability of accurate mitigations measures. These include first, limitations on the permissible flying regions (i.e. geofencing), flight time, and time exposure and second, the installation of DAA technologies or surveillance devices, for instance ADS-B and FLARM among others [4, 8, 21, 22, 23, 25, 26].

SORA refers to the Airspace Encounter Categories (AEC) and the Initial Generalised Density Rating (IGDR) to reduce the ARC [23]. This proposed approach to devalue the ARC through the IGDR relies on the environment *on-ground*: in authors’ opinion, this should be considered as an intrinsic inconsistency of SORA. Despite this, the mitigation approach was implemented but no reductions turned out to be applicable, as flight over populated areas and at an altitude lower than 600 m are still not included.

In this context, flight data are resorted to quantitatively investigate the ARC. The FAM is considered as the nod of the logistics chain. For this reason, ADS-B data on aircraft traffic in the airspace surrounding the city of Aachen - available for 148 days over 2020 and 2021[5] - are explored [23]. The underlying data is based on the secondary radar coverage of Deutsche Flugsicherung (DFS) as well as on FLARM and the UTM system of DFS/droniq app [23]. The data set was limited to an area with a Radius of Interest (RoI) of 12.5 km around FAM to exclude regions that provide no additional value for the analysis. In addition, flights with less than five data points were excluded. Commercial aviation, according to Instrumental Flight Rules (IFR), is usually characterized by high speed and it is commonly

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[4] According to SERA.5005, the minimum flight altitude over the congested areas of cities, towns or settlements or over an open-air assembly of persons is at a height of 300 m (1000 ft) above the highest obstacle.

[5] From August 17, 2020 through June 9, 2021, 148 flying days were observed. It is worth noting that this period matches with the Corona Pandemic. This may lessen the importance of privately or commercially operated aviation services. Nonetheless, it is important to note that, according to official statistics, the private pilot sector departing from the FAM only had a 12.7 percent reduction in take-offs (take-offs in 2019: 22,303; take-offs in 2020: 19,465) [27]. As a result, this variance is rather minor. Furthermore, the majority of commercial flyovers are cargo planes bound for Liège Airport (ICAO code: EBLG). The region around Aachen thus, serves as the starting point for a typical instrument (ILS CAT II & III) approach for Runway 22L in line with AD 2.EBLG-IAC.01 [28]. Given the Liège Airport's prominent role as a freight hub, the number of aircraft movements remained steady in 2020, with 40,300 landings and take-offs compared to 39,886 in 2019 [29]. [23]

confined to a higher altitude. This contrasts with private pilots flying via Visual Flight Rules (VFR). Figure 5 supports this consideration and displays the separation between *slow and low-altitude* and *fast and high-altitude* flights that cross the study area. The separation is consequently set at 3000 meters.

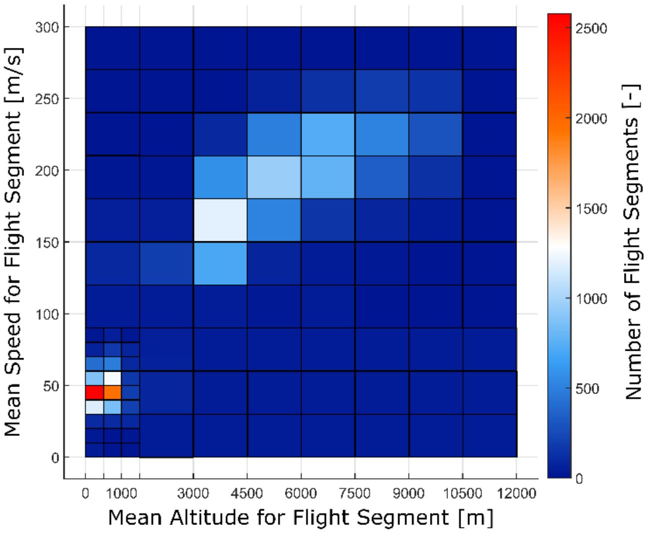


Figure 5 - Flights distribution - Altitude and Speed

Figures 6 and 7 are created by examining the number of flights in terms of geographical distribution at altitudes below and above 3000 meters. Figure 6 shows the flights distribution corresponding to altitude higher than 3000 m: the delineated route is the airway heading to the cargo airport of Liège [28, 29]. As the cruise altitude of the CUAV is limited to 150 m, an intersection to the commercial aviation is supposed quite improbable. Instead, Figure 7 illustrates the scenario with the altitude lower than 3000 m. The operations in the south-area of FAM are outlined: the crowded area coincides with the take-off and landing procedures at FAM. In [30], it is reported that the manoeuvres at FAM take place in an eastward direction for noise concerns and thus, this validates the data.

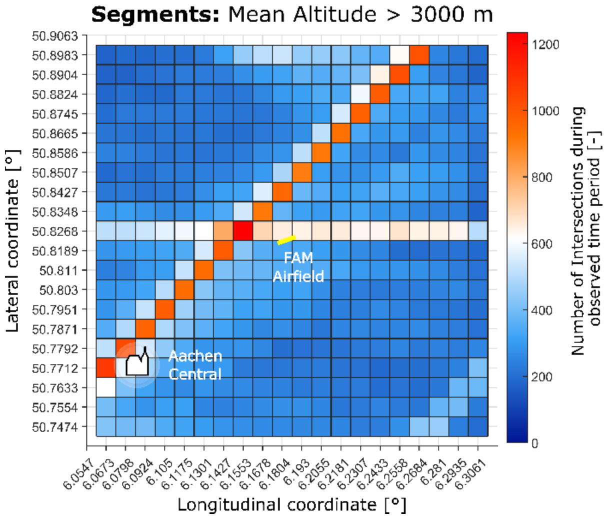


Figure 6 Flights spatial distribution-altitude > 3000 m.

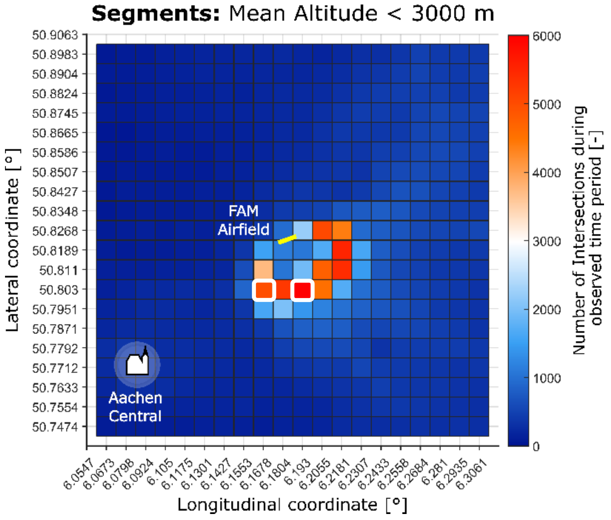


Figure 7 - Flights spatial distribution-altitude < 3000 m.

Figure 7 draws attention to two considerations. On the one hand, the STOL small aircraft departing from and arriving at FAM requires the runway intersection. For this reason, the take-off and landing procedures must be separately further investigated in the future because this compels a synchronized schedule with the manned aircraft to assure a flawless integration of the UTM within the ATM.

On the other hand, the route directing to the city centre of Aachen entails crossing the congested area and therefore, two sectors are examined in more detail (highlighted in Figure 7). In both sectors, the prescribed minimum altitude – according to the standard protocols – is 450 m [23]. Figure 8 displays that the majority of the flights operates at that flight altitude. Moreover, just a few aircraft fly lower than 300 m. Because of this, a distance buffer between the involved vehicles and any manned aircraft is always assured. Furthermore, the operating traffic hours are assessed in comparison to piloted aircraft to explore whether there is a chance to reduce the conflict risk by operating in distinct timeslots. Figure 9 shows that the operating hours of private air traffic can be delimited from 6 am to 9 pm with two peak hours at 11:30 am and 3 pm. These periods coincide with the planned operations of the proposed logistics chain and thus, they do not provide any additional benefit.

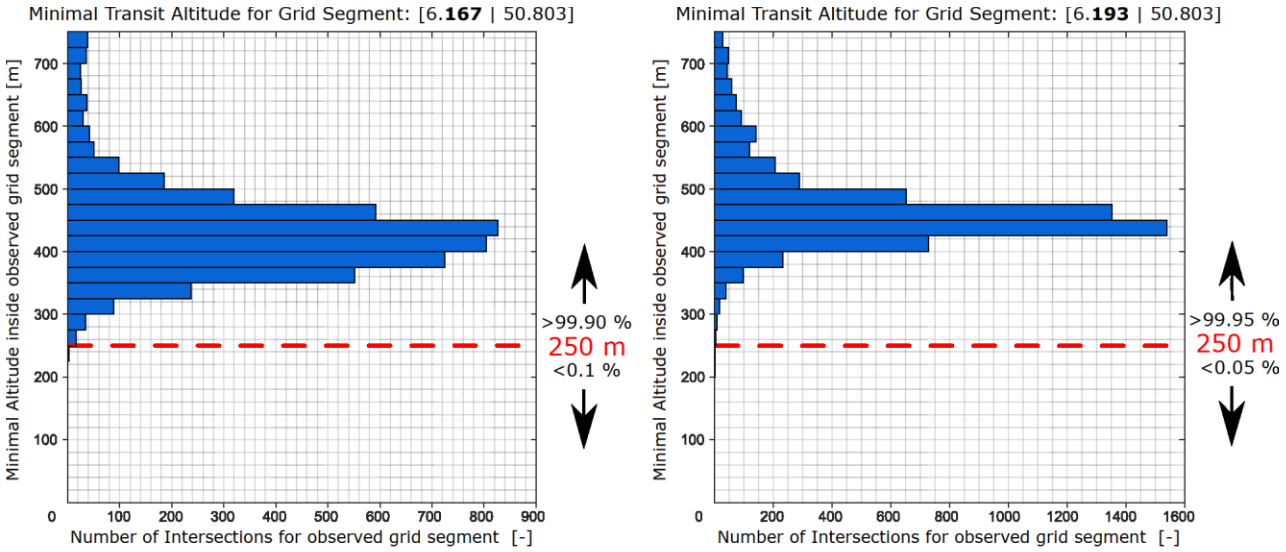


Figure 8 - Flight number distribution related to the altitude.

Unfortunately, none of the presented investigations can further mitigate the ARC. In authors' opinion, this lack of successful mitigation is not intrinsically attributable to SORA but rather it is due to shortages in unifying the aerial traffic. Although further promising mitigation tactics[6] might be put in place, for the time being, a conservative selection of ARC-c is assumed safer as the UTM-ATM integration is far from forthcoming.

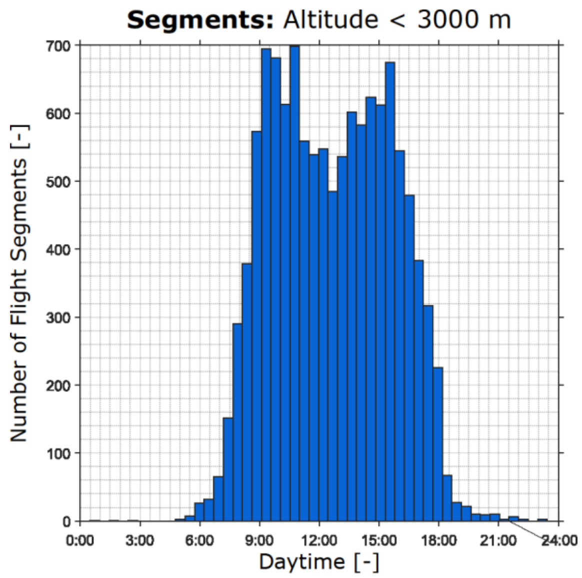
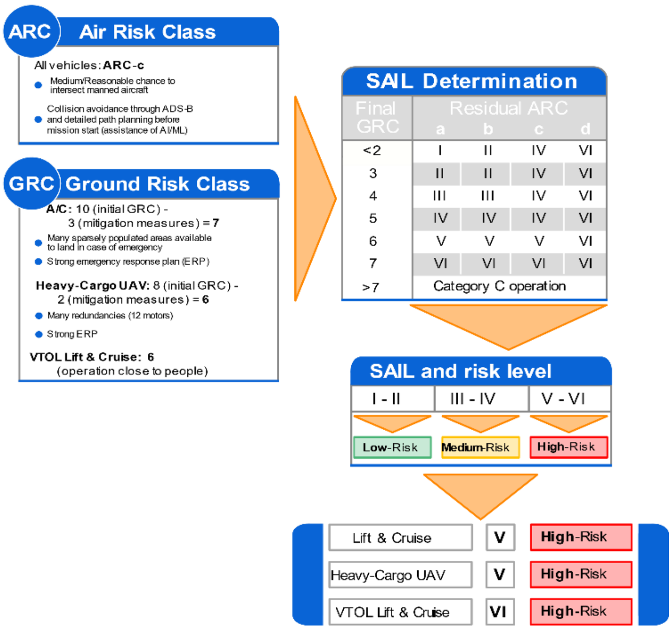


Figure 9 - Flight number distribution related to daily hours.



All vehicles: **ARC-c**

- Medium/Reasonable chance to intersect manned aircraft
- Collision avoidance through ADS-B and detailed path planning before mission start (assistance of AI/ML)

A/C: 10 (initial GRC) - 3 (mitigation measures) = **7**

- Many sparsely populated areas available to land in case of emergency
- Strong emergency response plan (ERP)

Heavy-Cargo UAV: 8 (initial GRC) - 2 (mitigation measures) = **6**

- Many redundancies (12 motors)
- Strong ERP

VTOL Lift & Cruise: 6 (operation close to people)

Final GRC	Residual ARC 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	Category C operation			

Lift & Cruise	V	High-Risk
Heavy-Cargo UAV	V	High-Risk
VTOL Lift & Cruise	VI	High-Risk

Figure 10 - SAIL determination through SORA.

4.6 Step #6 Safety Assurance and Integrity Level

Once the final GRC and the residual ARC are available, the SAIL corresponding to the mission can be derived [5]. SAIL VI is assigned to the small aircraft, whereas SAIL V is allocated to the heavy-lift drone and the VTOL Lift & Cruise. This signifies that all the vehicles are classified as High Risk (Figure 10).

4.7 Step #7 Operational Safety Objectives

At this point, the Operational Safety Objectives (OSO) are considered. The OSOs are grouped in technical issues, human errors, adverse operating conditions, and deterioration of the external supporting system [5, 6]. Most *high*-risk OSOs for *High* Risk level require a *high* level of assurance that

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[6] For instance, a further study is to locate the VTOL platforms on the north-west side of the FAM's runway close to where the helipad is now located.

must be proven through system tests and, afterwards, has to be validated by a competent party [25]. First, none of the vehicles can be physically tested, as they are still preliminary concepts. It is also challenging to accurately envisage how the certification process is going to be carried out. Second, the competent party can be either authorized entities, or manufacturers or regulating authorities that can attest the assurance based on appropriate documentation. Currently, neither documentation nor certified parties are available for the operational scenarios involved in this work (i.e. autonomous operations, in BVLOS mode, over populated areas). In this context, exclusively OSO 5 "*the system is designed considering safety and reliability*" emerges for further discussion. A default double redundancy is taken into account for all the equipment, for instance Electronic Speed Controller (ESC), IMU, cameras, and Radio Communications, among others. Diverse frequencies are also used as extra redundancy to avoid the complete loss of communication. Fundamental devices for navigation and control are tripled-redundant. OSO 5 also specifies the failure likelihood that the system must fulfil based on [31, 32]. A quantitative safety analysis must be carried out at this stage to determine whether the failure probabilities lay in the tolerable range [31, 32]. This safety analysis necessitates the iterative implementation of a reliability study on the system. On the one hand, the results point out how to adjust the system architecture to satisfy the failure probabilities expressed in [31, 32]. On the other hand, the outcomes show where the system is overly reliable and so, where the equipment redundancies can be reduced to make the system lighter. All this is presented in a future work.

It can be stated that the safety-based approach used in this work to satisfy OSO 5 assures that these aerial vehicles and their associated operations are being designed with a high level of confidence and robustness facilitating the acquisition of a future flight approval.

5 Results and Discussion

The results of this study point out that the application of SORA assists the identification of design inadequacies from a safety perspective already at the initial design stage. Furthermore, it aids the designer in determining remedial actions – technical and/or operational. To diminish the overall risk level, this safety-based design approach entails revising the UAV design and putting in place strategic operational countermeasures until the safety level is satisfactory. This is still challenging when dealing with the ARC as the future merged air traffic cannot be accurately envisaged.

In the presented scenarios, the limit upon the permitted BVLOS operations amid manned traffic is severely exceeded. Moreover, the proposed logistics chain is intended to set up a high-level of autonomous and automated operations, which are not encompassed by today's policy. Because of these limitations, the aircraft must be licensed within the "Certified" category.

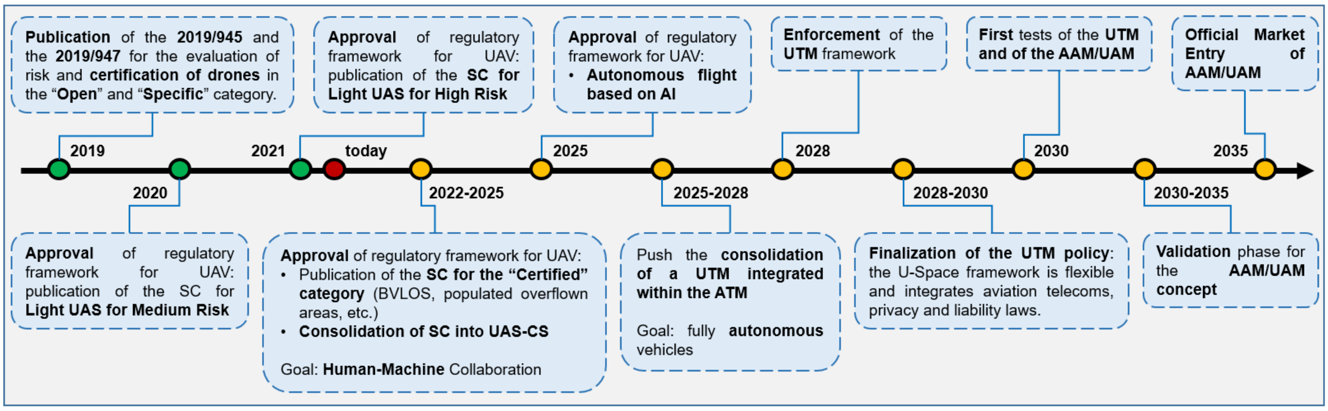

Figure 31 - Roadmap of the Entry into Service of the UAM/AAM.

However, the release of the "Certified" category directives is correlated to the finalisation of the UTM concept and thus, still demanding. Indeed, the analysis of the design outcomes highlights the persistent gap between the rapid progress of the UAV technology and the currently available UAV policy. Hence, this has supported the application of the SORA to the involved vehicles in order to obtain a preliminary safety assessment.

On this basis, a roadmap towards the consolidation of the AAM/UAM is established, namely, the emerged barriers are mapped, and a timeframe is proposed to coordinate the regulation development [5, 14, 24]. The UAV directives available to date are the baseline for outlining the roadmap (green dots on the left-hand side of Figure 11). According to [14], a first UTM policy proposal, taking into account flight with a high-level of autonomy, will be published by 2024. Considering a one-year margin to gather opinions on the aforementioned proposal, to publish amendments and release the updated version, the policy approval is expected by 2025. This entails the publication of the “Certified” category’s guidelines within the phase 2022-2025. The next step is the integration of the novel UTM policy in respect to the ATM: this will be finalised by 2028 [14]. Subsequently, a stage of protocol consolidation is the prerequisite to enable the first UAM/AAM tests planned by the 2030. On the one hand, this encompasses the development of UTM Service Providers, such as for flight path planning and approval, for weather assistance and for coordination with third parties (e.g. municipality, when flying over cities). On the other hand, it comprehends the set-up of operational infrastructures – vertiports. A five-year validation period is assumed to achieve a smooth certification process, provide a reliable ATM-integrated UTM network across Europe, and perceive unmanned air operations in cities as routine. The roadmap, thus, envisages the official entry into service of a safe UAM/AAM by 2035 and it is illustrated in Figure 11.

6 Conclusion

The application of the Specific Operation Risk Assessment (SORA) approach to aerial vehicles was presented in this work. The SORA is used in a systematic manner to examine the boundaries of a delivery service scenario. Even though SORA does not specifically include delivery services, the proposed approach can be utilized to limit the risk of such operations. Nonetheless, more effort is needed to mitigate the risk associated with a high level of automation, especially when UAV share operational volumes with manned aircraft. The findings are also a fundamental know-how to contribute to the collaboration with the authorities. Indeed, UAV designers and EASA should work together in this regard to extend SORA to delivery service scenarios. This entails a high level of autonomy, BVLOS mode, and flying in urban environment. Pending prospective SORA amendments addressing the aforementioned aspects, this work shows that the strength of the current version of SORA lays in its flexibility to be applicable to operations that are riskier than those, for which it was delineated. In this way, safety objectives of novel concepts can be outlined and further investigated from the preliminary design phase. Consequently, the design can be accordantly adjusted.

A future study aims to propose a comprehensive holistic method incorporated into SORA, which involves a Bayesian Network for simulation-based UAV safety evaluation that quantifies the system's reliability. This enables the calculation of the risk associated to an operational scenario through simulation results to assure the compliance of complex autonomous aerial systems before entry into service.

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9 Copyright Statement

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