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Abstract

U-AGREE suggests a new air risk model that distinguishes specific cases like the involvement of urban air mobility, the collision between drones or wildlife strikes. This document describes how the model calculates the probability of collision and then how to estimates the severity of the collision for the different combinations of air users involved.

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U-AGREE

U-space Air and Ground Risk modEls Enhancement

U-AGREE

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1 Executive summary

This document represents the U-AGREE deliverable D3.4 and contains the final version of the U-AGREE Air Risk Model. This model tries to be better adjusted to the idiosyncrasy of a U-space environment, its expected scenarios and airspace user types. This means for instance the consideration of the urban air mobility, the collision between different categories of drones, or the effect on these of wildlife strikes.

The proposal suggests a way to calculate the probability of encounter and then adds an estimation of the severity in case it happens, and its applicability is illustrated with examples.

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2 Introduction

2.1 Purpose of the document

This document describes the proposal of a new air risk model to evaluate the probability and severity of airspace users encounters in U-space environments.

2.2 Intended readership

This is a public document. The following is a list of potential stakeholders involved in the development, implementation, and oversight of U-space operations and airspace risk assessment within the SESAR 3 JU ER02 framework that could find its content of interest:

- **Regulatory Authorities (e.g., Civil Aviation Authorities, SESAR 3 JU, EASA, AESA)**: To assess the alignment of the U-AGREE solution with regulatory frameworks and its impact on U-space airspace designation and operations.
- **Air Navigation Service Providers (ANSPs):** To understand how the U-AGREE solution can help to quantify and mitigate the risk of UAS operations in controlled airspace.
- **Common Information Service Providers (CISPs)**: For CISPs can be useful to understand the integration of risk models as part of the authorisation process within U-space airspace, and how can this affect their centralizing role in this process. The CISP could be responsible for sharing data, constraints or thresholds used by the risk models.
- **U-space Service Providers (USSPs)**: To explore the application of the U-AGREE solution for enhancing safety, security, and compliance of U-space operations, and how U-space services provided by USSPs are mitigating the risks for UAS operations in U-space airspace.
- **UAS Operators and Industry Stakeholders**: To evaluate the potential impact of U-AGREE's risk assessment framework on operational efficiency and regulatory compliance, by facilitating the U-plans approval process and ensuring safety.
- **Research and Academic Institutions**: To contribute to the advancement of risk assessment methodologies and integration of artificial intelligence into U-space safety mechanisms.

2.3 Background

The advent of Uncrewed Aerial Systems (UAS) has represented a great challenge for aviation authorities, worldwide, because the number, type and characteristics of the operations with UAS are commonly very different than in crewed aviation. Therefore, although UAS operations should be as safe as those in crewed aviation, they require proportionate risks mitigation according to the level of risk involved, the operational characteristics of the UAS concerned and the characteristics of the area of operation. To cater with the different requirements linked to the different types of UAS operations, Commission Implementing Regulation (EU) 2019/947 established three categories of operations: the 'open', 'specific' and 'certified' categories.

Operations in the 'open' category are very limited in the risks posed for people on the ground and other airspace users, so they can be developed without any operational authorisation from the National Aviation Authority. On the contrary, operations in the 'certified' are so risky that they need to demonstrate the fulfilment of requirements related to the airworthiness, the organisations and the persons involved in the operation of UAS; similarly, to how these requirements are demonstrated in crewed aviation.

Most UAS operations are expected to fall in the 'specific' category, which requires an operational authorisation issued by the competent authority to be performed, based on the acceptance of the adequate mitigation of the risks of the operation. To develop the necessary operational risk assessment, European Union Aviation Safety Agency (EASA) considers as an acceptable means of compliance the SORA methodology, developed by Joint Authorities for Rulemaking on Unmanned Systems (JARUS).

SORA [1] is a risk assessment methodology to establish a sufficient level of confidence that a specific operation can be conducted safely. It allows the evaluation of the intended concept of operation and a categorization into 6 different Specific Assurance and Integrity Levels (SAIL), recommending operational safety objectives to be met for each SAIL. The SORA methodology provides a systematic guidance to evaluate the risks related to a given operation and then determines proportionate requirements that an operation should meet to ensure a Target Level of Safety (TLS) is achieved.

SORA addresses individual operations conducted according to a ConOps defined by the UAS operator and estimates the risk of a collision on the ground due to a loss of control (**ground risk**) and the risk of an UAS colliding in the air with a crewed aircraft (**air risk**). For a given operation, **SORA applies a ground and an air risk model** (detailed in annexes F and G to SORA, respectively) to determine intrinsic (unmitigated) ground risk classes (GRC) and initial air risk classes (ARC) and apply mitigation measures to get residual air and ground risk classes, which are then combined in a SAIL. Afterwards, UAS operators must go through 17 operational safety objectives (OSOs) demonstrating to show compliance with the required level of robustness depending on the SAIL.

The present work suggests a **new air risk model** addressed to more faithfully fit to the reality and diversity of the expected U-space scenarios.

2.4 Structure of the document

The document is organized into the following main sections:

- **Introduction**: Purpose, scope, intended readership, background, and structure of the document.
- **U-AGREE Air Risk Model:** Description of the suggested air risk model, first introducing how the probability of encounter is calculated and after how the severity of the collision is ranked. Examples of applications of the model are also provided.
- **Assumptions and future work:** Being this a first baseline proposal of the model, some work and data required for its evolution is described here.
- **References**

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2.5 Glossary of terms

Term	Definition	Source of the definition
Airspace Risk Assessment	Evaluation of operational, safety and security risks that takes into account the required levels of safety performance as defined in the European Plan for Aviation Safety and the State Safety Program referred to in Articles 6 and 7 of Regulation (EU) 2018/1139, the type, complexity and density of the traffic, the location, altitudes or heights and the airspace classification	COMMISSION IMPLEMENTING REGULATION (EU) 2021/664
Visual Line of Sight (VLOS)	Type of UAS operation in which, the remote pilot is able to maintain continuous unaided visual contact with the unmanned aircraft, allowing the remote pilot to control the flight path of the unmanned aircraft in relation to other aircraft, people and obstacles for the purpose of avoiding collisions	EASA
Beyond Visual Line of Sight (BVLOS)	Type of UAS operation which is not conducted in VLOS	EASA
Extended Visual Line of Sight (EVLOS)	A UAS operation whereby the remote pilot maintains uninterrupted situational awareness of the airspace in which the UAS operation is being conducted via visual airspace surveillance through one or more human Visual Observers (VOs), possibly aided by technological means. The remote pilot has direct control of the UAS at all times.	EASA
Common Information Service Provider (CISP)	Actor that provides USSPs with the necessary information.	ENAIRE
Specific Operations Risk Assessment (SORA)	Methodology for the classification of the risk posed by a drone flight in the specific category of operations and for the identification of mitigations and of the safety objectives.	EASA
U-space	Set of new services and specific procedures designed to support safe, efficient and secure access to airspace for large numbers of drones. These services rely on a high level of digitalization and automation of functions, whether they are on board the drone itself, or are part of the ground-based environment.	Blueprint

Table 1. Glossary of terms

2.6 List of acronyms

Term	Definition
AAM	Advanced Air Mobility
ADS-B	Automatic Dependent Surveillance – Broadcast
AMC/GM	Acceptable Means of Compliance (AMC) and Guidance Material (GM)
AESA	Agencia Estatal de Seguridad Aérea
AEC	Airspace Encounter Category
AGL	Above Ground Level
ANSP	Air Navigation Service Provider
ARC	Air Risk Class
ATC	Air Traffic Control
ATM	Air traffic management
BVLOS	Beyond Visual Line of Sight
CTR	Control zone
DAA	Detect and Avoid
EASA	European Union Aviation Safety Agency
EU	European Union
eVTOL	Electric Vertical Take-off and Landing aircraft
FAA	Federal Aviation Administration
ICAO	International Civil Aviation Organization
MAC	Mid-air collision
OPS	Operations
OSED	Operational service and environment description
SESAR	Single European sky ATM research
SESAR 3 JU	SESAR 3 Joint Undertaking
SORA	Specific Operations Risk Assessment
TCAS	Traffic Alert and Collision Avoidance System
TLS	Target Level of Safety
TMPR	Tactical Mitigation Performance Requirement
UAS	Uncrewed Aircraft System
UAT	Universal Access Transceiver
USSP	U-space Service Provider

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UTM	UAS Traffic Management
VLOS	Visual Line of Sight

Table 2. List of acronyms

3 Extended Air Risk Model

3.1 General description

This model's purpose is to quantify the individual risk of a planned trajectory in an individual airspace. The idea is to estimate the risk of a mid-air conflict or collision as precisely as possible given the available information. Since the risk is a combination of probability and severity, first it will be described how the probability is calculated and then the way to estimate the severity of the collision for the different combinations of airspace user encounters.

3.1.1 Necessary input data

A number of data needs to be available in order to carry out the process of calculating the individual air risk. In detail these are:

- Historical flight data of air traffic in the area of the planned trajectory (for instance, FlightAware for aircraft equipped with ADS-B Out transponders). All air traffic that may pose a risk to the planned operation should be included in this database, e.g., general aviation and regular manned aviation, gliders, parachutes, and other types of small crewed aircraft, helicopters, and other drone traffic including possible people-carrying vehicles. The amount and nature of the data depend on the local circumstances of the area of operation[2]:
    - If the air-traffic is known to be more or less equally distributed over the year it is best to consider the air traffic for an entire year, preferably as close as possible to the planned trajectory, e.g., the previous year.
    - If the area is known to show significant seasonal changes in activity, e.g., during holiday seasons or due to a nearby airfield closing down in certain months it is advisable to use air traffic data from the month of the planned trajectory only. To increase reliability of the computation, data from that month of the previous two or three years should be used.
    - If the area is known to have greater changes in activity in even shorter time-frames, e.g. during a local (air sports) festival at a dedicated week or day, it is possible to use data from that day only. In that case data from more than one year should be used, e.g., from the previous three to five years to make sure that a significant amount of data is used.

[2] The use of chronological time instead of total flight hours is intentional. It tries to reflect the usual occupation of the airspace during the candidate flight time frame, rather than the behaviour of the flights in the area. For this last case, the sample should be large enough to be statistically meaningful, but in our case, we want to reflect the no presence or little presence of flights.

- Furthermore, to include other risks than air traffic in the model, data about the presence of wildlife, most prominently birds, should be available. Preferably, these can be given as historical records of wildlife movements, e.g., from wildlife radars or camera surveillance. If these are not available, estimations based on observations, preferably in form of probability maps can be used. It is necessary to not only have 2D maps giving the location but also have information about the flight altitude of the wildlife. If these are not available, this parameter can be estimated if the species of the animal is known.

3.1.2 Model Calculation

3.1.2.1 Presence probability in a map cell

The air risk model is based on the a-priory calculation of a probability map, giving the probability that in a given cell (square) of the map is at least one vehicle present at any arbitrary point in time. To calculate this map the following definitions are used:

1. A *trajectory* is a (in general continuous) set of points in space with individual times, i.e., $T = \{p_0, \dots, p_n\}$ with $p_i = (x, y, z, t) \in \mathbb{R}^4$.
2. We define for $p \in \mathbb{R}^4$ to be $p|_t$ the projection/restriction of p to the axis t, i.e. the t-component of p. For a trajectory $T = \{p_1, \dots, p_n\}$ the projection is defined by $T|_t := \{p_1|_t, \dots, p_n|_t\}$.
3. For any given trajectory or set of trajectories T, the *time domain* is defined to be: $\operatorname{domain} T \coloneqq [\min T|_t, \max T|_t]$
4. If a trajectory T can be expressed as a finite union of compact, disjoint sub-trajectories $T = T_1 \cup \dots \cup T_n$, then the support of T is defined as $$\operatorname{supp} T \coloneqq \operatorname{domain} T_1 \cup \dots \cup \operatorname{domain} T_n =: I_1 \cup \dots \cup I_n$$
5. The length of a domain or a support $I = I_1 \cup \dots \cup I_n$ is defined as the lengths of all its disjoint intervals: $$\operatorname{len} I \coloneqq \sum_{[t_1, t_2] \in I} t_2 - t_1$$
6. A *cell* C (of a map) is given by the canonical product of the intervals $C \coloneqq [x_1, x_2] \times [y_1, y_2] \times [z_1, z_2] \times [-\infty, +\infty]$ representing a cuboid in 3D with unlimited time of existence.
7.

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8. A *map* is a set of cells covering a given (geographic) area organized in a regular grid over dimensions x, y, z (Figure 1). Each cell is identified over integer number coordinates with adjacent cells having adjacent coordinates.

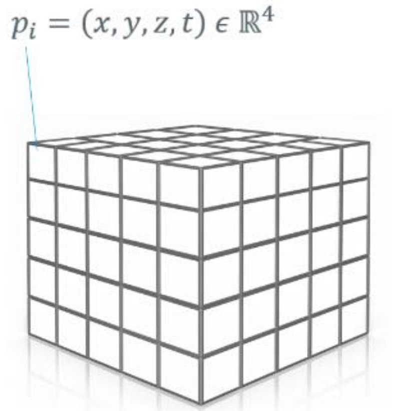

Figure 1. Map of cells, each one with its associated probability of encounter.

9. For a cell C in a map with coordinates i, j, k each cell with coordinates l, m, n with $\max\{|i-l|, |j-m|, |k-n|\} < 1$ is an element of $N26(C)$, the (26-)*neighbourhood* of C. Note that, although it is called 26-neighbourhood, N26 contains 27 cells including the generating central cell.

10. The *presence* of a trajectory T in a cell C is defined by the set $\mathrm{supp}(T \cap C)$. Note, that this can be a set of disjoint intervals representing the presence intervals of T in C.

Let Ψ be the set of all trajectories of aircraft (or wildlife) for the time-frame of interest (Figure 2). For a given cell C of the probability map to be calculated, the union of all presences for all vehicles (or wildlife) is determined:

$$\wp(\Psi, C) = \bigcup_{T \epsilon \Psi} \mathrm{supp}(T \cap C)$$

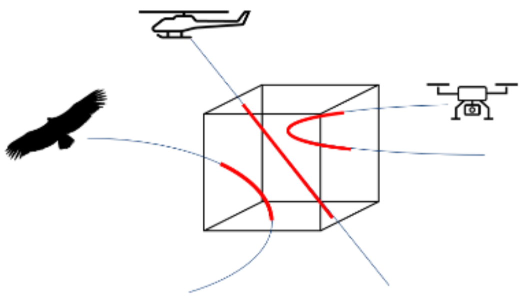

Figure 2. The set of red lines represents Ψ, the set of all trajectories of aircraft or wildlife inside a cell for the time-frame of interest

The total length (sum) of these intervals divided by the total duration of the data-set, the time domain, gives the average probability of presence of traffic in this cell:

$$P(\Psi, C) \coloneqq \mathrm{len}\, \wp(\Psi, C) \,/\, \mathrm{len}\,(\mathrm{domain}\, \Psi)$$

3.1.2.2 Encounter probability for a given trajectory

Here, an encounter is defined to be the simultaneous presence of two aircraft in the same cell. Given a probability map $M = \{C_1, \dots, C_n\}$ we can calculate the encounter probability of the trajectory T with other aircraft (or wildlife) during the flight in the time domain of the dataset:

$$P(T, M) = 1 - \prod_{C \epsilon M} \left(1 - P(\Psi, C)\right)^{\frac{\text{len}(\text{supp}(T \cap C))}{\text{len}\,(\text{domain}\,T)}} = 1 - \prod_{C \epsilon M} \exp\left(\frac{\text{len}(\text{supp}(T \cap C))}{\text{len}\,(\text{domain}\,T)} \cdot \ln\left(1 - P(\Psi, C)\right)\right) \tag{1}$$

Note, that the map M may contain several altitude layers, i.e., representing a 3D map.

3.1.2.3 Choice of map dimensions

The overall goal of calculating the encounter probability of a planned trajectory is to ensure safety of the later flight. It is therefore advisable to choose the map dimensions according to safety considerations of the planned scenario. The number developed in Section 3.1.2.2 gives the probability of an encounter or a conflict defined within the bounds of the individual cells only. At each point in time traffic may, however, be present exactly on the edge of a neighbouring cell (Figure 3). Therefore, in order to ensure that one can calculate the probability of a conflict with a horizontal distance of d and a vertical distance v of to all surrounding traffic one has to:

1. Choose d and v as the horizontal and vertical dimensions of the map cells (Figure 4),
2. Sum up Equation 1 over all neighbouring cells instead of just individual cells (Figure 4).

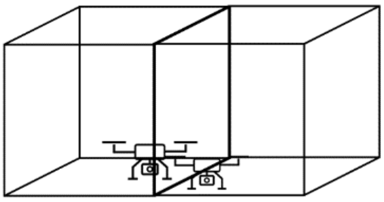

Figure 4. Despite on different cells, a traffic can be under a desired separation distance d.

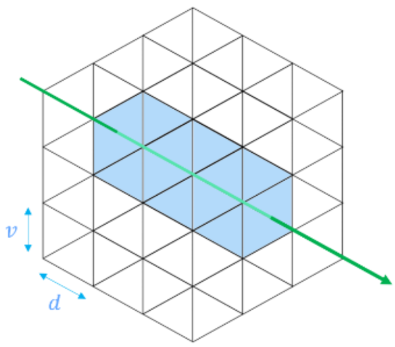

Figure 3. Neighbouring cells of the cells of interest are added to the equation.

We obtain the following modified formula:

$$P(T, M) = 1 - \prod_{C' \epsilon M} \left(\prod_{C \epsilon N26(C')} \left(1 - P(\Psi, C)\right)^{\frac{\text{len}(\text{supp}(T \cap C'))}{\text{len}\,(\text{domain}\,T)}} \right) \tag{2}$$

3.2 Example of use of the model to calculate the encounter probability

As a first step, in a given operations area a reduction of the air traffic database to that area needs to be applied. Figure 5 shows the Braunschweig area with the control zone of the local airport. Figure 6 shows an exemplary dataset of an entire year (2022) restricted to the control zone. Each cell is computed with a dimension of 100 m x 100 m. An orange cell typically represents conflict probabilities in the magnitude of 10^{-3}, light green is $4*10^{-5}$, while dark blue is $4*10^{-6}$. Note, that this graphical representation is not limited in altitude, i.e., it shows the entire range from ground to maximal altitude.

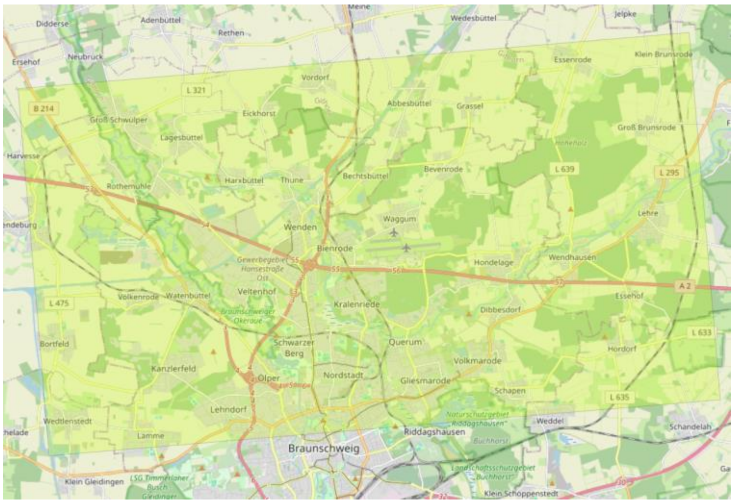

Figure 5. Surroundings of Braunschweig with control zone.

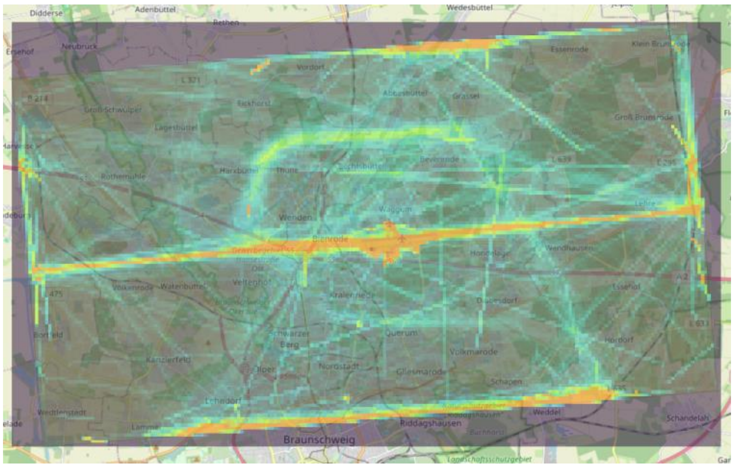

Figure 6. Local conflict probabilities for the Braunschweig area for an entire year.

Further, from the statistical analysis we get the altitude distribution in Table 3 for the Braunschweig area:

Table 3. Traffic distribution by altitude in the dataset

Altitude	Number of aircraft
0-150 m	7902
150-300 m	9239
300-450 m	9862
450-600 m	8428
600-750 m	5247
Above 750 m	16622

We plan a mission trajectory at the altitude of 200 m, so we restrict our data to the altitude band of 150 to 250 m. Figure 7 shows the database restricted to the altitude band 150 m to 250 m, using the same coloring as in Figure 6. One recognizes that aside from the direct approach a conflict in free air becomes rather improbable.

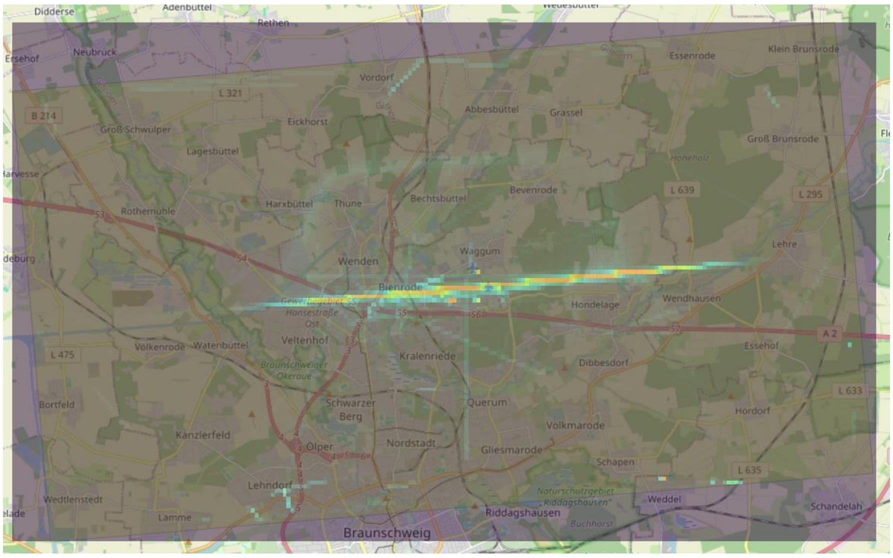

Figure 7. Conflict probabilities for the altitude band 150-250 m.

For sake of simplicity, we plan a trajectory with a constant speed of 20 m/s and an altitude of 200 m, running straight from Hondelage to Essenrode (see Figure 8).

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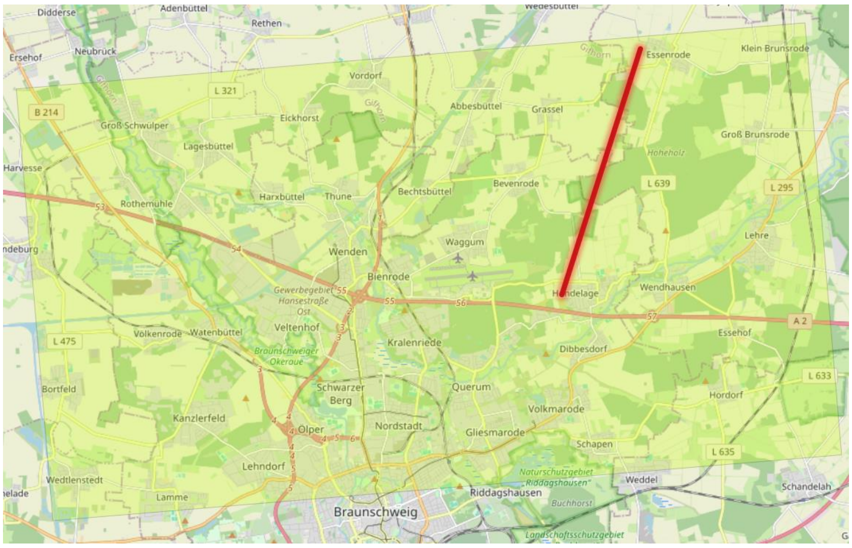

Figure 8. Exemplary mission trajectory from Hondelage to Essenrode.

The probabilities are weighted and multiplied according to Section 3.1.2. The result in this example is:

$$P(T, M) = 2.729 \cdot 10^{-5}$$

3.3 Inclusion of the severity to the model

3.3.1 Drones and Wildlife

3.3.1.1 Introduction – Wildlife Strike Risk in Conventional Aviation

Every flying vehicle is to share the airspace with surrounding wildlife, namely birds and bats. Since the beginning of aviation, this has led to mutual negative impacts, ranging from disturbance of wildlife to collisions resulting in fatalities on both the human and animal side.

Due to highest abundance of wildlife at lower heights, the impacts are highest for low-level flight operations [2]. Considering collisions – so called wildlife strikes - this has been reflected in strike numbers, as visualized in Figure 9. It can be seen that the number of strikes is highest close to the ground and decreases with increasing height. The decrease in damaging strikes is less prominent. This is resulting from higher aircraft speeds at higher heights as well as from the fact that larger animals fly higher than smaller ones, both leading to higher kinetic energy and thus impact force.

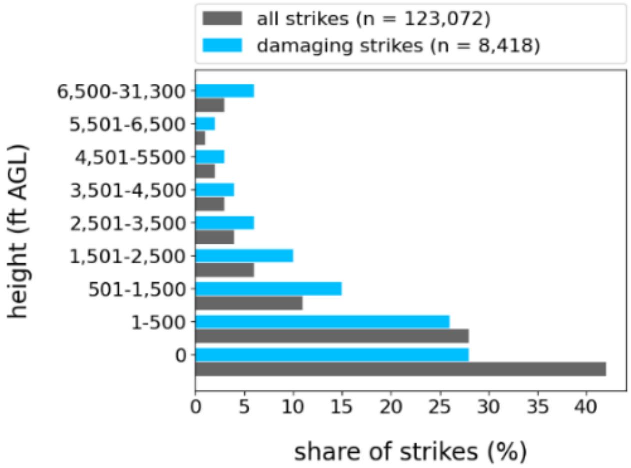

Figure 9. Wildlife Strikes to Civil Fixed-Wing Aircraft in the United States from 1990 to 2023 (Source: [3])

To reduce this risk of wildlife strikes – the likelihood of encounter as well as the likelihood for damaging outcomes, multiple measures are undertaken (cf. e.g. [4]). Wildlife Hazard Management is primarily performed at aerodromes to reduce the occurrence of wildlife, as mandated by ICAO Annex 14 [5]. Strategies range from habitat management to dispersal and killing of critical wildlife. Information to flying personnel about current wildlife activity which could become critical to flight operations is, with exceptions (cf. [6]), limited in civil aviation. Information provided include highlighting of known wildlife-abundant areas at the airport or en-route within the Aeronautical Information Publication or general Notices to Airmen (NOTAM), for example during migration season.

In military aviation, where more low-level operations are in place, mapping tools and warning systems are implemented to inform flying personnel as well as to impose flight restrictions in case of critical wildlife abundance [7]. That study demonstrated that air forces using such systems have a decrease of damaging wildlife strikes by 45 % compared to air forces without any system in place.

To increase the chances of wildlife avoiding approaching aircraft, it has been found that increasing conspicuity of aircraft helps wildlife to perceive the approaching opponent earlier, increasing chances of successful escapes. Positive effects have been shown for installations of pulsing lights, striped patterns on propellers and for fuselages with high contrast to the surrounding environment (e.g. [8]; [9] and [10]). The use of on-board ultrasonic sound as repellent is currently being investigated [11].

To limit the impact of occurring strikes, airframes and engines have to demonstrate impact resistance capabilities within the certification process by the Civil Aviation Authorities. Counterintuitively, larger aircraft which pass the critical low-level altitudes only during departure and arrival have more stringent requirements than smaller aircraft which predominantly fly at wildlife-abundant altitudes, as is shown in **¡Error! No se encuentra el origen de la referencia.**. The adverse effects of this limitation are demonstrated by damaging strike rates – while approximately 10 % of large fixed-wing strikes reported to the Federal Aviation Administration (FAA) between 1990 and 2011 result in damage, the share of damaging strikes amounted to approximately 35% in rotorcraft in that period [12] [13]. A working group installed by the FAA proposed "wildlife strike safety procedures" [14] to reduce the risk of wildlife strikes to rotorcraft since it was established that more restrictive airframe regulations would not be economically viable. The suggested procedures can be summarized as "fly high, fly slowly, make the rotorcraft as conspicuous as possible and wear helmets with visors in case of breaking windshields".

Considering the limited impact requirements for electric Vertical Take-off and Landing aircraft (eVTOL), not to speak of smaller drones without such requirements, combined with their low-level flight altitudes, a large number of adverse effects has to be expected for their operations. The specifics for these novel or even future airspace users are discussed in the subsequent sections.

Table 4. Airframe Impact Resistance Requirements by EASA (CS) and the FAA (Parts)

Aircraft Type	*Category (Part/CS)*	*Description*	*Requirements*
Fixed-Wing	23	Max 19 passenger seats or max take-off weight of 19,000 lb	Windshield: 2 lb at maximum approach flap speed (aircraft with max seats of 10 to 19 only)
	25	Multi-engine airplanes with more than 19 seats or max take-off weight greater than19,000 lb	Windshield: 4 lb at cruise speed, Structure:4 lb at cruise speed at sea level or 0.85 *cruise speed at 8,000 ft (more critical condition applies), Empennage (FAA only): 8lb at cruise speed
Rotorcraft	27	Max take-off weight of 7,000 lb or max of nine passenger seats	none
	29	Category A: more than 20,000 lb max take-off weight, Category B: more than 7,000 lb max take-off weight and 10 or more passenger seats	After impact of 2.2 lb at lower of VNE[3] or VH[4], Category A: Ensure safe flight and landing , Category B: Ensure safe landing
General	35	propellers	Withstand the impact of a 4 lb wildlife at the critical location(s) and flight condition(s)of a typical installation without causing a major or hazardous propeller effect
eVTOL	MOC-SC-VTOL [5](EASA) 21[6] (FAA)		1 kg (single wildlife strike), 0.45kg (multiple wildlife strike) Identical to Part 29

[3] VNE: never exceed speed
[4] VH: maximum speed in level flight with maximum continuous power
[5] Proposed Means of Compliance with the Special Condition VTOL
[6] Special Class Airworthiness Criteria for the Joby Aero, Inc. Model JAS4-1 Powered-Lift

3.3.1.2 The Risk of Wildlife Strike for Smaller Airspace Users (Drones and eVTOLs)

As introduced above, smaller airspace users are more vulnerable to wildlife strikes due to flying at wildlife-abundant heights during all of their flights and due to smaller or even no requirements to prove impact resistance.

In contrast to rotorcraft which have similar vulnerabilities considering wildlife strike risk, eVTOLs and drones are even smaller and emit much less noise. Hence, it is more difficult for wildlife to perceive these airspace users as potential opponents, making it harder to initiate timely avoidance manoeuvres (cf. e.g. [15]). Some territorial species even may perceive these slow, quiet and small flying objects as intruders and actively attack them (e.g. [16]), leading to additional collisions.

In terms of damage resulting from collisions with wildlife, already impact of small animals at low speeds may have adverse effects. In Metz et al. [17] it was compared EASA's certification requirements for eVTOLs (cf. **¡Error! No se encuentra el origen de la referencia.**) with the impact force generated with various wildlife species under various conditions. Among others, they found that, given the relatively low airspeed of eVTOLs, wildlife speed is highly critical to be considered when determining required impact resistance. With the regulations only taking into account aircraft speed, the likeliness for damaging strikes is underrated.

Following a collision with wildlife, the likelihood of damage not only depends on impact resistance but also on individual components. Most drones and eVTOLs are equipped with multiple propeller systems. Damage to one propeller can negatively impact the ability for stable flight. In addition, debris might damage other parts of the vehicle, leading to cascading effects. This becomes especially critical when battery systems are hit [16].

Many operations of drones and eVTOLs lead over urban areas which further increases the overall risk of wildlife strikes. First, these areas are attractive to many wildlife species. Second, there are limited spaces for emergency landings in case of collisions. Third, debris or even hull losses may lead to damage, injuries or fatalities on the ground.

Provided that the flight profiles as well as the regulatory framework are set and occurring collisions have a high likelihood to result in damage, means to limit the probability of collisions in the first place need to be developed. These can build on existing systems used by the air forces and open for public use, which are introduced in the next section.

3.3.1.3 A Framework for Risk Modelling for Smaller Airspace Users

Recent research [6], developed a framework for mitigating wildlife strikes in the context of Advanced Air Mobility (AAM). It concluded that risk estimation and mapping tools are the first priority to address.

There is existing work upon which such tools can build. In Europe, the FlySafe Bird Avoidance Model [18] provides near-real time as well as forecasts of avian wildlife density for Belgium, Germany and the Netherlands obtained from weather radar data. The resulting information is plotted as altitude profiles of wildlife densities and translated into BIRDTAM values as shown in Figure 10. These serve the air forces to approximate the risk of wildlife strike and to impose operational procedures, e.g. for increased rates of climbs to above critical layers or for closing specific airspace segments to operations. Since the information is publicly accessible, it can also be used by civil users.

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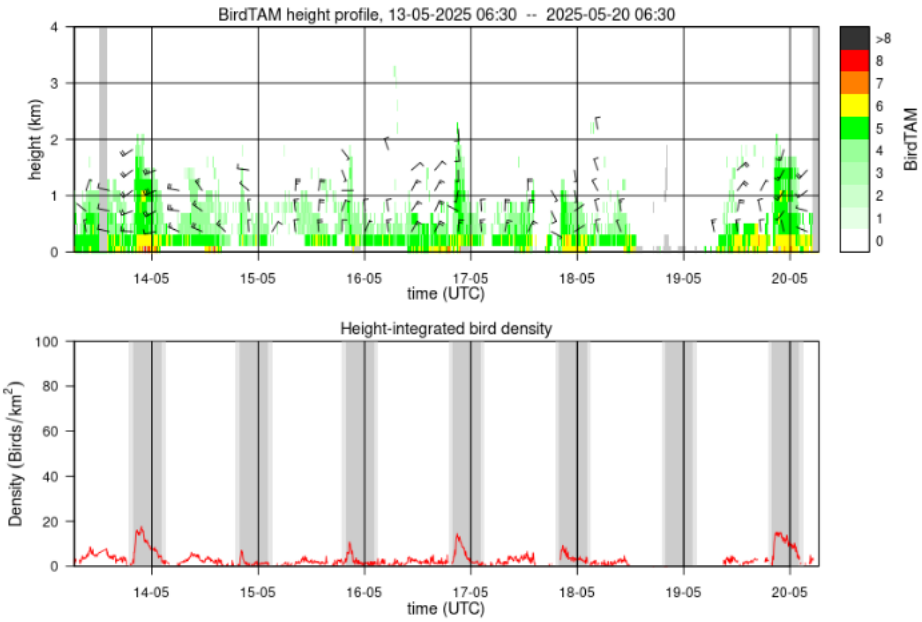

Figure 10. BIRDTAM for Rostock, Germany [18]

The U.S Air Force provides a web-based, publicly accessible mapping tool both for military and civil airspace users, the Avian Hazard Advisory System [19]. It provides real-time risk-mapping as well as forecasts of future wildlife strike risk. Filtering biological signals from the Next Generation of Weather Surveillance Radars (NEXRAD) station across the U.S, airborne wildlife density is obtained. In AHAS, this information is displayed upon the user's need, e.g. for selected areas or specific visual or instrument flight routes (cf. Figure 11). In case of high risk, alternative route suggestions are provided.

Such tools can be used without limitations by drone or eVTOL operators. In addition, operations or route adjustments can be performed on short notice in areas with known patterns of intense local wildlife movement, as demonstrated in various examples from conventional aviation. In Australia, for example, different airports experience high-density movements of bats which occurs at specific daytime conditions (dawn and dusk) during some weeks of the year. In a first step, the airport informs airlines in advance, when the respective season comes up and proposes alternative slots for flights scheduled during critical daytimes. Airlines themselves advise their crew to carry additional fuel for potential holdings or the need to land at an alternative site. At the airport, the beginning of movements is closely watched by the wildlife control units and communicated to Air Traffic Control (ATC) which forward the information to pilots to decide to delay departure or arrival to the port [20] [21]. Similar examples are known from South Africa [4] and Canada [22].

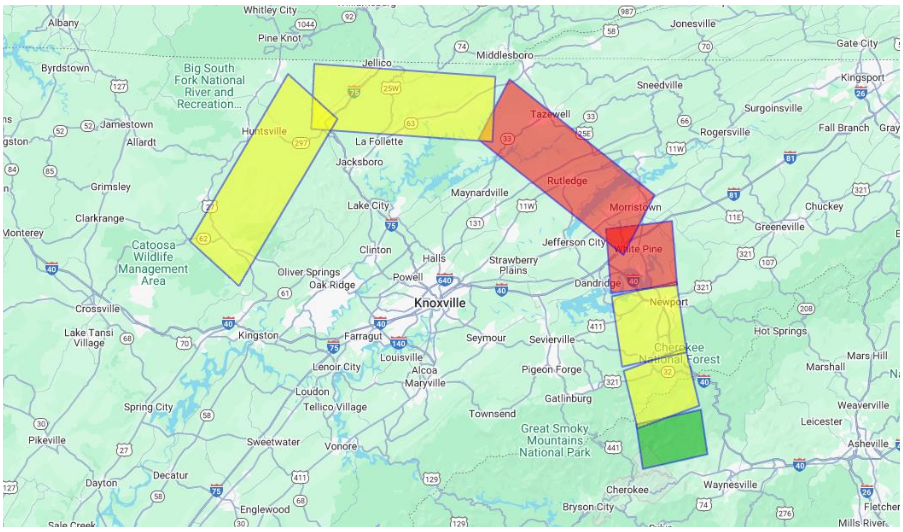

Figure 11. Example for risk mapping for an instrument flight route in flight area IR002 (20 May 2025, 0700-0800 UTC, U.S. Air Force, 2025)

3.3.2 Categorization of the severity of the collision

The damage or consequences of a collision between two airspace users can be very different depending on different factors. Aspects like size, speed or weight can give some clues about the possibilities of recover the control after the collision, or if it will most likely end in a crash. In this step this will be reflected through a value that will be referred to as *actual collision hazard*, which will also mean that there could be consequences on the ground (the estimation of the consequences on the ground is addressed by the ground risk model also suggested in U-AGREE).

However, the severity of a crash can be very different for the traffic involved. Clearly, the crash of a drone delivering a pizza will not have the same seriousness than the crash of an aircraft with people on board. The economic loss will be different too. These aspects will also be represented and added to the previous formulas.

The first step was to determine categories for the traffic involved in the collision (Table 5). Each category or class is associated with an ***S*** **2-dimensional vector** where its components represent lives endangered and monetary loss (Table 6). Given this, in a conflict the severity of the conflict partners gets added like:

$$S(X, Y)=(f(X, Y),1)\cdot(S(X)\oplus S(Y))$$

With $\oplus((a, b),(c, d))\coloneqq(a+c, \max(b, d))$

Example:

$$S(A, B3) = (f(A, B3), 1)\cdot((200, 10^8) + (0, 10^3)) = (1, 1)\cdot(200, 10^8) = (200, 10^8)$$

Note that for monetary loss only the exponent of the sum is considered, effectively taking the maximum of both values.

Table 5. Categories of airspace users. Images: Wikimedia.org, CC BY-SA 4.0 (left, top) © DJI (right bottom 3)

Class	Description	Example
A	Large passenger aircraft.	A320
A2	Advanced air mobility	prototypes
C	Small passenger aircraft.	Cessna 172
G	Glider or ultra-light aircraft.	Grob G103
B4	Very large animal.	crane
B3	Large animal.	goose
B2	Medium animal.	crow
B1	Small animal.	sparrow
D4	Very large drone.	Heron TP
D3	Large drone.	DJI FlyCart 30
D2	Medium drone.	DJI Matrice M30T
D1	Small drone.	DJI Neo

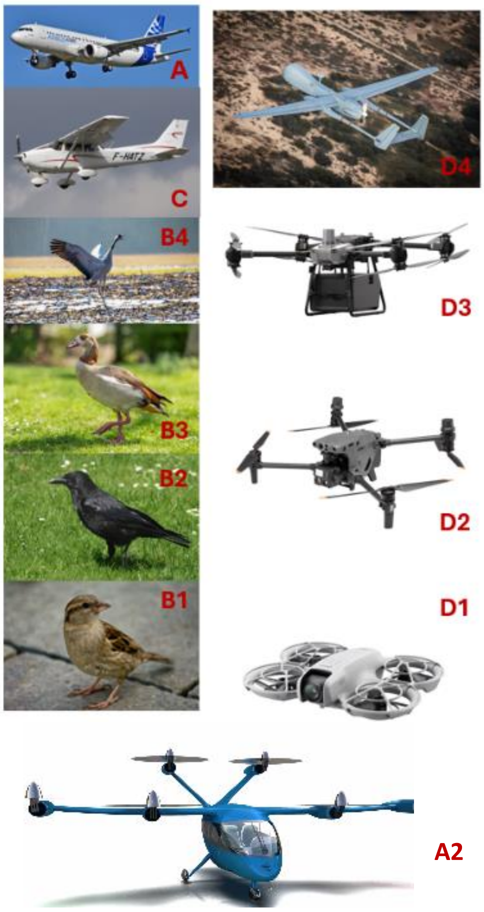

Table 6. Estimation of lives endangered and monetary loss for each class (source for impact resistance of AAM vehicles —1 kg single animal, 0.45 kg flocking birds— [23]).

Class	Lives endangered	Monetary loss (€)
A	200	10^8
A2	2	10^6
C	5	10^5
G	2	10^5
B4	0	10^3 – 10^4
B3	0	10^3
B2	0	10^3
B1	0	10^3
D4	0	10^8

D3	0	10^4
D2	0	10^4
D1	0	10^2

For the lives endangered a factor *f* has to be considered weighing the **actual hazard** of the collision. A hull loss is assumed as a worst case in that cases that are marked as 1 in the *f*-table. If a hull loss is possible but unlikely, one could use a small positive number instead of 1, e.g. the probability of hull loss if it is known.

To assess the final risk, the collision probability gets multiplied with the severity vector, giving a risk vector:

$$R = (\boldsymbol{Mortality}, Monetary\ Loss) = R(X, Y) = P(T, M) \cdot S(X, Y)$$

With the mortality given in Mort or Micromort units ant the monetary loss in € or $. Example:

$$R(A, B3) = 10^{-6} \cdot (200, 10^{8}) = (2 \cdot 10^{-4}, 10^{2})$$

In this case the life endangered risk would be $2{\cdot}10^{-4}$, that is 200 Micromort; the monetary risk would be €100.

It is up to authorities, operators and insurance companies to decide for acceptable limits of risk.

Table 7. Values that estimate the actual hazard to human lives given the pair of airspace users involved.

f	A	C	G	B4	B3	B2	B1	D4	D3	D2	D1
A	1	1	1	1	1	0	0	1	1	1	0
A2	1	1	1	1	1	0	0	1	1	1	0
C	1	1	1	1	1	0	0	1	1	1	0
G	1	1	1	1	1	0	0	1	1	1	0
B4	1	1	1	0	0	0	0	1	1	1	1
B3	1	1	1	0	0	0	0	1	1	1	1
B2	0	0	0	0	0	0	0	0.5/1	1	1	1
B1	0	0	0	0	0	0	0	0	0	0/0.5	0.5/1
D4	1	1	1	1	1	1	0	0	0	0	0
D3	1	1	1	1	1	1	0	0	0	0	0
D2	1	1	1	1	1	1	0/0.5	0	0	0	0
D1	0	0	0	1	1	1	0.5/1	0	0	0	0

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3.4 Environmental and social impact

In U-AGREE, the estimation of the environmental and social impact of drone operations has been included in the ground risk model (see deliverable D3.5), since it could be understood that while the cause is aerial, the consequences belong to the ground sphere. However, following are a few references of recent research on the topic.

Regarding drones used for delivery service, we can find in [24] an evaluation of the impact of these operations on environmental, societal and airside traffic flow factors when supported by the U-space framework. A comparison between a drone delivery service with and without the orchestration of U-space is investigated for the exemplary city region of Aachen, Germany. Noise emissions, visual pollution and flight times are assessed to conclude that the noise generated is within generally acceptable acoustic levels below 50 dB(A) and that the probability of drone presence is highest near the take-off and landing zones. Therefore, drone-based parcel delivery appears as operationally and environmentally viable approach to urban logistics, provided that specific conditions and constraints are met.

In [25] the use case is also in parcel delivery but with the focus on privacy concerns. Two different flight patterns — free-route airspace and a grid-based network — in Madrid are compared to determine that a grid-based routing leads to quite higher quantity of population exposed, especially during the morning. This work was part of the project MUSE (Measuring U-space Social and Environmental Impact) [26]. In MUSE the estimation of the noise was done in function of the flight altitude, but without involving a survey to the population. This will be somehow fixed in CORUS five. The ongoing project CORUS five [27], aimed at updating the U-space ConOps, will include a set of impact indicators and a template of questionnaire for the citizens that pretends to be the reference for these evaluations. Keep an eye also on the CORUS five output for a state of the art of the last five years of the topic.

Project ImAFUSA (Impact and Capacity Assessment Framework for U-space Societal Acceptance) [28] was also dedicated to the environmental, safety, societal and economic impact of urban air mobility. It included noise measurements and acoustic and psychoacoustic characterization of different drone models. Experiments in open field with local residents were performed to reflect the perception of the noise generated by a drone.

On 2025, the DLR's Institute for Flight Guidance, together with the German Environment Agency (UBA), carried out extensive acoustic measurements on drones at the DLR National Experimental Test Center for Unmanned Aircraft Systems in Cochstedt. Three unmanned platforms were measured: the S500, EVO X8 Heavy and the HD4-1100 rescue drone. The tests were based on the newly developed ISO 5305:2024 standard [29] for noise measurement of unmanned aerial multirotor vehicles under 150 Kg, which includes multiple positions around the UAS, covering typical flight phases (hover, cruise, take-off, landing). The aim of this measurement campaign was to test the practical suitability of the new ISO standard on various types of drones under real operating conditions. Also to compare the results of these outdoor measurements with existing data from indoor measurements. This should help to assess whether future noise measurements exclusively indoors or outdoors are sufficient - an important step towards making noise investigations more efficient.

EASA provides also guidelines on noise measurements for drones below 600 kg [30] for medium risk operations; their application is voluntary in EU. An example of these measurements can be found in [31], though this study concluded that such recommendations do not apply well to smaller drones.

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4 Assumptions and future work

The process detailed in this document is a purely mathematical description of the method to obtain an estimation of the air-risk of a planned trajectory. In order to become a fully-normative process as part of, e.g., a SORA process, several details would have to be added. For example, normative, trusted and possibly certified databases for historical traffic would have to be identified and listed as part of the process. Furthermore, map dimensions in terms of minimal distances d and v (see Section 3.1.2.3) would have to be defined. Given that, a number of cases would have to be considered, e.g., the possibility of sudden changes in airspace use, along with the probability of emergency or contingency situations like the presence rescue helicopters.

In this version of the model, encounters with flocking birds are not considered, even when the consequences could be quite relevant; e. g., a flock of 100 starlings, that are class B1, could take down a class A aircraft. More research would be necessary to consider the complex evaluation of different distributions of animal sizes and flocks per species and world region. A possible way to integrate the flocks in the model would be add categories for the different flocks of each animal category or for specific species.

Advanced Air Mobility is, at the moment of writing this document, still a thing of the future. Therefore, the consideration of two people on board or the price of these aircraft are just —reasoned— conjectures. When this means of transport comes into service, more categories could be created for their different types, that could depend of the size, number of passengers, pilot onboard, or any other aspect with an impact on the risk.

The issue of the altitude references

In the context of air risk assessment, particular attention should also be given to the implementation and interpretation of a Common Altitude Reference System. The increasing coexistence of conventional aviation and drone operations introduces multiple altitude reference frameworks, including Above Ground Level (AGL), Above Surface Level (ASL), ellipsoidal height, terrain-relative height, height above take-off (T/O) as well as less known to drone community but widely used in manned aviation QNH, QFE, QNE references. The conversion between pressure-based altitude references and ellipsoidal height systems inevitably introduces uncertainties, which in specific operational scenarios may become significant enough to affect the reliability of air risk calculations.

These discrepancies may originate from ambiguities or inconsistencies related to geodetic undulation models, Digital Surface Models (DSM), Digital Terrain Models (DTM), atmospheric pressure measurements, local atmospheric conditions, and sensor inaccuracies. Additional errors may arise from the coexistence of different mathematical and geospatial reference systems, as well as from human factors, particularly when operators assume that altitude information is fully harmonised while the underlying reference systems remain misunderstood or only partially defined.

Historically, aviation relied almost exclusively on pressure-based altitude references. However, the introduction of drones and Advanced Air Mobility operations has significantly expanded the number of operational altitude concepts and reference frames. As a consequence, the proper harmonisation

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of altitude references becomes a critical element for reliable encounter probability estimation and separation assurance.

An idea to consider the risk generated by the different altitude references in a future version of the air risk model would be possible if we had the reference of altitude for each traffic in the history of flights. While calculating the probability of collision, it could be checked the variability of altitude references of the flights in the area. If usually all the traffic uses the same reference, then that would not increase the risk, otherwise we could start adding more probability depending on such variability. To evaluate this variability, it can be followed the guidance and methodologies developed within the ICARUS project.

If enough variability and therefore increase of the risk is identified, as a measure to improve the safety in the area, it is advised to use an altitude reference service like the Common Altitude Reference System suggested in the ICARUS project.

The altitude uncertainties are expected to be further analysed, quantified, and formally defined within the continuation of the ICARUS project, named DEDALUS, which is planned to start later this year. The project is expected to contribute to the harmonisation of altitude reference methodologies and to provide additional guidance for managing vertical reference inconsistencies in future U-space and Advanced Air Mobility operations.

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