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Abstract

This document recommends 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). It then recommends operational safety objectives to be met for each SAIL.

Keywords

SORA, SAIL, Specific, Risk, Ground Risk, Air Risk, Containment

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EDITION NUMBER	EDITION DATE	REASON FOR CHANGE	PAGES / SECTIONS AFFECTED
2.5	08.11.2022	Version for JARUS External consultation	First Edition
2.5	13.05.2024	Public release	Reflects changes in SORA documents since Edition 2.0 Section on the containment model with respect to risk to adjacent areas has been moved to Annex F. Justification for Adjacent Airspace Containment expanded to reflect submitted comments during external consultation.

NOTE FOR THE READER

This paper contains:

- A general description of the main changes introduced in the SORA 2.5 Main Body and Annexes A, B, E, I and F;
- The rationale for the updated containment requirements with regards to air risk (Appendix A);

The changes in the containment requirements of SORA 2.5 were performed by a dedicated containment subgroup of the JARUS WG-SRM. The principles were developed by an “authorities only” subgroup, and eventually integrated into SORA (Main Body, Annexes E & F) by the members of the SRM-Task Forces Main Body & Quantitative Methods for Ground Risk. The assumptions of the new containment model with regards to air risk are explained in the Appendix, and will be integrated into a future release of SORA.

The Appendix was written by the following main contributors:

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- Bruno Rabillet – Eurocontrol,
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1. Introduction

This document is an explanatory note for major changes introduced with SORA 2.5. The changes were developed by JARUS WG SRM considering the lesson learned derived by the application of SORA 2.0. SORA 2.5 introduces a quantitative ground risk assessment methodology and has had a general review of the structure and text to simplify the language and clarify those areas where questions were raised during internal and external consultation. It was also possible to redesign the triggering factors and increase the granularity of the containment requirements.

SORA 2.5 package includes amendments to the Main Body and Annexes A, B, E, I. and the Cyber Safety Extension. In addition, it introduces Annex F. The main changes introduced with SORA 2.5 are described below.

SORA Annexes C and D were not modified as part of this package. These annexes are expected to be part of a future revision of SORA, following a reworking of the air risk model and will be published alongside Annex G featuring the quantitative background of the air risk model.

2. SORA Main body updates

The main changes in the SORA main body are:

- The Main body has been fully restructured:
    - The Executive Summary is now an integral part of the Main Body and not a separate document
    - To facilitate the use of the main body, information has been moved to more appropriate sections of the document.
- There is now a clear structural separation between guidance (marked G) and recommendation (marked R) which can form the basis for requirements in official means of compliance when the SORA is adopted by a competent authority. The wording in the "R" sections is aiming at using precise instructional language to provide task descriptions to applicants.
- Phase based approach:
    - a paragraph was introduced to recommend that the SORA process should be carried out in 2 phases to avoid developing evidence based on risk assumptions not agreed with the competent authority. However, an operator may decide not to use this phased approach and contact the competent authority directly when all documentation and evidence collection have been finalised. The approach consists in:
        - 1st phase – Requirements derivation: the operator carries out a preliminary risk assessment, utilising the operational context to make safety claims (the intrinsic ground risk class, ground risk mitigations, initial air risk class, strategic mitigations for air risk) and to derive requirements (final ground risk class, residual air risk class, tactical mitigation performance requirements, SAIL and associated OSOs, and the containment requirements).. At the end of this phase, the operator is not expected to have developed evidence, but instead developed a preliminary description and risk assessment of the operation. The end of this phase is an opportune point in time for the operator to contact the competent authority to verify the acceptability of the final ground risk class, residual air risk class, TMPR, SAIL and level of containment.
        - 2nd phase – Compliance with requirements: the operator develops all evidence that demonstrates compliance with the safety claims and derived requirements, and compiles this into a Comprehensive Safety Portfolio, which should provide the necessary context, linkages and references between all the documents such that the CSP makes a justified safety case that the operation has met all its SORA objectives.

- The explanations of key definitions and of the semantic model has been expanded considerably to give authorities and applicants a better basis to understand all requirements. This should also improve global standardization of SORA application.

- SORA Step #1
    - SORA Step #1 has been updated to provide more detail and clarity on what information should be collated to successfully progress through the SORA process. Reference to Annex A Chapter A3 has been included to ensure applicants can find relevant template and guidance to complete this step.
- SORA Step #2
    - A new ground risk class table was introduced linking each class to a population density value and a critical area value, with the intent to facilitate the identification of ground risk quantitatively linking it to the target level of safety. The major difference in outcomes from the new ground risk table comparing to the old 2.0 table is that there are more categories for different densities of people allowing a more accurate intrinsic ground risk assessment.
    - The operator is expected to use population density maps showing the average population density. In cases when accurate maps are not available, a proposed correspondence with the qualitative identification of the population density is provided.
    - The basic table UA critical areas are assigned based on a maximum characteristic dimension and maximum speed. The operator may calculate the actual critical area of the UA using a formula defined in Annex F. If the critical area corresponds to the one identified in Annex F for a smaller UA, then the corresponding risk class may be used. A special case is given for UA below the mass of 250g to acknowledge the fact that this small UA area considered harmless and given the smallest ground risk value regardless of population density.
    - There is added clarity in all used definitions, process phases and on the optimal types of population density maps recommended.
- SORA Step #3
    - The reduction of the ground risk class value due to VLOS operation was moved from the ground risk table to M1 mitigations.
    - The M1 mitigation has been split up into three separate mitigations that can be combined. This solves the issue in SORA 2.0, where mitigations up to –4 GRC have been allowed, and where multiple separate mitigations were already possible. However, this had produced inconsistencies with the level of assurance as two simple mitigations would end up in a medium assurance requirement, which is not always necessary.
    - Mitigation M2 has been updated to include the possibility to have up to 3 credits for the high level of robustness (Annex B).
    - Mitigation M3(ERP) has been removed since the reduction of the population at risk using an emergency response plan (ERP) has been identified to be possible only on very rare cases. An ERP is always required and its requirement was moved to OSO #8.
    - The final identification of the ground risk of the adjacent area has been introduced, with guidance on defining which ground mitigations might have an effect in the adjacent area.
- SORA Step #4
    - The changes in Step #4 have been limited to minimal clarifications of the text that did not impact the underlying air risk concept.

- SORA Step#5
  - An explanation on how to use VLOS operation as a strategic mitigation in order to reduce the ARC by one class has been added.
- Step #6
  - No major change to SORA 2.0
- Step #7
  - No major change to SORA 2.0
- Step #8 Containment (formerly Step #9 in SORA 2.0)

  This Step has been significantly updated in SORA 2.5 with several modifications being introduced.

  In the use of SORA 2.0 over the last several years, several insights on usability were gained:

  - There was no clear definition of adjacent area and adjacent airspace
  - The need for ending the flight after leaving the operational volume was only implicitly mentioned in the semantic model, but not stated as a part of the containment requirements
  - There was no defined level of assurance for the requirements of “basic” and “enhanced” containment.
  - In certain use cases, the trigger for requiring “enhanced containment” was too conservative and not risk-proportionate.
  - An analysis of containment requirements was always required, irrespective of the available containment performance of the intended drone system.
  - Operations at higher SAIL levels (III-VI) do not receive automated credit with respect to their containment performance, even though increasing SAIL naturally reduces the loss of control of operation rate.

  The new Annex F, section 4, provides a detailed explanation on the changes related to containment considering the ground risk. The rationale for air risk containment is given in Appendix A to this document.

  The main changes to containment have been:

  - A new system to derive operational limits in conjunction with a containment performance level
  - There are now clear guidelines to determine the size of the adjacent area as well as to determine the relevance of assemblies of people in the adjacent area.
  - There are now three levels of containment (low, medium, high), which are downwards compatible to SORA 2.0. Former “basic” containment equals “low”, while former “enhanced” containment equals “high”, providing more granularity by introducing a new intermediate level.
  - The positive influence of SAIL on containment performance is now correctly modelled.
  - The triggering mechanism for the containment levels has been updated to be more risk proportionate.
  - Containment of the adjacent airspace is sufficiently complied with by “low” containment. Since “low” is also the minimum level, it was possible to remove the assessment of the adjacent airspace without compromising overall safety.
  - The containment requirements were moved to Annex E, section 4. They now also explicitly include operational aspects as well as assurance requirements for all criteria.
  - An alternative more detailed method to determine containment can now be found in Annex F. This is only suitable for certain edge cases, that are expected to be quite uncommon in practical operations. This alternative method is mostly equivalent to the more extensive containment method described in the external consultation draft of SORA 2.5.
- SORA Step #9 (formerly Step #8 in SORA 2.0)

- The OSO list was restructured while the topics of the OSOs has not been changed.
    - The new list of OSOs follows the order they appear in Annex A (and therefore the order possibly used by the operator when developing an operator manual). The order might be subject to further changes, depending on how the final version of Annex A.
    - The duplications of OSOs (when in Annex E multiple OSOs share the same requirement) were removed.
    - The organisation that may develop the evidence was included. The operator is responsible to submit to the competent authority the evidence showing compliance with the OSOs, mitigations and containment. However, as part of the application for an operational authorisation, the operator may rely on evidence produced by:
        - design organisations of the UA or a component. Depending on the SAIL these may consist in a declaration of compliance or a different kind of certificates, up to a type certificate, as defined by the competent authority.
        - Training organisations. Depending on the SAIL these may be a declaration of compliance or a different kind of certificates, up to a remote pilot license, as defined by the competent authority.
- The term optional 'O' in the OSO table has been replaced with 'NR ' (not required to show compliance) since the operator is encouraged to consider all OSOs, including those not required to be shown compliance to.
- In the external consultation, it was considered to renumber the OSO with roman numbers. However, due to multiple comments by stakeholders, this decision was reversed, and the former numbering remains in place.

- Step #10

  This section has been updated to provide more detail on the purpose of Step #10 to "close the loop" on the risk assessment, and for the end product to effectively provide a justified safety case that the proposed operation meets all of the SORA safety objectives. Reference to Annex A has been added to ensure users know of the additional guidance.

3. Annex A updates

The main changes in Annex A are:

- The revised document has been restructured to align with the SORA V2.5 package.
- Operations Manual guidance has been replaced with a structured template. The operations manual guidance material has been moved to the JARUS WG OOP group for further development.
- Templates for documenting the Phase I SORA analysis as well as a compliance matrix to show compliance with Step #10 as the final step of Phase II have been introduced.
- Duplications of requirements between the external consultation draft of Annex A and Annex B and E have been removed.
- New Section A.5 introduced on how to present a flight area.

4. Annex B updates

The main changes in Annex B are:

- The revised document includes updated language to reflect a general principle that was already valid in in SORA 2.0: in order to obtain 1 point of credit reduction the operator needs to demonstrate a reduction of one order of magnitude in the population at risk.
- New M1A for sheltering mitigations is added to harmonize the implementation of the most common mitigation which is assumed to function in a very large number of UAS operations.
- Previous M1 mitigations relating to operational restrictions have been renamed M1B and given more clarity in requirements.
- New M1C has been introduced for operations using ground observation as a mitigation to replace the “VLOS” credit in Step #2 of SORA 2.0. VLOS/BVLOS strategies have been removed from Step #2 since they are more commonly associated to air risk.
- For M2 the table with the critical areas used in the ground risk model detailed in Annex F is included, in addition to the percentage reductions of lethality of the impact
- M3 ERP mitigation was removed from Annex B due to it causing confusion and it has now been moved to Annex E.
- The mitigations have been reviewed to ensure no overlap issues arise between individual mitigations.
- The new mitigations table provides the redefined effects magnitudes for the new division of mitigations into M1(A, B, C) and M2.

5. Annex E updates

The main changes in Annex E are:

- Annex E used to have several redundant numbers (like OSO#08, #11, #14 and #21) which was an artifact from earlier versions of SORA when the methodology was first discussed and linked to a bowtie risk model. As this has been confusing, the redundant OSO numbers have been removed. During external consultation Annex E was renumbered entirely by using roman numbers. As this posed a problem with supplemental guidance documents and some industry standards, this idea was discarded.
- OSO #01 now clarifies when to employ an ICAO compliant Safety Management System.
- OSO #04 clarifies that the design standards referenced are Airworthiness Design Standards (e.g. EASA SC-Light-UAS, STANAG 4703, CS-LUAS, CS-23) that deal with the entire design; OSO#04 gives additional guidance on how to separate requirements from the ADS from technical design requirements covered by other OSOs.
- OSO #05 provides additional guidance and incorporates former OSO#10/#12.
- OSO #07 has been renamed to “Conformity check of the UAS configuration” in order to remove the ambiguity on the intent. New guidance clarifies that t pre-flight inspections are not covered by OSO #07.
- OSO #8 has a new criterion related to the ERP that was transferred from the Main Body (refer to discussion on Step 3 of the main body); it clarifies as well that the operator should develop procedures to protect involved persons.
- OSO #09 no longer requests operation specific training to be “competency-based”.
- OSO #10 was merged with OSO #05. This was possible by the probability to have a catastrophic event for SAIL I to OV operations are very low and no single failure criterion are either already covered in OSO #05 or in Annex B mitigations M2.
- OSO #16 now explicitly requires proper phraseology as part of the crew coordination procedures.

- OSO #19 procedures and training criteria have been removed, as this is now covered by OSO #08 and OSO#09 respectively.
- OSO #20 has new integrity requirements for SAIL VI.
- OSO #23 procedures and training criteria have been removed, as this is covered by OSO #08 and OSO#09 respectively.
- OSO #24 now adds a reference to the manufacturer supported flight manual, which needs to lay out the aircraft environmental limitations.
- The possibility to use a functional test-based method to qualify the UA or procedures was added to Annex E with a new section 5 explaining the concept.
- The containment requirements have been moved from the main body (SORA 2.0) to a new section 8 of Annex E. It is now consistent in form with other Annex E requirements and now features clear levels of assurance (which were missing in SORA 2.0).

6. Cyber Safety Extension to Annexes B&E

- The Cyber Annex to SORA 2.0 Annex E with recommendation for adjusting the OSO with cyber safety related elements has been updated, to reflect the structural changes in SORA 2.5.
- There are no content changes to the Cyber Annex V2.5 compared to 2.0. The Cyber Annex will be updated as part of the SORA 2.5 package. It has been renamed to “Cyber Safety Extension to Annexes B&E”.

7. Annex F introduction

Annex F details the ground risk model used to define the ground risk classes and the reduction provided by the ground risk mitigations. It is JARUS WG SRM intention to update in the final version of SORA 2.5 all references to Annex F listed in the SORA main body or its annexes with a precise indication of the paragraph of Annex F where the information can be found.

Annex F provides the principles, calculations, and assumptions used in the SORA ground assessment process (i.e., SORA Steps #2 and #3). The high-level goal for this annex is to ensure that for most cases, there is a path to operational approval when ground risk is conservatively mitigated to an acceptable level of safety, commensurate with manned aviation. This intent is achieved by providing:

- Quantitative traceability between the SORA Specific Assurance and Integrity Levels (SAIL) embedded within the Operational Safety Objectives (OSO) and how the technical characteristics of a platform and its intended operation use subsequently affect the associated risk of a ground collision.
- A mechanism to establish whether the actual risk of the operation is aligned with the nominal iGRC classification (Step #2 of SORA) by providing a detailed analytical basis.
- A quantitative framework that outlines the effect of population, platform characteristics, and mitigations (Step #3 of SORA) on ground risk.
- A list of assumptions used in the above calculations. For circumstances where those assumptions are not applicable to a particular system or operation, a process is detailed (including equations), by which an applicant or authority can manually calculate the expected ground risk class.

8. Annex I updates

Annex I has been updated to include a list of abbreviations and to revise or add the definitions of terms used in SORA. The most important update is the introduction of the definitions of:

- UAS maximum dimension used to identify the ground risk class;

- multiple simultaneous operations, to cover both the cases of swarm operating relative to each other's (e.g. light shows) and those independent of each other;
- flyaway, in relation to loss of containment;
- UAS component design and production organisation vs UAS component installer;
- UAS operation to clarify the difference with UAS flight.

9. Future steps

SORA 2.5 remaining item:

Annex H – Considerations for UAS Service Providers will be published in a few months and will be fully compatible with SORA 2.5.

Future versions of SORA may deal with the following issues:

- Introduction of Annex G Air Risk Model
- Introduction of Annex J “Guidance to Aviation Authorities”
- Rework Annexes C “Strategic Air Risk Mitigations” and Annex D “Tactical Air Risk Mitigations” to reflect the better documented risk model of Annex G, focussing on better usability.
- Introduce updates to the Main Body to help assess modern use cases, e.g. use of several drones with a single control station, etc.
- Update Annexes B & E with references to applicable standards as it is expected that new applicable standards to SORA requirements will most likely emerge.

Appendix A Rationale for the updated containment requirements in SORA 2.5

A.1.1 Introduction to the Appendix

This document is an explanatory note for major changes in the operational containment rules of SORA. It provides the reasoning behind the proposed methods of assessing adjacent airspace. This work was made by several aviation authority experts from around the world and presents the best arguments found for choosing the values and methods used in the changes made to Step #8 (former Step #9 in SORA 2.0) of the main body.

These explanatory parts that will not be used by applicants routinely, will be added to the ground and air risk annexes of the SORA at a later stage:

With SORA 2.5 there are three options for containment, that most likely will have the following likelihood of being required:

i. **low robustness containment**, very common, most operations will require this (in SORA 2.0 this was corresponding to 'basic containment' and it was mandatory for all operations), in densely populated parts of the world like East Asian or European countries, it can be expected that due to airspace and population distribution this will be the required minimum.

ii. **medium robustness containment**, common in large cities and close to gatherings of people. This is a new intermediate robustness level that sits between the mandatory basic containment and the enhanced containment of SORA 2.0

iii. **high robustness containment**, only needed in rare case for SAIL I & II. In SORA 2.0 this was called enhanced containment.

Low and high robustness containment are based on SORA 2.0 and are largely backwards and forwards compatible. More clarity on the need to end the flight has been added.

Medium robustness containment is an easier to handle mix of the basic and enhanced performance requirements. It will cover most cases that used to require Enhanced Containment in SORA 2.0.

SORA 2.5 introduces considerable change to the containment logic. Two of the main changes are:

i. Remodelling the adjacent area ground risk triggers for containment, leading to a more risk proportionate approach.

ii. Removing the considerations for adjacent airspace, as the driving factor for containment is primarily ground risk.

iii. The underlying assumptions for containment that explain the changes in the first bullet above are now being published as part of Annex F (Ground Risk Model, section 5).

iv. The rationale for removing the need for a separate airspace containment provision will be added to future Annex G (Air Risk Model). However, since this Annex is still under development and this information is considered to be helpful to the drone community, this Appendix will be used for dissemination in the meantime.

The changes to the ground risk as well as air risk containment assumption were also part of the Explanatory Note to the external consultation version of SORA 2.5 and have been publicly consulted.

A.1.2 Adjacent Airspace Air Risk

A.1.2.1 Adjacent Airspace Containment Requirements Background

The workgroup initially evaluated proximity to aerodromes as a potential triggering condition for increasingly robust containment requirements. Such an approach is logical in the context of systems such as the Low-Altitude Authorization Notification Capability (LAANC) in the United States, which permits UAS operations in close proximity to airports. However, aerodrome layout, traffic patterns and the paths of charted arrival and departure procedures – among other factors – heavily influence the concentration of crewed aircraft in the vicinity of aerodromes, which makes it difficult to determine a generalizable and easy-to-use set of rules for containment near airports.

To assess the adjacent airspace containment requirements, the workgroup evaluated several worst-case flyaway scenarios. The scenarios were selected based on the availability of traffic count and/or historical surveillance data, as well as the complexity of the aerodrome layout and airspace. The workgroup then considered more general flyaway scenarios involving mixed air risk profiles and consideration of multiple flyaway paths and their likelihood. Details of these evaluations are presented in the following sections (A.1.2.3 and A.1.2.4).

In stress-testing the containment formula(s) that underpin the requirements, the workgroup determined that low-robustness containment, which is the minimum requirement for any adjacent ground risk area, also satisfies every worst-case airspace flyaway scenario at both TLOS values established in SORA (10^{-7} and 10^{-9}) – even for on-field operations where a flyaway could result in crossing several other runways. While these findings seem initially counterintuitive, the exposure time in which a UAS would be transiting across another active runway is only a few seconds. This, along with several other factors described in the following sections, substantially reduces the probability of midair collision in the event of a flyaway.

Ultimately, there is no need to identify a higher containment requirement for certain airspace or aerodrome situations so there is thus no need to calculate and apply an adjacent airspace definition to the containment requirements. Put simply, low-robustness containment provides a sufficient safety margin for adjacent airspace collision risk, regardless of SAIL level or proximity to an airport.

A.1.2.2 Adjacent Airspace Containment Requirements Assessment

Loss of containment into adjacent airspace *in some cases* increases the likelihood of encounter, near midair collision (NMAC, as commonly defined, when two aircraft are within 500 feet laterally and +/- 100 feet vertically) or midair collision (MAC) with manned aircraft. It is improbable that flight into adjacent airspace would *guarantee* a MAC with manned aircraft. As such, the following general assumptions and analytical framework regarding loss of containment events is applied for assessment purposes.

General Assumptions:

(a) A fly-away scenario occurs when the UAS leaves the operational volume and the mechanism to end the flight malfunctions such that the UAS continues its flight without the ability for the operator to intervene or regain control. It is assumed using low robustness containment:

- There is a 10^{-3} chance (0.1%) that the aircraft leaves the operational volume (Pc = 0.001).
- There is a 10^{-1} chance (10%) the flight termination system fails (Pe = 0.1).
- There is a $10^{-1} \times 10^{-3} = 10^{-4}$ likelihood or rate of prolonged, continued flight into the adjacent airspace (Pec = 0.0001). This is equal to the likelihood of exiting the ground risk buffer.
- These assumptions pertain to SAIL I and II. Higher SAIL's have lower Pc values (see Annex F, 5.2.5). This contstitues a worst case scenario with respect to adjacent air risk analysis.

(b) A fly-away scenario can originate from any location on the operational volume perimeter and the fly-away path can adopt any heading from that location such that the UAS does not re-enter the operational volume. It is assumed that a fly-away trajectory:

i. Follows a linear (fixed heading) flat (fixed altitude) path from the operational volume perimeter if flight termination does not occur. Eventually the UAS adopts a downward profile (due energy/fuel limits), resulting in a level then downward sloping trajectory.

ii. Follows a linear (fixed heading) diagonal (downward) path from the operational volume perimeter if flight termination occurs. Immediately, the UAS adopts a downward profile resulting in a downward sloping trajectory (e.g. ground impact occurs within 1 minute for flights below 500 feet AGL).

For assumed paths (i) or (ii) above, there will be limited exposure time to any single region or specific location within the adjacent airspace (i.e. no loitering is assumed). There will be greater airspace exposure for assumed path (i) compared to (ii) (see Remark 1).

(c) The adjacent airspace size is equivalent to the adjacent ground risk size (see Annex F, 5.1). This means that adjacent airspace can extend up to 35km from the operational volume.

(d) Strategic and tactical air risk mitigations are not applicable in the adjacent area (see Remark 2). Containment measures help to reduce the amount of adjacent airspace traversed, but they do not change the air risk in the adjacent airspace (i.e. they are not intended to mitigate air risk as calculated in Step 4).

(e) The charted boundaries of controlled airspace are assumed to include a nominal buffer to protect against blunders of any aircraft (not just UA) into that airspace. Therefore, a SORA-defined air risk buffer would be redundant and thus no air risk buffer is required. This is true regardless of the ARC class for the operational volume (Remark 3).

Remark 1: Flight termination is assumed to occur immediately after existing the operational volume (containment breach) so it is expected in all cases the UAS quickly adopts a downward sloping path. This slant distance will have a lateral projection smaller than a purely lateral escape. This means a lateral containment analysis will assess more airspace and therefore address diagonal (downward) airspace containment scenarios given typical airspace class (ARC) structures.

Consideration of direct vertical accents paths were not considered. The assumption is that such paths would be no worse than paths crossing (multiple) active runways. See case studies 1 and 2.

Remark 2: Communication procedures and conspicuity have an impact on collision risk. If the drone is detectable and/or the operation is coordinated, then even in a flyaway scenario this aids pilot and ATC intervention. No credit for such intervention(s) is assumed and thus risk estimates are conservative.

Remark 3: The pairing of operational and adjacent airspace does not matter. In ARC-d operational airspace, the residual risk is addressed through strategic and tactical mitigations which are assumed to have failed in a fly-away situation. The flyaway risk from ARC-d (operational) is therefore the same as if the drone had a flyaway from ARC-a (operational) to ARC-d (adjacent).

General Framework:

The mathematical framework to assess adjacent airspace risk is consistent with the basic framework that was used for Annex C (SORA 2.5) and expected updates (SORA 3.0). Assumed values for specific elements are consistent with assumptions that were used for Annex C (SORA 2.5).

Consider the following expression linking adjacent airspace risk to the target level of safety (TLOS) such that

$$TLOS = p(F|MAC) \cdot p(MAC|NMAC) \cdot p(\mathrm{NMAC}|\mathrm{WCV}) \cdot \mathrm{p(ARC)} \cdot \mathrm{ARC} \cdot T_{Exposure} \cdot \lambda_f \qquad (1)$$

where:

- $\boldsymbol{\lambda_f}$ is the prolonged fly-aways per flight hour into the adjacent airspace. It is the product of the failure rate (or probability) and containment system failure probability (or rate). For low robustness containment $\boldsymbol{\lambda_f = 10^{-1} \times 10^{-3} = 10^{-4}}$.
- **T$_{\text{Exposure}}$** is the exposure time in hours for each flight path or airspace region crossed.
- **ARC** is airspace density measured as the well-clear violations per flight hour (WCV/FLH) where the well-clear volume is a cylinder centered on each aircraft with radius of 2000 feet and height +/- 250 feet. The ARC values are based on the worst cases identified during airspace classification studies as follows:

ARC-a: 10^{-4}	ARC-b: 10^{-2}	ARC-c: 1	ARC-d: 10

(b) Reference: "Likelihood of Unmitigated Collision Risks for Uas in Defined Airspace Volumes, 2020"

- **p(ARC)** is the probability of being in the adjacent airspace defined by ARC (see above). This depends on the assumed or allowed flyaway paths.
- **p(NMAC|WCV)** is the conditional probability of near midair collision (NMAC) given a well-clear violation, and is assumed to be 0.1. Reference: "Well-clear recommendation for small unmanned aircraft systems based on unmitigated collision risk", Journal of Air Transportation, 2018" and "Correlated Encounter Model for Cooperative Aircraft in the National Airspace System" MIT, 2008
- **p(MAC|NMAC)** is the conditional probability of midair collision given an NMAC, and is assumed to be 0.01 (for UAS <= 3m size). Reference: "On Estimating Mid-Air Collision Risk", AIAA, 2010"
- **p(F|MAC)** is the conditional probability of fatality given a MAC, and is assumed to be 0.1. Reference: "Airborne Collision Severity Evaluation", ASSURE, 2022"
- **TLOS** is the adjacent airspace TLOS measures as MAC per flight hour. It is 10^{-7} in ARC-a, ARC-b and ARC-c airspace, and 10^{-9} in ARC-d airspace.

Remark 4: Competent Authorities and Operators should note that this containment analysis is only applicable for single operations. In complex airspace with recurring and/or multiple simultaneous UA operations UA operations, additional analysis should be conducted to ensure that the aggregate or cumulative rate of expected flyaway events does not result in a TLOS that is higher (less conservative) than assumed for the ARC.

For example, analysis of a single operation may result in a risk level that is 10^{-10} MAC per flight hour. This would mean one such operation could be allowed with an additional order of magnitude safety factor or ten (10) such operations would be permissible before the TLOS is exceeded. Competent Authorities have the flexibility to stipulate such preferences.

A.1.2.3 Airspace Containment Scenarios – Worst Case

A variety (three) worst-case scenarios were considered to test whether containment requirements more stringent than low robustness containment would ever be required. These cases concern operations directly in or very near aerodromes. **Additional assumptions** on UAS behaviour for loss of containment scenarios are stated in each case.

Case 1

An extreme scenario considering **aerodrome traffic** occurs for an operation in **Atlanta airport (KATL),** which is intended to be confined to the northern-most 08L/26R runway (see Fig. 1, small green box). The next closest runway is 08R/26L at 850' between edge strips. Another pair of runways are located adjacent to the ramp area followed by a single runway located further south. The greatest risk occurs with a loss of containment that proceeds from the northern 08L/26R runway south/south-east and crossing 4 parallel runways (yellow arrows).

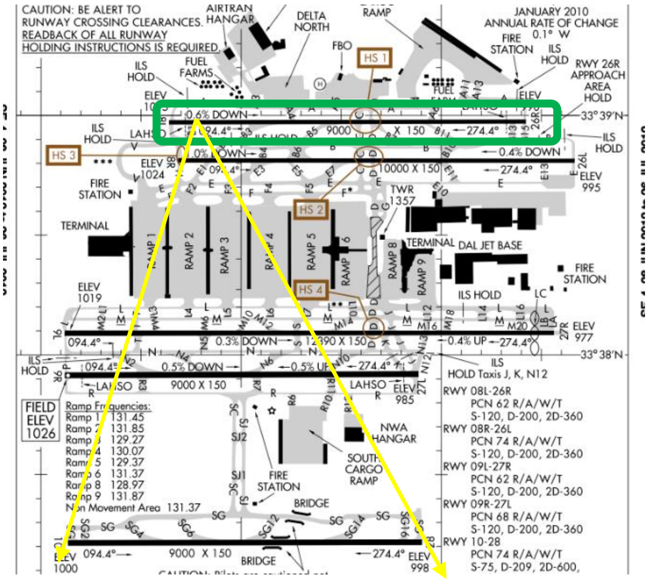

Fig. 1 Atlanta airport adjacent airspace containment example for on-field operations (green box) with potential flyaway crossing multiple runways (yellow arrow region)

Using the following assumptions:

(a) Low robustness containment is applied since the operation is in, and adjacent to, ARC-d airspace ($\lambda_f = 10^{-4}$).

(b) In the event of a loss of containment, there is a 24% chance (**p(ARC)** = 0.24) that the UAS flies in the direction of an intersecting flight path of the next closest runway. This value (i.e. angle) decreases for airports with multiple runways (e.g. the clockwise from south-east to south, yellow arrows)

(c) The loss of containment trajectory is linear, and the UAS crosses four flight paths, for a total exposure time of 16 (15.8) seconds ($\mathbf{T_{Exposure}}$ = 4 x 0.0011 = 0.0044 hours) assuming a **200 ft crossing path** (of the runway) at 30kts.

(d) **ARC** value = 10.

(e) **p(NMAC|WCV)** = 0.1.

(f) **p(MAC|NMAC)** = 0.01.

(g) **p(F|MAC)** = 0.5.

(h) Therefore, probability of fatality according to (1) is (0.5)(0.01)(0.1)(0.24)(10)(0.0011)(10^{-4}) = $\mathbf{1.32 \times 10^{-10}}$ for a single runway crossing and (0.5)(0.01)(0.1)(0.24)(10)(0.0044)(10^{-4}) = $\mathbf{5.28 \times 10^{-10}}$ for four runway crossings. The risk for 1 - 4 runway crossings is between these values compared with the TLOS = 10^{-9} for the airspace. Noting (b) above, these estimates are thus conservative.

Result: A **low robustness** containment is shown to achieve the required TLS for mid-air collisions (MAC) even operating in extremely dense airspace within aerodrome environments.

Case 2

An extreme scenario considering **aerodrome** and **general aviation traffic** occurs for an operation north of the **Las Vegas airport (KLAS)** which is intended to be confined to a small region (see Fig. 2, small red circle). The large red circle shows an approximately 5km adjacent airspace region. The heatmap background shows annual flight tracks from official FAA surveillance systems between SFC and 1000 feet AGL. Traffic within this Class B surface area is highly proceduralised and concentrated in specific locations: arrivals to runways 19R/19L, departures from runways 1R/1L, a helipad (red dot near center) and a defined VFR helicopter tour route above the Las Vegas Strip (diagonal and slightly curved paths from left edge to top-center). The greatest risk occurs with a loss of containment that proceeds from the operational area in any direction towards the airport landing paths from southeast, clockwise to southwest (yellow arrows). This case can be seen in other major aerodromes such as **San Francisco (KSFO).**

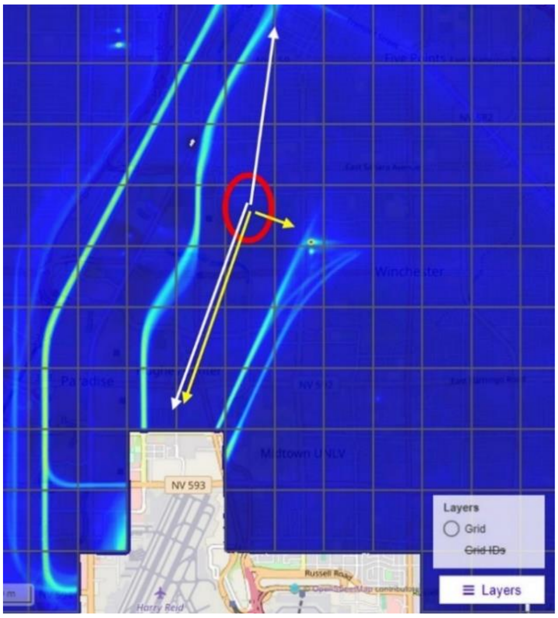

Fig. 2 Las Vegas airport adjacent airspace containment example for near field operations (red circle) with potential flyaway path toward parallel runways (yellow arrow region) or nearby helicopter routes (white arrow region).

Using the following assumptions:

(a) Low robustness containment is applied since the operation is in, and adjacent to, ARC-d airspace ($\lambda_f = 10^{-4}$)

(b) In the event of a loss of containment, there is a 25% chance (**p(ARC)** = 0.25) that the UAS flies in the direction of an intersecting flight path (clockwise from southeast to southwest, yellow arrows) and a 48% chance (**p(ARC)** = 0.48) of flying towards the helicopter routes (white arrows).

(c) The loss of containment trajectory is linear, and the UAS crosses two flight paths, for a total exposure time of 40 (39.5) seconds ($\mathbf{T}_{\mathbf{Exposure}} =$ 0.011 hours) assuming a **1000 ft crossing path** (of the runway) at 30kts.

(d) **ARC** for airport =10 and **ARC** for helicopter routes = 1.

(e) **p(NMAC|WVC)** = 0.1.

(f) **p(MAC|NMAC)** = 0.01.

(g) **p(F|MAC)** = 0.1.

(h) Therefore, probability of fatality according to (1) is (0.1)(0.01)(0.1)(0.25)(10)(0.011)(10^{-4}) = $\mathbf{2.75 \times 10^{-10}}$ for CAT traffic, compared with the TLOS for the airspace of 10^{-9} and (0.1)(0.01)(0.1)(0.48)(1)(0.011)(10^{-4}) = $\mathbf{5.28 \times 10^{-11}}$ for GA traffic, compared with the TLOS = 10^{-9} for the airspace. The combined risk is the sum of these risk elements (as only one can occur) resulting in $\mathbf{3.28 \times 10^{-10}}$.

Result: A **low robustness** containment is shown to achieve the required TLS for mid-air collisions (MAC) even in proximity to extremely dense airspace with mixed traffic types.

Remark 5: If the ARC values increase (up to appx. 40) to account for even busier aerodromes (i.e. more movement per hour) then the resulting risk approaches the TLOS of 10^{-9}. Increasing the ARC too much does not make sense as this implies unrealistic number of approach/departures for a single runway given wake and separation considerations (e.g. ARC = 100 implies a landing every 36 seconds).

Remark 6: The assumed values for p(F|MAC), p(MAC|NMAC), and p(NMAC|WVC) may change in specific instances, but should each be evaluated logically. For example, some drones will have a demonstrable p(F|MAC) that is larger than the assumed value of 0.1 stated above, but the operation may also have reduced p(MAC|NMAC) and/or p(NMAC|WCV). Additionally, the assumptions above assume a simultaneous vertical and horizontal overlap between the UAS and the crewed aircraft. In nearly all circumstances, a flyaway drone may pass above or below a crewed aircraft; or to one side of a crewed aircraft, thereby further reducing collision risk. Operators and competent authorities are encouraged to revise and validate their assumptions when conducting this analysis.

A.1.2.4 Airspace Containment Scenarios – General

A variety (six) general scenarios were considered to test whether containment requirements more stringent than low robustness containment would ever be required. These cases concern operations away from, between, directly in or near multiple aerodrome. **Additional assumptions** on UAS behaviour in loss of containment scenarios include:

(a) Limited (but up to 360-degree) possibility of continued flight after leaving a cylindrical operational volume (fly-away) with probability of flying towards each adjacent airspace type dependant on the location of the flyaway on the operational boundary perimeter. The flyaway may occur at any point on the operational boundary with equal probability. This results in many possible flyway locations and paths from each location (i.e. allowable directions) that therefore cross different adjacent airspace types.

(b) Each adjacent airspace location has an **ARC** value given by its specific well clear rate (WCV/FLH) calculated from advanced airspace characterisation studies (See Remark 3). The ARC values are therefore not as stated in the assumptions as above but unique to each location (i.e. ARC class not required).

(c) Each flyway path has an exposure time $\mathbf{T}_{\mathbf{Exposure}}$ made up from each segment of the path (i.e. $\boldsymbol{T}_{\boldsymbol{Exposure}}$ is the sum of segments $\boldsymbol{T}^{\boldsymbol{i,j,k}}_{\boldsymbol{Exposure}}$). Each $\boldsymbol{T}^{\boldsymbol{i,j,k}}_{\boldsymbol{Exposure}}$ depends on the flyaway velocity, path direction (and thus intersection of the adjacent airspace regions) and maximum flyway distance which is limited to 25 nm (assuming a 1000 foot altitude at max. 30kts for duration < 20 minutes)

(d) The robustness containment level/value is not assumed but back derived given TLOS values (10^{-7} and 10^{-9}).

These assumptions mean that the **mathematical framework** (1) requires the following additions:

$$TLOS = p(F|MAC)\ \cdot p(MAC|NMAC) \cdot \left(\frac{1}{K}\sum_{k=1}^{K}\frac{1}{J_k}\sum_{j=1}^{J_k}\sum_{i=1}^{N_{k,j}}\ p(NMAC|WCV)^{i,j,k}\cdot \mathrm{ARC}^{i,j,k}\cdot T^{i,j,k}_{Exposure}\right)\cdot \lambda_f \tag{2}$$

Where the term in brackets essentially accounts for the exposure to each risk profile in all possible adjacent airspace regions such that K is the number of flyaway locations (on operational volume perimeter), J_k is the allowable flyaway directions from location k and $N_{k,j}$ is the number of path segments (or different adjacent airspace risk values/types) on the j^{th} path originating at the k^{th} location. Note, the internal sum over J_k approximates **p(ARC)** for each ARC from each location on the operational volume perimeter.

Remark 7: Full details of the analysis will be available in the paper A. McFadyen et al "Adjacent Airspace Risk and Containment Requirement Estimation for Uncrewed Operations," (ICUAS'24, Public Release: June 2024).

Cases 4 - 10

The more general scenarios consider (six) operations within mixed airspace including aerodromes (major and training), general aviation and commercial operations. Each operation is defined by a cylindrical operational volume (diameter 500 m) of height 1000’ AMSL located within the greater Brisbane region. The region includes a major international airport (YBBN), major domestic airport (YBSU), training aerodrome and traffic (YRED, YCAB, YCDR, YBAF) and areas and spans multiple urban, semi-urban and rural areas. The region is largely flat (near coastline) with some low mountains/hills west and north between YBBN and YBSU. Each operation is located very near different aerodromes, between aerodromes and far from aerodromes (relatively). The region and operation locations are shown in Fig. 3 (left).

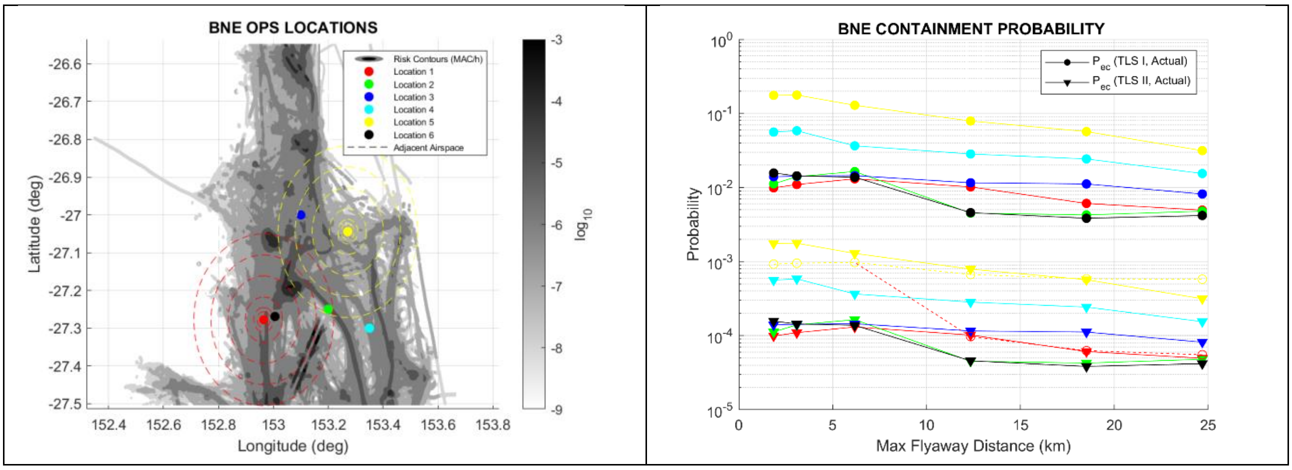

*Fig. 3 **Left**: Operational locations and example maximum flyaway distances (dashed circles) overlaid on airspace characterisation results (greyscale). The airspace characterisation shows the MAC rate (λ^k_{MAC}) for each airspace in orders of magnitude using ADS-B data (only) for a busy 3 month period at 1000’ AMSL. **Right:** Resulting containment requirement for each ops. location w.r.t maximum flyaway distance and TLOS requirements of TLS I = 10^{-7} (□) and TLS II = 10^{-9} (q).*

Quantitative, data-driven methods are used to estimate unmitigated air risk at any location. The approach calculates the conditional likelihoods and rates associated with the causal events leading to a collision and then produces risk maps for these risk elements (e.g MAC rate, WCV rate etc.). The p(NMAC|WCV) and ARC are computed (as well as MAC rate and more) considering uncertainty on the data and UAS locations (resulting in 0.5nm lateral and 100’ vertical variances) which embeds realistic conservatism. The analysis does not use grid cells and instead assesses thousands of locations with appropriate consideration of the well clear dimensions expected in that airspace (i.e. traffic type). The result is high resolution numerical air risk profiles for a region (see **Fehler! Verweisquelle konnte nicht gefunden werden.**Fig. 3 - left).

Using the risk analysis for the p(NMAC|WCV) and ARC values in (2), the resulting containment requirements w.r.t flyaway distance for each operational location can be found (see Fig. 3 - right).

For comparison to the previous cases the following assumptions are used:

(a) No containment is applied (this is calculated for each operation, flyaway distance and TLOS).

(b) Total exposure time $\mathbf{T_{Exposure}}$ = 20 mins (velocity variable) with individual exposure times for each airspace $T^{i,j,k}_{Exposure}$ summing to $\mathbf{T_{Exposure}}$)

(c) **ARC** = Variable (airspace dependent, ranging from 10^{-5} to 10^{0} order of magnitude).

(d) **p(NMAC|WVC)** = Variable (airspace dependent, ranging from 10^{-3} to 10^{-1} order of magnitude).

(e) **p(MAC|NMAC)** = 0.01.

(f) **p(F|MAC) = 1**.

(g) **TLOS** = 10^{-7} or 10^{-9} (both TLOS investigated given mixed airspace types)

Result: A **low robustness** containment is shown to achieve the required TLS for mid-air collisions (MAC) in mixed airspace that includes dense airspace with mixed traffic types and airspace environments. This considers the likelihood of each possible flyaway location and paths from each location given it is not guaranteed that the worst-case path results from a flyaway event.

Remark 8: There are cases where the adjacent airspace could include the runways from a major aerodrome and the circuit pattern from a training aerodrome. There is evidence that the worst case in such a scenario can be flying toward the circuit pattern if this is a heavy use training aerodrome and the UAS operates at or near circuit altitude (see red and black operation location in figure 3).

Remark 9: There is evidence to suggest that regardless of flyaway distance (up to 25km) the containment requirement never reaches 1 x 10^{-5} and is typically between 5 x 10^{-5} and 5 x 10^{-4} (and thus an average of 10^{-4}). Before appx. 6km the containment requirement is equal to or greater than 10^{-4} (aligning to assumptions on flyaway minimums). After appx. 12km there is limited variation in containment requirement (less than half associated order of magnitude) due to exposure to diverse airspace risk. Note, in all cases the P(F|MAC) = 1 is assumed and thus conservative for many operations.

Note, a comprehensive analysis of all possible flyaways from all locations worldwide is not possible. These results provide reasonable evidence of containment requirements due the diversity of airspace operations assessed.

A.1.2.5 Airspace Containment Conclusion

This explanatory note has considered single UAS operations in different environments. Based on the results, it was determined that **low robustness containment** provides a sufficient degree of protection (See Annex F 5.2.5) for all SAIL in all fly-away events, regardless of complexity of the airspace or proximity of the UA to dense airspace regions including aerodromes. Therefore, there is no need for Medium or High containment solely because of adjacent airspace; such a requirement would be driven by adjacent ground area (see Remark).