Civil Aviation Authority Norway
Section for Unmanned Aviation

CAA Norway AltMoC

Alternative **M**eans **o**f **C**ompliance

AltMoC to AMC1 Article 11, Step 9 section 2.5.3

AltMoC to SORA 2.0 Containment requirements

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Applies to	UAS Operators in Specific category within Norway
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Date	Issue	Revision	Highlight of Revision	Prepared by	Released by
07.12.2023	1	0	First Issue	Karine Borgerud	CAA Norway
26.03.2024	1	1	Minor correction on new triggers for enhanced containment	Karine Borgerud	CAA Norway

Table of Contents (ToC)

0 Introduction

This Alternative Means of Compliance (AltMoC) is intended to change the containment requirements and the assessment currently found in chapter 2.5.3 Step 9 of AMC1 to Article 11 of (EU) 2019/947 or the JARUS SORA v2.0 methodology.

Currently all UAS used in the specific category must adhere to the points 2.5.3(a)&(b) of the requirements. This is seen as proportional by CAA Norway and only a small addition included in the AltMoC for better clarity. On the other hand, point 2.5.3(c) requires enhanced containment performance when certain conditions are met. However, by the latest understanding of CAA Norway, enhanced containment is triggered in some situations where the actual risk of the operation does not justify its applicability and the containment requirements of points (a)&(b) would be sufficient.

This Alternative Means of Compliance (AltMoC) focuses on changing the assessment triggers in point 2.5.3(c) which mandate enhanced containment from certain UAS operators. No change in the technical implementation requirements of the containment systems is proposed.

The purpose of having containment requirements at all is that the rest of the SORA risk assessment focuses on the operational area, which could be thought of as the most likely area at risk. To ensure that SORA does not leave out any significant risks unassessed, certain questions should be considered, such as:

- What if the aircraft leaves this assessed operational area?
- Are there areas of credible significant risk in proximity to the operational area?

0.1 Terms and Conditions

The use of the male **gender** should be understood to include male and female persons.

The most frequent **abbreviations** used by the **EASA** are listed here: easa.europa.eu/abbreviations.

When used throughout the AltMoC the terms such as «shall, must, will, may, should, could, etc.» shall have the meaning as defined in the English Style Guide of the European Commission.

0.2 Legal References

Commission Regulation (EU) No 947/2019:

- Article 11
- AMC1 Article 11

1 Proposed Target Level of Safety TLS for the AltMoC

The general qualitative target level of safety (TLS) in Article 11(3) of (EU) 2019/947 is set to be equivalent to that of manned aviation.

“The assessment shall propose a target level of safety, which shall be equivalent to the safety level in manned aviation, in view of the specific characteristics of UAS operation.”

Keeping in mind the goal of achieving this equivalency, the considered TLS for ground and air risk are further detailed in the following sections.

1.1 Ground risk TLS

For risks to third parties on the ground the equivalent risk is assessed in JARUS AMC RPAS.1309 issue 2 as 1.0 * 10^{-6} deaths / flight hour for manned aviation.

1.2 Air risk TLS

The TLS per UAS flight hour for air risk in this AltMoC is 1.0 * 10^{-7} Mid Air Collisions (MAC) with General Aviation (GA) aircraft per flight hour and 1.0 * 10^{-9} MAC with Commercial Air Transport (CAT) aircraft per flight hour. These values are commonly accepted as TLS *Lin, Xun & Fulton, Neale & Westcott, Mark. (2009). Target Level of Safety Measures in Air Transportation – Review, Validation and Recommendations*. With conservative assumptions of every collision being catastrophic and 500 passengers for each CAT aircraft and 5 passengers for each GA aircraft the fatalities per UAS flight hour would be:

$$500\,passengers * 10^{-9}\,{}^{MAC}/_{FLH} = 5 * 10^{-7}\,{}^{Dead}/_{FLH}$$

$$5\,passengers * 10^{-7}\,{}^{MAC}/_{FLH} = 5 * 10^{-7}\,{}^{Dead}/_{FLH}$$

Measured in deaths per UAS flight hour, the targets are the same for both encounter types, less than the ground risk TLS and equal to the safety level in manned aviation.

2 Understanding of unmanned aircraft fly-away probability

For an unmanned aircraft to fly-away out of the assessed operational area the following sequence of events must happen:

1. The control of the operation/drone is lost. The probability of this happening is directly linked by definition to the SAIL[1] of an operation. For example, a SAIL II operation is assumed to lose control less than once in a hundred flight hours. (Probability of loss of control of an operation rate equals 10^{-SAIL});

SAIL	I	II	III	IV	V	VI
Probability of loss of control per flight hour	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}

2. The loss of control does not lead to a crash inside the operational volume or ground risk buffer;
3. The containment mitigations applied to the operation fail, including the basic containment, since it is applicable to all UAS subject to a SORA;
4. The aircraft flies outside of the ground risk buffer.

The number of different failures or combinations of failures that could lead to this chain of events and a fly-away can be estimated. UAS are complex systems that can have many different types of failures, but some generalizations can be made to assess what failures may lead to a fly-away.

2.1 Potential failure types that could lead to a fly-away:

	Failure type	Potential failure effect
1.	**GPS failure**	total loss, inaccuracy.
2.	**Internal Navigation System**	total loss, inaccuracy, drifting.
3.	**Flight Control**	last input stays, full power, power off, control surface actuation, etc.
4.	**Pilot error**	incorrect input, incorrect navigation, flight planning failure
5.	**Environment** (Wind, Electromagnetic interference, Temperature)	drifting out of area, battery drained early
6.	**Data Link**	fly straight, hover, return to home, gain altitude
7.	**Other potential failure**	

These failure types need to be mitigated by containment requirements.

The assumption taken is that there could be up to 10 different failure types in an unmanned aircraft operation that can lead to a fly-away either individually or in combination.

This AltMoC proposes no changes in the technical implementation requirements of the containment systems, but addresses only the trigger criteria. The following presents an analysis of the estimated containment performance to determine whether the current targets are adequate and proportional to the overall risk to the system.

[1] Specific Assurance and Integrity Level SAIL models the reliability of an unmanned aircraft operation and the assumed total loss of control rate for the operation

2.2 “Basic containment” - SORA 2.5.3(b)

> *“**No probable failure** of the UAS or any external system supporting the operation shall lead to operation outside of the **operational volume**.”*

Basic containment is required for all UAS operations in the specific category and sets the minimum level of containment performance. This requirement sets a total allowed probability of single failures that may lead to a fly-away. Single failures leading to fly-away are still allowed to occur, but their probability should be “no probable”, meaning **Remote**[2].

- “Probable” failure means occurrence every 10^{-3} / flight hours
- “Remote” failure means occurrence every 10^{-4} / flight hours

In combination with the assumption of up to 10 potential **Remote** failure conditions in UAS operation that can lead to a fly-away, the basic containment requirement would set a fly-away rate outside of the operational volume of less than 10^{-3} / flight hour. However, every operation is planned with a ground risk buffer that is meant to capture the most likely crash area of an operation in a loss of control event. The ground risk buffer can be estimated to contain 90% of all loss of control situations and subsequent crashes inside it due to gravity and the attempts of the remote pilot to end the flight.

Therefore, Basic containment is estimated to reach a containment performance of 10^{-4} /flight hour for fly-away events outside of the ground risk buffer.

2.2.1 “Enhanced containment” – SORA 2.5.3(c)

> ***“The probability of leaving the operational volume shall be less than 10-4/FH.***
>
> ***No single failure** of the UAS or any external system supporting the operation shall lead to operation outside of the **ground risk buffer**.*
>
> Software (SW) and Airborne Electronic Hardware (AEH) whose development error(s) could directly lead to operations outside of the ground risk buffer shall be developed to an industry standard or methodology recognized as adequate by the competent authority.”

Enhanced containment requirements require that two independent failures happening at the same time are only allowed to lead to a fly-away. The requirements are also setting a quantitative operational volume containment requirement. The fact that no single failure is allowed to lead to fly-away means that there should at least be an independent COTS level (10^{-2} failure rate) back-up system to end the flight within the ground risk buffer. In combination these two requirements are assumed to combine into a fly-away probability outside of the ground risk buffer of less than 10^{-6} /flight hour.

$$P_{\text{fly out from operational volume}} * P_{\text{fly out from ground risk buffer}} \Rightarrow 10^{-4} * 10^{-2} = 10^{-6}\text{/FLH probability of fly-away}$$

The point 2.5.3(c) also includes the triggers for applying Enhanced containment, which based on CAA Norway’s experience and analysis are not proportional to the actual risk posed by most UAS operations. This AltMoC changes these triggers, which are:

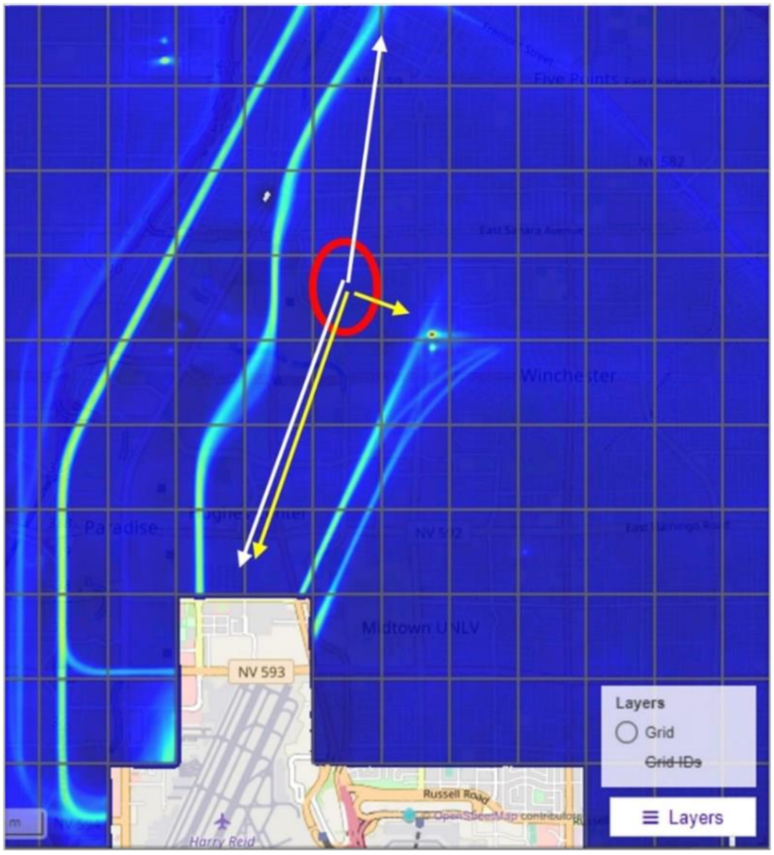
> *Where adjacent areas are:*
>
> *i. **Assemblies of people** unless already approved for operations over gathering of people OR*
> *ii. **ARC-d** unless the residual ARC is ARC-d*
>
> *Or operational volume is in **populated environments** where:*
>
> *i. **M1 mitigation** has been applied to lower the GRC*
> *ii. Operating in a **controlled ground area***

[2] Definitions from JARUS AMC RPAS.1309

3 Estimating outcomes of worst-case scenarios for fly-away events: Air risk

The JARUS group set to amend the current Step 9 has considered a variety of worst-case scenarios to test whether containment requirements more stringent than Basic Containment would ever be required. Two of them are described in this section.

Example 1



The most extreme scenario considers an operation north of the Las Vegas airport (LAS), which is intended to be confined to the small red circle. **LAS** had 543,391 yearly landings and departures on average between 2017-2019 according to "FAA Air Traffic by numbers 2022". This is on average 1489 landings and departures every day or roughly ~1.0 movement every minute. The heat map background shows annualized flight tracks from official FAA surveillance systems between the surface and 1000 feet AGL. Traffic within this Class B surface area is highly proceduralized 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 towards the airport CAT traffic. While the helicopter routes cover a larger sector next to the operation the TLS and density are not as high as for the CAT traffic.

Using the assumptions in the previous section:

- Basic containment is applied;
- In the event of a loss of containment, there is a 25% (sector 90°/360°) chance that the UAS flies in the direction of the airport and a 48% (sector 173°/360°) chance of flying towards the helicopter routes;
- Loss of containment is linear, and the UAS crosses two flight paths, for a total exposure time of 40 seconds (0.011 hours, assuming a 1000-foot distance across the landing path at 30kts);
- ARC-d value for Airport = 10 (WCV/FLH) (The ARC values are based on the worst cases seen during airspace classification studies "Likelihood of Unmitigated Collision risk for UAS in Defined Airspace Volumes, 2020");
- ARC-c value for Helicopter routes = 1;
- p(NMAC|WCV) = 0.1 (Well-clear recommendation for small unmanned aircraft systems based on unmitigated collision risk, Journal of Air Transportation, 2018);
- p(MAC|NMAC) =0.01 for UAS in 1m and 3m categories ("Correlated Encounter Model for Cooperative Aircraft in the National Airspace System, MIT, 2008").
- p(fatality/MAC) = 0.1 (Airborne Collision Severity Evaluation, ASSURE, 2022)

The probability of a lethal MAC is the product of the values of each of the above eight bullets, including the exposure time:

$(10^{-4})(0.25)(0.011)(10)(0.1)(0.01)(0.1) = \mathbf{2.75 \times 10^{-10}}$ for CAT traffic

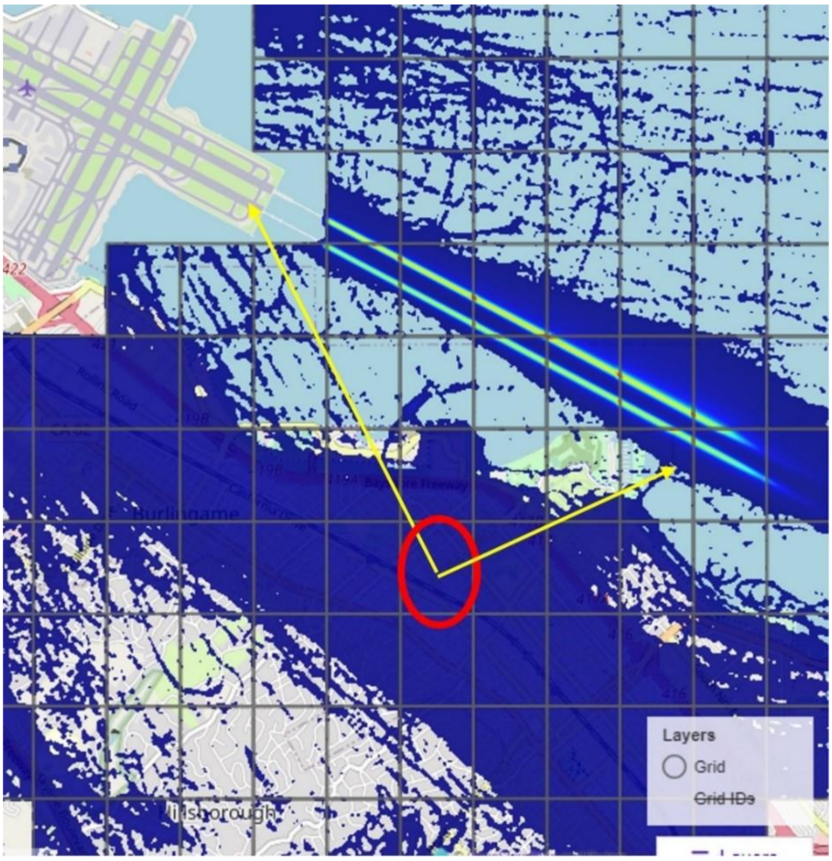
$(10^{-4})(0.48)(0.011)(1)(0.1)(0.01)(0.1) = \mathbf{5.28 \times 10^{-11}}$ for GA traffic

In conclusion, the basic containment is shown to achieve the required TLS for mid air collisions even in proximity to extremely dense airspace below 500 feet altitude.

Example 2

San Francisco airport (SFO) had 462,422 yearly landings and departures on average between 2017-2019. This is on average 1267 landings and departures every day or roughly ~0.88 movements every minute.

The preceding assumptions were also applied to the region SFO, depicted with a similar heat map at below right. In this scenario, the drone is again operating within the red circle, with a loss of containment from northwest clockwise to northeast (yellow arrows) presenting the greatest risk to the dual parallel final approaches.



Using the same assumptions:

- Basic containment is applied;
- In the event of a loss of containment, there is a 25% chance that the UAS flies in the direction of an intersecting flight path;
- Loss of containment is linear, and the UAS crosses two flight paths, for a total exposure time of 40 seconds (0.011 hours);
- ARC value =10;
- p(NMAC|WVC) = 0.1;
- p(MAC|NMAC) =0.01.
- p(fatality/MAC) = 0.1

In this case, the probability of a lethal MAC as the product of the values of each of the above six bullets, including the exposure time is: (10-4)(0.25)(1)(0.1)(0.01)(0.1)(0.011) = 2.75 x 10-10 for CAT traffic.

As in the previous example, the basic containment is proven to be enough to achieve the required TLS.

3.1 Comparison to situation in Norway

These extreme US airport examples show that the TLS order of magnitude is met with only the basic containment. The busiest airport in Norway is Oslo airport OSL with 204,138 flight movements in 2022, according to Avinor's traffic statistics. If we compare the years before the pandemic, OSL has an average of flight movements of 255,965 in the years 2017-2019. This is still half of the traffic of LAS and should achieve a similar, but slightly safer result.

Another way to calculate the risk would be to imagine 1000 drones circling around Oslo airport continuously with only Basic containment requirements implemented and calculating how long it would take until a MAC is expected to happen.

$$\frac{1}{2.75 * 10^{-9} \ * 1000 \text{ drones}} = 363{,}636\, hours = 41\, years$$

Therefore, it is concluded that Basic containment requirements are enough to guarantee the TLS for air risk, independent of the ARC of the adjacent airspace below 500 feet AGL. The limitation of this AltMoC to below 500 feet is due to the air risk analysis method not being suitable for the less structured airspace higher above.

3.1.1 Assessment of the UAS size in regard to operating in an airport environment

ASSURE (Alliance for System Safety of UAS through Research Excellence) published a paper on research on small Unmanned Aircraft Systems (sUAS) MAC likelihood analysis with General Aviation (GA) and Commercial aircraft. The study showed that the use of a smaller UAS can be considered a passive mitigation factor for both the probability and consequence. The unmitigated p(MAC|NMAC) is lowered by a factor of 2 from the smallest sUAS to the largest sUAS, assuming both aircraft have the same capabilities.

The UAS's used in this study varied from the smallest fitting in the 1m category, and the largest fitting in the 3m category. If we consider this in the risk assessment of an UAS operating in an airport environment, it is safe to assume that a UAS in the 1m category have a smaller MAC probability and consequence than a UAS in the 3m category.

4 Estimating outcomes of worst-case scenarios for fly-away events: Ground risk

4.1 M1 mitigation as a trigger for Enhanced containment

The triggering of Enhanced containment always by the application of M1 mitigation within populated areas can be shown to be not required:

- Each Ground Risk Class (GRC) score mitigation of 1 corresponds to an order of magnitude reduction in risk. In the case of M1 mitigation “reduction of people at risk” this means a reduction of population density at risk within the operating area to 10% of the originally estimated population or, put another way, a factor 10 higher population density outside of the operating area;
- As shown above, a basic assumption is that the ground risk buffer provides 90% probability of ending the flight within it;
- Therefore, a Low Robustness M1 mitigation of -1 GRC increases the surrounding population density by a factor of 10, but the ground risk buffer offers a reduction of risk to adjacent areas by a factor of 10 ending up at no increase for the surrounding areas. When it comes to general time-activity pattern sheltering arguments for M1 mitigation, these would also be applicable to areas outside of the ground risk buffer and would not cause any increase in the population density difference.

It can be concluded that only M1 mitigations of Medium or High robustness that do not also apply to adjacent areas within populated areas would potentially increase the surrounding population density enough to cause a significant increase in the assessed risk to adjacent areas.

4.2 Worst case scenario assessment for Enhanced containment from ground risk

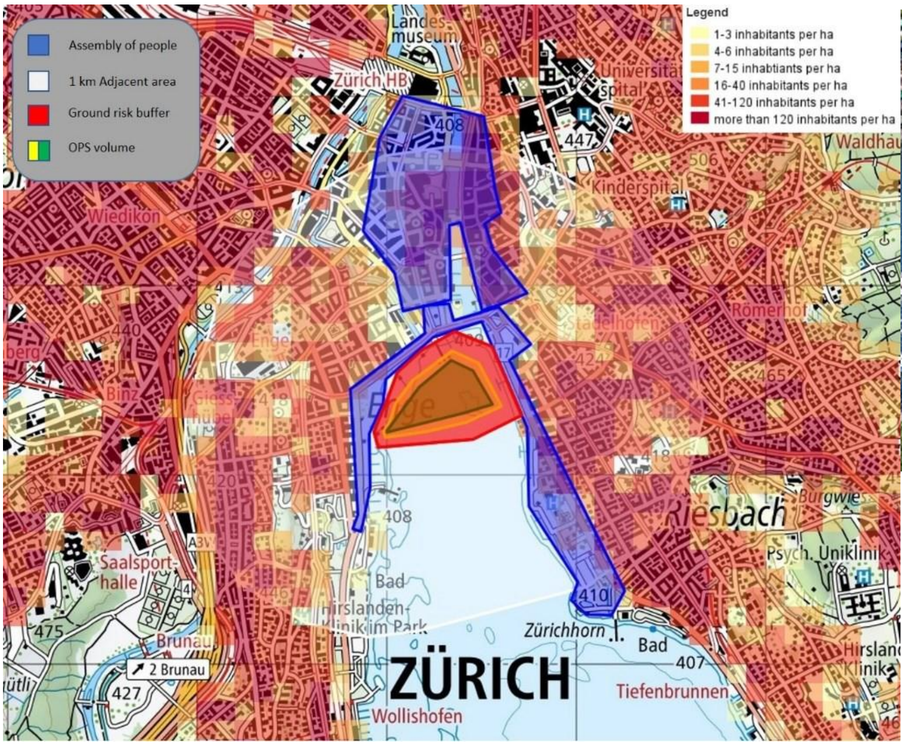
The Enhanced containment is considered to be meant for situations where the ground risk outside of the ground risk buffer is assessed to be considerably high. Practically this means a large number of people right next to the ground risk buffer. A worst-case scenario example is a gathering of people next to a controlled ground area.

Therefore, the worst-case scenarios to assess are controlled ground areas inside densely populated areas (city centers) or operations next to gatherings of people. The examples later show how only large gatherings of people ~20,000 ppl or more will move the assessed risk significantly enough to warrant triggering of Enhanced containment.

The following worst case ground risk containment scenarios show examples of using a proposed 1km distance to quantitatively evaluate surrounding gatherings of people and populated areas. The proposed size of adjacent area of 1 km for ground area considers what would be the closest acceptable safety buffer from a gathering of people, beyond which a gathering of people would not be adjacent to the operational volume. This 1km buffer is selected to be more conservative towards gatherings of people than the one defined in (EU) 2019/947 AMC1 UAS.OPEN.030(1) for subcategory A2 UAS, because the trigger for gatherings is adapted to only large gatherings.

Furthermore, the maximum dimensions of gatherings of people are rarely multiple kilometers in size so as to occupy major parts of the adjacent areas. Crowds that large would be pragmatically possible to avoid with prior knowledge of an event taking place (e.g. concert, trade show, sports event).

4.2.1 Example 1: Street parade Zürich around 200,000 people (comparable in Norway to Oslo Pride)



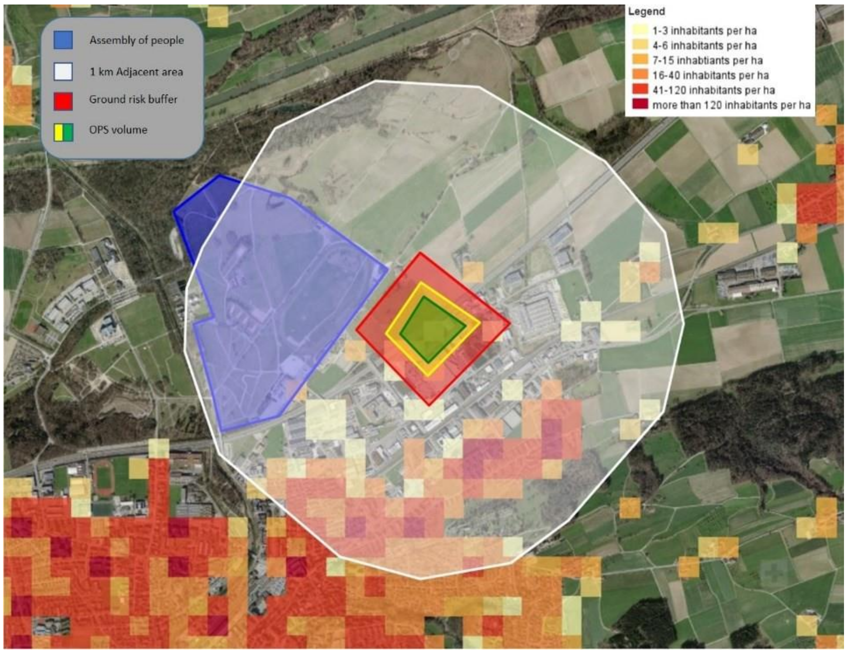
Adjacent area – Ground risk

$A_{OPS+GRB}$ (km²)	A_{ADJ} (km²)
0.3	5.14

	Description	**Density**	**Pop**	**% of A_{ADJ} 1km**
#3	Assembly shopping center (blue area north)	50000	30000	11.67%
#2	Assembly street parade (blue area near shore)	500000	200000	7.78%
#1	Average base population in 1km A_{ADJ}	4936	25370	
#4	All together	49683	255370	

The Street parade example shows that there is a minimum increase in population density of factor 10 or a factor 100 measured within 1km of the operational volume measured from the average base population density(#1). The difference could also be much more if the operational area is a controlled ground area.

4.2.2 Example 2: OpenAir Frauenfeld around 150,000 people (comparable in Norway to Øyafestivalen ca. 100,000 people)



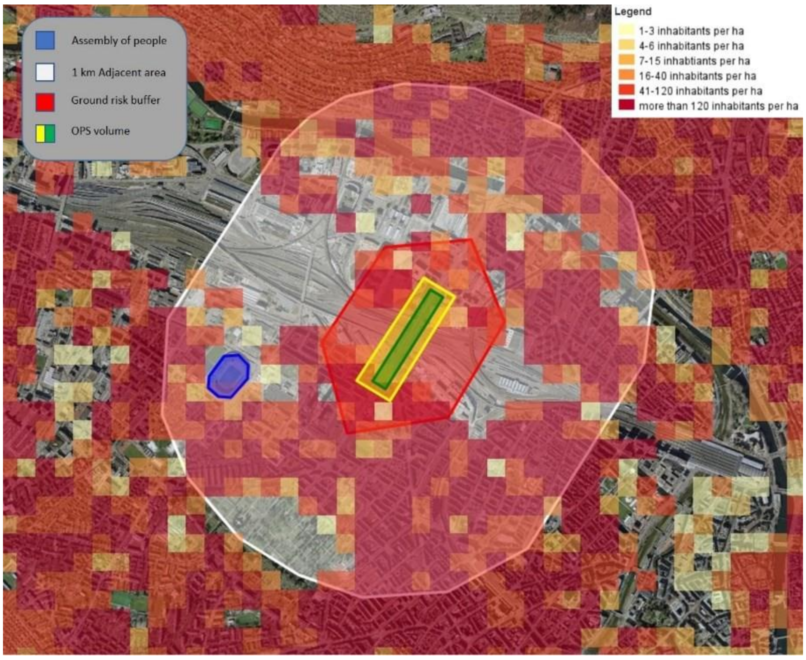
Adjacent area – Ground risk

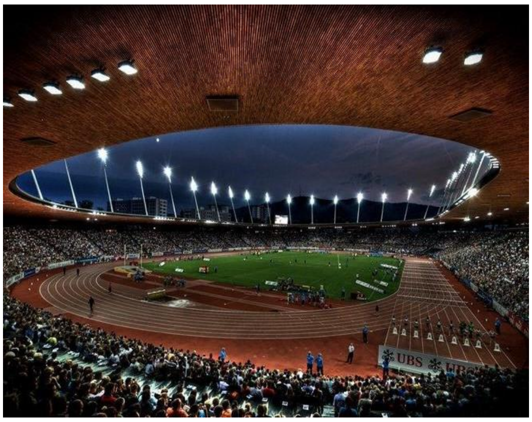
$A_{OPS+GRB}$ (km²)	A_{ADJ} (km²)
0.3	4.49

	Description	**Area km²**	**Density**	**Pop**	**% of A_{ADJ} 1km**
#2	Assembly Openair Frauenfeld (Blue area)	0.81	185185	150000	18.04%
#1	Average 1km A_{ADJ} base population	4.49	1073	4820	100%
#3	All together	4.49	34481	154820	

The OpenAir Frauenfeld example also shows that there is a minimum increase in population density of factor 10 or a factor 100 measured within 1km of the operational volume measured from the average base population density(#1). The difference could also be much more if the operational area is a controlled ground area.

4.2.3 Example 3: Stadium Letzigrund around 30,000 people (comparable in Norway to Ullevaal Stadion: 27,200 people)





Adjacent area – Ground risk

$A_{OPS+GRB}$ (km^2)	A_{ADJ} (km^2)
0.69	4.58

	Description	Area km^2	Density	Pop	% of ADJ 1km
#2	Assembly Stadium Letzigrund (Blue area)	0.81	37037	30000	17.69%
#1	Average 1km A_{ADJ} base population	4.58	9031	41360	
#3	All together	4.58	15893	71360	

The Stadium example shows that a 30,000ppl gathering inside an already densely populated area does not significantly increase the population density measured within 1km of the operational volume. However, as with the previous examples the difference could also be much more if the operational area is a controlled ground area.

4.3 Worst case scenarios estimations applicability to Norway

To use the three examples from Switzerland as relevant estimations for the applicability of this AltMoC in Norway, each example is compared to an equivalent operation in Norway.

- The Pride festival in Oslo had a record number of 85,000 participants in the 2023 parade. This is considerably smaller than the street parade in Zürich and, in addition to this, the Pride festival and parade are located in the city centre of Oslo which is covered by a restricted area. To fly within this restricted area, one needs to apply for a dispensation to CAA Norway and, among other things, contact the police before and after every flight.
- The largest festival in Norway is Øyafestivalen, with around 100,000 visitors. This is considerably less than OpenAir Frauenfeld with its around 150,000 people.
- Norway's largest stadium is Ullevaal Stadium which accommodates around 27,200 people. This is equivalent to Stadium Letzigrund used in example 3.

5 Changes to AMC1 to Article 11 point 2.5.3 on Enhanced containment triggers

Supported by the considerations described in the chapters above, the changes from this AltMoC can be summarised as follows:

For clarity, the following requirement is added to point 2.5.3(b):

> When the aircraft leaves the operational volume, an immediate end of the flight must be initiated.

The current text in point 2.5.3(c):

> (c) The enhanced containment, which consists in the following three safety requirements, applies to operations conducted:
>
> - either where the adjacent areas:
>   - i. contain assemblies of people unless the UAS is already approved for operations over assemblies of people; or
>   - ii. are ARC-d unless the residual ARC of the airspace area intended to be flown within the operational volume is already ARC-d;
> - Or where the operational volume is in a populated area where:
>   - i. M1 mitigation has been applies to lower the GRC; or
>   - ii. operating in a controlled ground area.

is to be replaced by the following new triggers for Enhanced containment:

> (c) The enhanced containment applies to operations conducted:
>
> - Where a large assembly of people (~20,000 ppl or more) is present within 1km distance from the operational volume, unless already approved for operations over assemblies of people. The operator should have procedures in place to check this before each operation.
> - Where adjacent areas are populated areas:
>   - i. And M1 mitigation of Medium or High robustness has been applied, unless the mitigation applies also to adjacent areas;
>   - ii. Operation is conducted over a controlled ground area.
> - Height of the operational volume is above 150m altitude AGL, where adjacent airspace is ARC-d. ATC or Competent authority permit is needed before the operation.
> - With a UAS larger than the 1m class flown in airport environment.

6 New Step #9 section 2.5.3 according to the AltMoC

As a result of this AltMoC, the new Step #9 with the adjustments, is as follows:

2.5.3 Step #9 – Adjacent Area/Airspace Considerations

(a) The objective of this section is to address the risk posed by a loss of control of the operation resulting in an infringement of the adjacent areas on the ground and/or adjacent airspace. These areas may vary with different flight phases.

(b) Safety requirements for containment are:

1. When the aircraft leaves the operational volume, an immediate end of the flight must be initiated.

2. No probable[i] failure[j] of the UAS or any external system supporting the operation shall lead to operation outside of the operational volume.

Compliance with the requirement above shall be substantiated by a design and installation appraisal and shall minimally include:

- the design and installation features (independence, separation and redundancy);

- any relevant particular risk (e.g. hail, ice, snow, electro-magnetic interference…) associated with the ConOps.

(c) The enhanced containment applies to operations conducted:

- Where a large assembly of people (~20,000 ppl or more) is present within 1km distance from the operational volume, unless already approved for operations over assemblies of people. The operator should have procedures in place to check this before each operation.
- Where adjacent areas are populated areas:
    i. And M1 mitigation of Medium or High robustness has been applied, unless the mitigation applies also to adjacent areas;
    ii. Operation is conducted over a controlled ground area.
- Height of the operational volume is above 150m altitude AGL, where adjacent airspace is ARC-d. ATC or Competent authority permit is needed before the operation.
- With an UAS larger than the 1m class flown in airport environment.

1. The probability of the UA leaving the operational volume shall be less than 10^{-4}/FH.
2. No single failure* of the UAS or any external system supporting the operation shall lead to operation outside of the ground risk buffer.

Compliance with the requirements above shall be substantiated by analysis and/or test data with supporting evidence.

3. Software (SW) and Airborne Electronic Hardware (AEH) whose development error(s) could **directly** lead to operations outside of the ground risk buffer shall be developed to an industry standard or methodology recognized as adequate by the competent authority.

As it not possible to anticipate all local situations, the operator, the competent authority and the ANSP should use sound judgement with regards to the definition of "adjacent airspace" as well as "adjacent areas". For example, for a small UAS with limited range, it is not intended to include busy airport/heliport environments 30 kilometres away. The airspace bordering the UAS volume of operation should be the starting point of the determination of adjacent airspace. In exceptional cases, the airspace(s) beyond those bordering the UAS volume of operation may also have to be considered.