EASA European Union Aviation Safety Agency	**Means of Compliance with Light-UAS.2512 / Means of compliance with SORA M2 (medium robustness)** **"M2 MoC"**	Doc. No. : MOC Light-UAS.2512-01 Issue : 1 Date : 06 July 2023 Proposed ☐ Final ☒

SUBJECT	:	Mitigation means linked with design
REQUIREMENTS incl. Amdt.	:	Special condition Light-UAS Medium Risk 01, point Light-UAS.2512 / AMC to Article 11 of Regulation 2019/947 (SORA Annex B - M2)
ASSOCIATED IM/MoC	:	Yes☐ / No ☒
ADVISORY MATERIAL	:	N/A

Introductory Note and Identification of Issue

In June 2022 EASA formulated an initial proposal for Means of Compliance (MoC) to SORA mitigation means M2 for medium and high robustness. The document received significant attention and was intensely commented. It was decided that the subject should be developed with a working group made of EASA and some NAAs.

In November 2022, after establishment of the UAS Technical Body [1] (TeB), this working group became part of the Airworthiness Task Force (AW TF) of the UAS TeB. The AW TF decided to develop 2 deliverables with priority, defined D1 and D2

- D1, <u>which is the MoC subject of this document</u>, addresses medium robustness mitigation means, always based on specific technical means associated with the UA
- D2, which aims at providing guidance on how to assess the UA critical area for the selection of the correct UA size in SORA step#2. D2 is not based on specific technical means associated with the UA

This document, which applies to all SAILs, is aimed at the following communities:

- Operators who are not designers of the UAS or of the mitigation means: they apply to the NAA for OA
- Operators who have also designed the UAS and/or the mitigation means: they may apply to the NAA for OA or to EASA for DV
- Designers who have designed the UAS and/or the mitigation means and do not operate the UAS: they apply to EASA for DV

[1] Advisory bodies | EASA (europa.eu)

The document is organized in three chapters:

- Chapter 1: conceptual clarification of the nominal integrity target associated with medium robustness M2, which is linked with a decrease of the GRC of 1 point
- Chapter 2: General Means of Compliance for M2 medium robustness mitigation means. An applicant may use this chapter to define the technical approach for its project by proposing to the competent authority a specific MoC for M2 medium integrity. This chapter is mainly addressed to manufacturers of UAS and/or mitigation means
- Chapter 3: An initial set of example ways to apply the general MoC. Compliance with these examples can be declared in the frame of a request for operational authorization, making available for the NAA the identified evidence of compliance.

Chapter 2 contains all necessary guidance to comply with M2 medium robustness in the frame of an EASA DVR or in the frame of an OA toward the NAA. Chapter 3 proposes examples applications of chapter 2. If an applicant is able to comply with one of the examples, the applicant can use the example of chapter 3 as means of compliance and skip chapter 2, using the examples in the frame of an OA to the NAA. The evidence defined by the document (chapter 2 or 3) should be delivered with the application. A list of supplementary evidence, when available, may be submitted to the authority.

The simple re-assessment of the critical area based on either the shape of the UA (e.g. multirotor which might be claimed to have a pure ballistic trajectory) or operational constraints (e.g. the remote pilot shall not accelerate the UA beyond a certain speed during the operation, but no technical means is provided to prevent such acceleration), or both, does not qualify for assessment under this document, will be treated by D2 in the frame of SORA step#2 and will not be addressed by DVR.

Members of the UAS TeB Airworthiness TF

- EASA
- AESA
- Austro Control
- DAC Luxembourg
- DGAC
- ENAC
- FOCA
- HCAA
- Irish Aviation Authority
- LBA
- CAA Latvia

- CAA Norway
- CAA Romania
- CAA Netherlands

List of acronyms

AEH airborne electronic hardware

AW TF airworthiness task force of the UAS Technical Body

CAn nominal critical area

CAc claimed critical area

DAL design assurance level

DVR design verification report

GRC ground risk class

GRr ground risk reduction

LoC loss of control

MoC means of compliance

OA Operational Authorization

PRS parachute recovery system

SAIL specific assurance and integrity level

Scd surface projected in the crash direction

SW software

TPTA Third Party Testing Agency

Definitions

a) Integrator: in the context of this document, integrator is entity responsible for the integration of all the various parachute components, the sUA, and the testing of the entire system, as specified by ASTM F3322.

b) Critical Area: the sum of all areas on the ground where a person standing would be expected to be impacted by the UA system during or after a loss of control event, and thus the area where a fatality is expected to occur if a person were within it.

c) The loss of control events to which this document refers are those leading to a crash in the operational volume or ground buffer.

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1. Nominal target for M2 mitigation with medium integrity

M2 mitigations are intended to reduce the effect of ground impact once the control of the operation is lost. This is done either by reducing the size of the expected critical area (herein defined as "type 1" M2), or by reducing the probability of lethality of a UA impact leveraging e.g. energy, impulse, transfer energy dynamics, etc. (herein defined as "type 2" M2) or using both methods ("type 3" M2).

As specified by the EASA AMC on Regulation 2019/947, the medium integrity ground risk reduction targets is 90%. This target should be assessed as in the following:

<u>Type 1</u>

In order to obtain a ground risk reduction (GRr) of approximately 90% by means of a reduction of critical area, the following should be achieved:

- Determine the correct column for the UA in the ground risk table according to SORA step#2, utilizing the maximum UA dimension and typical kinetic energy as per published EASA AMC to article 11 or IR 2019/947.
- The following table[2] shows the nominal critical area that should be considered associated to that column (CAn):

Max characteristic dimension (m)		≤1	≤3	≤8	≤20	≤40
Nominal critical areas (m^2)	0.8	8	80	800	8000	80000

E.g. for an UA of 4 m, CAn = 800 m^2.

- To achieve a 90% reduction the claimed critical area (CAc) must be shown to be equal to or less than that of the nominal critical area of the adjacent column to the left of the CAn.

[2] This table is a complement to the SORA step#2 table and assigns reference sizes of the assumed nominal critical area (basically the area of the ground impact)

Type 2

In order to obtain a ground risk reduction (GRr) of approximately 90% by means of a reduction of lethality only, the following applies:

- "Lethality" is defined as the probability of causing a fatal injury (fatality[3]) by the UA upon impacting a person, having applied M2
  - ➢ If lethality ≤ 0.1 (i.e. 10%) then 1 point less of GRC can be claimed

Type 3

In order to obtain a ground risk reduction (GRr) of approximately 90% by means of both methods (reduction of critical area and reduction of lethality), the following applies

- Lethality * CAc/CAn ≤ 0.1

The above values and equations are provided for nominal reference. For medium robustness mitigations it is acceptable to approximately reach the target safety gain.

2. General Means of Compliance for M2 medium robustness

Any M2 mitigation should specify the supporting evidence provided to support each of the three fundamental claims:

1. The mitigation means reduce the effect of ground impact
2. The mitigation means works with sufficient reliability in the event of a loss of control
3. The mitigation means does not increase risk

Applicants need to declare that they achieve all three claims. However, the applicant needs to support these declarations with evidence, which is documentation of appropriate testing, analysis, simulation, inspection, design review or operational experience. More detailed guidance on how to comply can be found in the sections below. Evidence from operational experience should be supported by operation records and flight data.

Compliance evidence associated to MoCs for any type of M2 should include the description of the mitigation means and how this reduces the effect of ground impact in case of loss of control. When the mitigation means require activation, its functioning should also be described

[3] For medium robustness, considering that the assurance could be partly qualitative, it is considered not appropriate to distinguish between a fatality and injury levels which could be considered not acceptable.

The activation might be combined with a termination function that ensures containment (as per step#9 of SORA) such that the mitigation means is triggered by the containment function and/or the mitigation means is an integral part of the containment function.

2.1 Provide a description of the mitigation and the involved systems

Task description:

2.1.1. Describe the elements and the functional principles of the mitigation means and highlight the mitigation type according to chapter 1 of this document.

a) Use simple wording and include drawings, images and/or graphs.

2.1.2. Describe the functional architecture of the mitigation means.

a) If applicable, this document should identify the mitigation means' functions and chain of events that lead to the activation of the mitigation means.

b) The description should include and highlight all UAS's functions necessary for the operation of the means.

c) The functional architecture should clarify the interfaces between the UAS and the mitigation means

2.1.3. If applicable, describe the installation of the mitigation means on the UAS.

a) should include, but may not limited to, system architecture, mechanical links, dedicated structural elements if any.

2.1.4. If applicable, document the required operational procedures for the utilization and maintenance of the mitigation means.

2.1.5. If applicable, supplement the recommended training and instructions for the personnel responsible for these tasks, including a training syllabus supplement for the operation of the mitigation means. The operator should be able to provide competency-based, theoretical and practical training based on the supplement.

Guidance:

The level of detail in the content should be limited to the information that will contribute to the substantiation of the hazard assessment in the steps below.

2.2 Provide evidence that the mitigation means reduces the effect of ground impact

Integrity requirement:
Medium level of integrity, criterion #1: “*(a) Effects of impact dynamics and post impact hazards are significantly reduced although it can be assumed that a fatality may still occur.*”

Task description:
2.2.1 Describe the principle on which the mitigation means works: Type 1, Type 2 or Type 3.

1. Type 1 means: to substantiate the claim, the applicant should demonstrate by analysis or test that the critical area after the application of the mitigation means is **lower than or equal to** the CAn of the adjacent column to the left of the one selected initially in step#2 of SORA. The demonstration will depend on the impact dynamics (gliding, spiral, ballistic descent…) and should take into account and identify the operational limitations beyond which the above reduction target is not achieved (e.g. maximum wind, maximum operating altitude, maximum speed). These operational limitations should then be considered addressing 2.2.3.
    i. For *parachutes or systems that will drift in the wind, the maximum wind to be considered as operational limitation is the one which, excluding gusts, would still allow achievement of target critical area*
    ii. For *non-drift systems, such as impact, glide or ballistic mitigations, the maximum wind to be considered as operational limitation is the one which, excluding gusts, would still allow achievement of target critical area analysis or testing, considering maximum operating altitude and maximum commanded speed. If there are probable failure conditions which would lead to operations outside of the maximum altitude or commanded speed, the system should be tested under those conditions*
2. Type 2 means: Demonstration of sufficient impact severity reduction should be achieved showing a 90% lethality reduction. This should be demonstrated by using one of the following ways:
    i. ASTM F3389/F3389M-21 methodologies could be proposed where it is possible to adapt the thresholds to reach 90% reduction
    ii. Demonstrate that an impact with a person in the most critical condition results at most in 30% probability of AIS3+ injuries[4];
    iii. Ensure a maximum impact energy of less than 175 J
    iv. Ensure a maximum transferred energy of less than 80 J in an impact with a person[5]
3. Type 3 means: Reduction of both critical area and lethality. To claim type 3 M2, it should be possible to determine approximately which percentage of the global reduction of risk can be respectively apportioned to the reduction of critical area and which to the reduction of lethality.

2.2.2 Compile all calculations, test evidence and other possible evidence into the report, showing that the mitigation means achieves the necessary performance target.

[4] AIS 2005: A contemporary injury scale https://doi.org/10.1016/j.injury.2006.07.009

[5] What counts regarding damage to people is the transferred energy. 80 J has a reference in the EASA regulation (class 1 drones) and the originl EASA EN provides the rationale according to which an impact KE of 175 J can be considered (in average) an acceptable proxi for 80 J transferred.

a. At least one representative flight test should provide the evidence of the claimed impact characteristics. Parameters to be assessed after activation of the mitigation would be for example descent speed, descent angle, evidence of parts detachment, impulse, transfer energy (where applicable).
b. Demonstration by simulation should be limited to cases in which testing would be highly impracticable. Every simulation model should be validated by means of representative tests.
c. The test report should describe the conditions in which the tests took place and the outcome of each test. A summary of results should be provided.

2.2.3 List any operational limitation associated with the safe operation of the mitigation including if applicable adding this information to the flight manual supplement.

Guidance

Please note that depending on the technical mitigation solution, there may be systems where more flight tests might be appropriate to identify the descent characteristics. The accuracy of these characteristics is the responsibility of the designers who therefore should perform more flight tests as they see fit. The evidence to be presented here should include at least record of one demonstration of the impact characteristics with the activated mitigation.

2.3 Provide evidence that the mitigation means works with sufficient reliability in the event of a loss of control

Integrity requirement:

Medium level of integrity, criterion #1: “*(b) When applicable, in case of malfunctions, failures or any combinations thereof [of the UAS] that may lead to a crash, the UAS contains all the elements required for the activation of the mitigation”*

This criterion implies that the mitigation means should still work when a malfunction resulting in a loss of control of the drone occurs.

Task description:
2.3.1 List all probable malfunctions that may cause the crash of the UA. Justify how the mitigation means can be successfully activated in each of these situations.

a) For SAIL I and II a design and installation appraisal should be available. This could be done according to ASTM F3309/F3309M-18 Simplified Safety Assessment of Systems and Equipment in Small Aircraft.

b) For SAIL III and higher the safety assessment on the mitigation means should be a part of the overall system safety assessment (OSO #05, OSO 10/12[6]).

2.3.2 Compile all test evidence and other possible evidence into the report, showing that the mitigation means achieves a reliability of at least 90% after activation, taking the following into consideration:

a) This may be done by component testing, flight testing, operational experience or a combination of the above.
   i) Tests may be substituted by operational experience where the mitigation means has been in operation with the same configuration and with the same UAS as planned to be demonstrated for
b) Applicant must conduct a series of at least 30 representative activation and deployment tests to determine the reliability of the mitigation means and write a test report about it. All tested activations should be successful to demonstrate a 90% reliability in operation. While at least one of the 30 tests should be performed in a representative flight state, the remaining tests may not necessarily be in flight, however they need to be conducted with a configuration representative of the operation in flight and they need to exercise all the chain of elements.
c) In exceptional cases in which not a single flight test is feasible, for example if the UAS is a large one-off for experimental purposes, alternatives could be used in coordination with the competent authority or EASA (as applicable).
d) The test report should describe the conditions in which the tests took place and the outcome of each test. A summary of results should be provided.

Guidance

The SAIL level in paragraph 2.3.1 refers to the resulting SAIL of the operation after applying an M2 medium mitigation. The analysis should aim at demonstrating that no Failure Condition (FC) can lead to both the crash of the UA and the failure or improper functioning of the mitigation means. If the mitigation means are intrinsic (require no activation) no FC should lead the UAS to violate the hypothesis/limitations. Failures or improper system behaviour during tests should be analysed and the root cause identified. Failed tests shall not be repeated without having performed an appropriate analysis of the causes and, where necessary, before appropriate design changes have been made.

[6] as substantiated by MoC to Light UAS 2510 when available; until then the demonstration of OSO5 and 10/12 will be proposed by the applicant and discussed with the authority

In case of malfunction of the means during testing, the applicant should continue correcting identified root causes and testing until all the issues have been solved and all tests are passed in the final configuration. Provide a report of the root cause analysis and a description of the design changes to correct the issue.

Please note that depending on the technical mitigation solution, there may be systems where more flight tests might be appropriate. A sufficiently reliable function is the responsibility of designers who therefore should perform more flight tests as they see fit. The evidence to be presented here should include at least record of one of the successful activation tests in flight.

Operational experience may be used in support of testing and/or to reduce the number of tests. The criteria should be the same as for testing. For example, if the means behaved as expected during an operation and a technical report or analysis of the occurrence exists, it may be used as flight test evidence as per the "Testing" section. The UAS configuration should be the same. For example, the parachute attachment points to the UA structure are not changed; the materials are the same when a frangible structure is claimed.

The design differences contributing to its aerodynamic behaviour should also be negligible. For example, weight for the shock loads on a parachute's risers; mass distribution and/or parachute attachment point's location if the attitude at impact of the UA is relevant for the claim.

2.4 Provide evidence that the mitigation means does not introduce additional risk for third parties

Integrity requirement:
Medium level of robustness, criterion #1: ***(c)*** *When applicable, any failure or malfunction of the proposed mitigation itself (e.g. inadvertent activation) does not adversely affect the safety of the operation.*

Task description:
2.4.1 Provide evidence that the probability of inadvertent activation of the mitigation is sufficiently low to not negatively affect the expected loss of control rate for an operation beyond acceptable levels.

a. This is a SAIL dependent requirement, as the risk of adverse safety affect must become smaller with rising SAIL. In order to comply with requirement (c) the probability of inadvertent activation of the means should be commensurate with the Safety Objective of the UAS.
   i. SAIL I operation: the safety objective for inadvertent activation is assumed met without further evidence being required.

ii. SAIL II operations: inadvertent activations should not be experienced in the testing of the system as per chapter 2.3.1 (General principles). A test report is considered to be sufficient evidence.
iii. SAIL III and higher: inadvertent activations need to be considered as part of the system safety assessment as required by OSO#05.

2.4.2 Explain how a failure or malfunction of the mitigation does not adversely increase the loss of control rate.

a. The applicant should assess risks to uninvolved persons linked with any intended or unintended behaviour of the mitigation means other than inadvertent activation above.
b. A mitigation means should not create unacceptable additional danger for the people on the ground or other airspace users in case of a malfunction.
c. This does not cover the reliability of the mitigation, as this is part of requirement (b).

Guidance

Because of inadvertent activation the means might be activated when they are not required. This could undermine the hypothesis at the basis of a SORA according to which, a UAS that conforms to the OSOs should achieve a given reliability depending on the SAIL. If a UAS design is reliable enough to fly operations up to a given SAIL, the introduction of the mitigation means should not decrease the operational safety performance. For example, if a UAS is designed to support operations having no more loss of control of operation events than one every 1000 hours (SAIL III), a parachute that is inadvertently activated every 100 hours would lead to have ten times more loss of control events leading to crashes than expected from the UAS operation.

3. Compliance examples

Example #1: ASTM compliant Parachute Recovery System (PRS) for sUAS (type 2 & 3)

Scope

- Applicable for UAS in 1m and 3m size categories at or below 25kg MTOM.
- ASTM F3322 – 18 compliant parachute recovery system installed on UAS.
- Parachute descent rate and wind speed limitation combine to a speed vector of less or equal to 10 m/s.

UAS Operator requirements for a declaration to a competent authority
The UAS operator should submit together with the declaration for a M2 mitigation: • description of the mitigation and the involved UAS systems (showing compliance to the example 1 scope) • installation and maintenance instructions for the PRS • description of the training given to remote crew on the PRS The UAS operator must be able to get the full TPTA report from the parachute integrator, if a competent authority requests to see the report.

UAS/Mitigation manufacturer requirements for producing evidence

The parachute integrator as defined in ASTM F3322 – 18, should test the PRS and produce the needed compliance evidence in the form of a TPTA report and the additional requirements of this example, which must be available to the competent authority on request.

Compliance to 2.1. - Description of the mitigation and the involved systems of the UAS

a) Add an image of the UAS with the installed parachute.
b) Add a table of UAS and parachute dimension and mass all together and as separate before installation.

Add a table of the operational limitations for the parachute (temperature, Wind, Minimum deployment altitude, other)

Table 1 - Operational limitations		
OL #1	Maximum operating wind speed ($Wind_{max}$)	$Wind_{max}(m/s) = \sqrt{10^2 - parachute\ descent\ rate^2}$ (excluding wind gusts)
OL #2	Minimum flight altitude (AGL)	ASTM F3322-18 chapters: -3.1.24 minimum deployable altitude, MDA -3.1.25
OL #3	Operating temperatures	Minimum temperature : Maximum temperature :
OL #4	Other (if necessary)	

c) Describe the activation methods and triggering parameters for the parachute.
d) Describe the operational procedures of the parachute
e) Describe the installation of the parachute on the UAS.

f) Describe the maintenance procedures of the parachute system.

Compliance to 2.2 - Evidence for the reduction of ground impact effects

Compliance to 2.2.1 is achieved in the following way. The parachute is a Type 2 mitigation for less than 11kg UAS and a Type 3 mitigation means for 11-25kg UAS reducing the impacted area and the severity of a potential impact with a person.

g) For UAS below or at the MTOM of 11kg equipped with a parachute descent rate and a wind speed limitation combining to a speed vector of below or at 10 m/s, the lethality reduction can be estimated to be more than 90%. This is estimated by combining worst case head impact collision tests[7], the maximum impact speed of 10 m/s (combining wind speed and descent speed) and the fact that a direct UA centre of gravity hit to a person's head is extremely unlikely[8]. The impact tests[7] used a UAS weighing 11kg and hitting a test dummy in the head at 10 m/s which resulted in a probability of lethality of 25%. Knowing that direct head impacts are much less likely than glancing hits this can be estimated to result in a probability of lethality less than 10% in average.

h) For UAS in 3m size class weighing between 11 kg and 25 kg with a parachute descent rate and a wind speed limitation combining to a speed vector of below or at 10 m/s, the probability of lethality can be assumed to be less than 50% from an impact. This is due to the centre mass hits to the head of a person being much smaller probability than a glancing impact with a minimal energy transfer to a person. Also, the critical area can be estimated to be approximately[9] 20% of the intrinsic critical area for a 3m size class UAS without a parachute. Estimated distance drifted with a parachute while below height of a person is 2.4m and human width is estimated as 0.3m. Estimated critical area CAc with the parachute
$(2.4m)x(3m+0.3m) + \pi \times (3.3m/2)^2 = 16.5m^2$
Lethality * (16.5/80) ≤ 0.1 -> 0.5*0.2 ≤ 0.1
which shows that lethality and critical area reductions together reach approximately a 90% ground impact effects reduction.

Compliance to 2.2.2 is achieved by completing the required tests in matrix of ASTM F3322-18 chapter 6.4 and compiling the results into the TPTA report 6.3.2.

Compliance to 2.2.3. is achieved by the Table 1 of this example

Compliance to 2.3 - The mitigation means works with sufficient reliability in the event of a loss of control

Compliance to 2.3 is achieved by completing the required test matrix of ASTM F3322-18 chapter 6.4 and by the TPTA report 6.3.2.

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[7] Ranges of Injury Risk Associated with Impact from Unmanned Aircraft Systems https://doi.org/10.1007/s10439-017-1921-6
[8] ASSURE Ground Collision Severity Evaluation Phase II – Annex A page 113 https://www.assureuas.org/projects/uas-ground-collision-severity-evaluation-2/
[9] sufficient to meet type 3 nominal target as defined in chapter 1 for type 3 mitigations

Compliance to 2.4 - The mitigation means does not introduce further risk for people

Compliance to 2.4.1 is achieved for:

i) SAIL I and SAIL II operations comply without further evidence to the TPTA report.

j) SAIL III and higher, inadvertent activations needs to be considered as part of the system safety assessment as required by OSO#05.

Compliance to 2.4.2. is achieved with the TPTA report.

Example #2: Parachute Recovery System (PRS) for sUAS (type 2 & 3).

Scope

- Applicable for UAS in 1m and 3m size categories at or below 25kg MTOM.
- Parachute recovery system installed on sUAS.
- Parachute descent rate and windspeed limitation combine to a speed vector of less or equal to 10 m/s.

UAS Operator requirements for a declaration to a competent authority
The UAS operator should submit together with the declaration for a M2 mitigation: • description of the mitigation and the involved UAS systems (showing compliance to the example 2 scope) • installation and maintenance instructions for the PRS • description of the training given to remote crew on the PRS The UAS operator must be able to provide the full compliance evidence, if a competent authority requests to see the report.

UAS/Mitigation manufacturer requirements for producing evidence

Compliance to 2.1. - Description of the mitigation and the involved systems of the UAS

- Add an image of the UAS with the installed parachute.
- Add a table of UAS and parachute dimension and mass all together and as separate before installation.
- Add a table of the operational limitations for the parachute (temperature, Wind, Minimum deployment altitude, other)

Table 1 - Operational limitations

OL #1	Maximum wind speed at ground level	$Wind_{max}(m/s) = \sqrt{10^2 - parachute\ descent\ rate^2}$ (excluding wind gusts)
OL #2	Minimum flight altitude (AGL)	Minimum deployable altitude as per testing of the PRS will be determined by the greatest recorded difference during all deployments, plus two times the full length of the parachute assembly.
OL #3	Operating temperatures	Minimum temperature : Maximum temperature :
OL #4	Other (if necessary)	

- Describe the activation methods and triggering parameters for the parachute.
- Describe the operational procedures of the parachute
- Describe the necessary interfaces between the UAS and the mitigation means.
- Describe the installation of the parachute on the UAS.
- Describe the maintenance procedures of the parachute system.

Compliance to 2.2 - Evidence for the reduction of ground impact effects

Compliance to 2.2.1 is achieved in the following way. The parachute is a Type 2 mitigation for less than 11kg UAS and a Type 3 mitigation means for 11-25kg UAS reducing the impacted area and the severity of a potential impact with a person.

a) For UAS below or at the MTOM of 11kg equipped with a parachute descent rate and a wind speed limitation combining to a speed vector of below or at 10 m/s, the lethality reduction can be estimated to be more than 90%. This is estimated by combining worst case collision tests[10], the maximum impact speed of 10 m/s (combining wind speed and descent speed) and the fact that a direct UA centre of gravity hit to a person's head is extremely unlikely[11]. The impact tests[7] used a UAS weighing 11kg and hitting a test dummy in the head at 10 m/s which resulted in a probability of lethality of 25%. Knowing that direct head impacts are much less likely than glancing hits this can be estimated to result in a probability of lethality less than 10% in average.

k) For UAS in 3m size class weighing between 11 kg and 25 kg with a parachute descent rate and a wind speed limitation combining to a speed vector of below or at 10 m/s, the probability of lethality can be assumed to be less than 50% from an impact. This is due to the centre mass hits to the head of a person being much smaller probability than a glancing impact with a minimal energy transfer to a person. Also, the critical area can be estimated to be approximately 20% of the intrinsic critical area for a 3m size class UAS without a parachute. Estimated distance drifted with a parachute while below height of a person is 2.4mand human width is estimated as 0.3m. Estimated critical area CAc with the parachute $(2.4m)x(3m+0.3m) + \pi \times (3.3m/2)^2 = 16.5 \ m^2$
Lethality * (16.5/80) ≤ 0.1 -> 0.5*0.2 ≤ 0.1
Lethality and critical area reductions together reach a 90% ground impact effects reduction.

Compliance to 2.2.2 is achieved by compiling a test report showing that the mitigation means achieves the necessary performance target with the following:

a) At least two representative flight tests should provide the evidence of the descent rate and minimum deployable altitude. The minimum deployable altitude should be tested at maximum take-off mass configuration. For powered lift aircraft the tests should be done at both hover and maximum forward speed. For fixed-wing aircraft the minimum deployable altitude should be tested at maximum forward speed stable flight and maximum forward speed maximum roll tests. Altitude is to be measured from

[10] Ranges of Injury Risk Associated with Impact from Unmanned Aircraft Systems https://doi.org/10.1007/s10439-017-1921-6
[11] ASSURE Ground Collision Severity Evaluation Phase II – Annex A page 113 https://www.assureuas.org/projects/uas-ground-collision-severity-evaluation-2/

the point of power cut to the point when the parachute has reached the stable descent speed. If the PRS is manually activated add 3 seconds of free fall distance to the altitude as a reaction time buffer.

b) The test report should describe the conditions in which the tests took place and the outcome of each test. A summary of results should be provided.

Compliance to 2.2.3. is achieved by the Table 1 of this example

Compliance to 2.3 - The mitigation means works with sufficient reliability in the event of a loss of control

Compliance to 2.3.1 is achieved by listing all probable malfunctions that may cause the crash of the UA. Justify how the mitigation means can be successfully activated in these situations. ASTM F3309/F3309M-18 standard can be used as a help in making this list.

Compliance to 2.3.2 is achieved by performing at least 30 successful representative activation tests and compiling a test report, showing that the mitigation means achieves the necessary reliability.

a) The test report should describe the types of tests done, conditions in which the tests took place and the outcome of each test. A summary of each test results should be provided in a table.
b) Applicant must conduct a series of at least 30 representative activation tests one of which must be in flight to determine the reliability of the mitigation means. If malfunctions happen during testing, then the root cause of the malfunction must be identified and corrected and a subsequent 30 tests performed.
   i. If evidence is provided by showing operational experience (substantiated as per chapter 2), then the mitigation means must have been in operation with the same type of UAS. Operational activation events should be logged with the same data requirements as for a parachute test including the prevailing conditions.

Compliance to 2.4 - The mitigation means does not introduce further risk for people

Compliance to 2.4.1 is achieved for:

a) SAIL I operations comply without further evidence.
b) SAIL II operations if the test report for the parachute shows no inadvertent activations for the last 30 test.
c) SAIL III and higher, inadvertent activations needs to be considered as part of the system safety assessment as required by OSO#05.

Compliance to 2.4.2. is achieved by justifying how any other failures or malfunctions than inadvertent activations of the mitigation do not adversely increase the loss of control rate. This can be achieved by listing other failures and malfunctions of the parachute than inadvertent activation and showing that the effect does not lead to the loss of control of the UAS. For example, the parachute battery failing should not lead to a loss of control of the UAS.

Example #3: Parachute Recovery System (PRS) for large UAS (type 1).

Scope

- Applicable for UAS in 8m and larger size categories.
- Parachute Recovery System installed on large UAS.
- Parachute descent speed less or equal to 8 m/s.

UAS Operator requirements for a declaration to a competent authority
The UAS operator should submit together with the declaration for a M2 mitigation: • description of the mitigation and the involved UAS systems • installation and maintenance instructions for the PRS • description of the training given to remote crew on the PRS The UAS operator must be able to provide the full compliance evidence, if a competent authority requests to see the report.

UAS/Mitigation manufacturer requirements for producing evidence

Compliance to 2.1. - Description of the mitigation and the involved systems of the UAS

- Add an image of the UAS with the installed parachute.
- Add a table of UAS and parachute dimension and mass all together and as separate before installation.
- Add a table of the operational limitations for the parachute (temperature, Wind, Minimum deployment altitude, other)

Table 1 - Operational limitations

OL #1	Maximum wind speed at ground level	14 m/s (excluding wind gusts)
OL #2	Minimum flight altitude (AGL)	Minimum deployable altitude as per testing of the PRS will be determined by the greatest recorded difference during all deployments, plus two times the full length of the parachute assembly.
OL #3	Operating temperatures	Minimum temperature : Maximum temperature :
OL #4	Other (if necessary)	

- Describe the activation methods and triggering parameters for the parachute.
- Describe the operational procedures of the parachute
- Describe the necessary interfaces between the UAS and the mitigation means.
- Describe the installation of the parachute on the UAS.
- Describe the maintenance procedures of the parachute system.

Compliance to 2.2 - Evidence for the reduction of ground impact effects

Compliance to 2.2.1 is achieved in the following way. The parachute is a Type 1 mitigation means reducing the impacted area and the severity of a potential impact with a person.

a) For UAS in the 8m class or above descending with a parachute at a rate below or at 8 m/s, the critical area reduction can be estimated to be more than 90%.

Max characteristic dimension (m)		≤1	≤3	≤8	≤20	≤40
Nominal critical areas (m^2)	0.8	8	80	8000	8000	80000

With the limitations on descent rate and wind speed it can be expected that the UAS will sweep a 3m long area below the height of people before impacting the ground. Therefore, a simple approximation using following values:

- UAS characteristic dimension = 8m
- Maximal wind drift distance below the height of a person = 3.5m
- Width of a person 0.3m
- Height of a person 1.8m

  Critical area = (3.5m) x (8m + 0.3m) + π x $(8.3m/2)^2$= 83.2 m^2, which is acceptably similar to the 3m class critical area and provides the target 90% reduction in critical area.

Compliance to 2.2.2 is achieved by compiling a test report showing that the mitigation means achieves the necessary performance target with the following:

a) At least two representative flight test should provide the evidence of the descent speed and minimum deployable altitude. The minimum deployable altitude should be tested at maximum take-off mass configuration. For powered lift aircraft the tests should be done at both hover and maximum forward speed. For fixed-wing aircraft the minimum deployable altitude should be tested at maximum forward speed stable flight and maximum forward speed maximum roll tests. Altitude is to be measured from the point of power cut to the point when the parachute has reached the stable descent speed. If the PRS is manually activated add 3 seconds of free fall distance to the altitude as a reaction time buffer.
b) The test report should describe the conditions in which the tests took place and the outcome of each test. A summary of results should be provided.

Compliance to 2.2.3. is achieved by the Table 1 of this example

Compliance to 2.3 - The mitigation means works with sufficient reliability in the event of a loss of control

Compliance to 2.3.1 is achieved by listing all probable malfunctions that may cause the crash of the UA. Justify how the mitigation means can be successfully activated in these situations. ASTM F3309/F3309M-18 standard can be used as a help in making this list.

Compliance to 2.3.2 is achieved by performing at least 30 successful representative activation tests and compiling a test report, showing that the mitigation means achieves the necessary reliability.

a) The test report should describe the types of tests done, conditions in which the tests took place and the outcome of each test. A summary of each test results should be provided in a table.

b) Applicant must conduct a series of at least 30 representative activation tests one of which must be in flight to determine the reliability of the mitigation means. If malfunctions happen during testing, then the root cause of the malfunction must be identified and corrected and a subsequent 30 tests performed.

i. If evidence is provided by showing operational experience (substantiated as per chapter 2), then the mitigation means must have been in operation with the same type of UAS. Operational activation events should be logged with the same data requirements as for a parachute test including the prevailing conditions.

Compliance to 2.4 - The mitigation means does not introduce further risk for people

Compliance to 2.4.1 is achieved for:

a) SAIL I operations comply without further evidence.
b) SAIL II operations if the test report for the parachute shows no inadvertent activations for the last 30 test.
c) SAIL III and higher, inadvertent activations needs to be considered as part of the system safety assessment as required by OSO#05.

Compliance to 2.4.2. is achieved by justifying how any other failures or malfunctions than inadvertent activations of the mitigation do not adversely increase the loss of control rate. This can be achieved by listing other failures and malfunctions of the parachute than inadvertent activation and showing that the effect does not lead to the loss of control of the UAS. For example, the parachute battery failing should not lead to a loss of control of the UAS.

Example #4: UA maximum impact energy of less than 175 Joules (type 2)

Scope

- The mitigation is linked to the inherent UAS characteristics showing a less lethal impact kinetic energy.

UAS Operator requirements for a declaration to a competent authority
The UAS operator should submit together with the declaration for a M2 mitigation a description of the UAS and the following evidence: 1. UAS complying with requirements associated to the C0 or C1 class of regulation 2019/945 qualify for the less than 175J impact energy by showing the class marking in the description of the UAS. 2. Other types of UAS shall include as evidence with the declaration: • Terminal velocity calculation based on drop test measurement. The UAS operator must be able to provide the video of the drop test, if a competent authority requests to see it, OR • Terminal velocity calculation using conservative estimates.

The speed of the UA to be considered to check that the impact KE threshold of 175 Joules is not exceeded should be either the terminal velocity or the maximum UA speed, whichever is higher. The formula to assess the KE is: KE = 0.5*(MTOM)*(Vterminal or Vmax)^2.

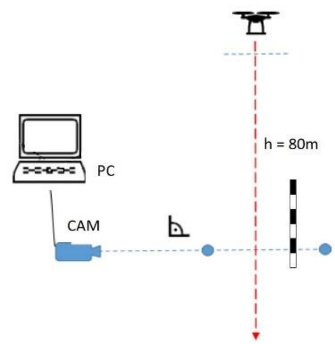
Requirements for producing evidence for declaration

Compliance to 2.1. - Description of the UAS

- If declaring a C0 or C1 UAS. Include a picture of the C marking on the drone.
- Add images of the UAS with the dimensions marked in top and side profile views.
- Add a table of UAS dimensions, maximum speed and MTOM.
    - If using the conservative calculation method. Include a technical drawing showing the smallest cross-sectional area of the UA with dimensions.

Compliance to 2.2 – Evidence required for the drop tests

The terminal speed should be estimated by measuring the fall of the UA from at least 80m altitude from the measurement point using a high-speed camera capable of recording 250 frames per second. The measurement set-up should be such to allow measurement of the speed in reference to a clock and a reference measuring stick in the background.



Compliance to 2.2 – Evidence required for the conservative calculation

Alternatively, terminal velocity can be calculated selecting a drag coefficient of 0.8, air density of 1.255 Kg/m^3 and the minimum cross-sectional area of the UA. Different values should be determined in the frame of the application of chapter 2. The formula to assess the terminal velocity is:

$$V_{terminal} = \sqrt{\frac{2 * MTOM(kg) * 9.81\ (\frac{m}{s^2})}{0.8 * 1.255 * minimum\ cross\ sectional\ area\ (m^2)}}$$