SUBJECT	:	**Containment**
REQUIREMENTS incl. Amdt.	:	**Special condition Light-UAS Medium Risk 01 is.1, point Light-UAS.2511**
ASSOCIATED IM/MoC	:	Yes☐ / No ☒
ADVISORY MATERIAL	:	**N/A**

INTRODUCTORY NOTE AND IDENTIFICATION OF ISSUE:

EASA has received several applications for design verification projects (DVP) focused on enhanced containment. In the frame of EASA DVPs, SC Light UAS is utilized as design verification basis and, for enhanced containment, Light-UAS 2511 (b) applies:

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(b) When the risk associated with the adjacent areas on ground or adjacent airspace is significantly higher than the risk associated with the operational volume including the ground buffer:

(1) the probability of leaving the operational volume must be demonstrated to be acceptable with respect to the risk posed by a loss of containment;

(2) no single failure of the UAS or of any external system supporting the operation must lead to its operation outside the ground risk buffer; and

(3) software and airborne electronic hardware whose development error(s) could directly lead to operations outside the ground risk buffer must be developed to a standard or methodology accepted by the Agency.

Several of these applications leverage flight termination as method to avoid breach in adjacent areas. For this reason the need has been identified to establish a means of compliance to Light-UAS.2511 purely based on a flight termination system (FTS). An FTS is by its nature an emergency measure, which is not intended as a standard contingency measure. Its triggering should not be assumed to lead to a crash within the operational volume[1]. However, if the probability of exit from the ground buffer ensures that the overarching quantitative target level of safety (TLOS) [2] is still met in adjacent areas, an FTS should be considered an acceptable means[3] to demonstrate compliance with Light-UAS 2511 (b).[4]

[1] Light-UAS 2511 (b1) mentions the operational volume
[2] Probability of fatality on ground < 10^{-6} / FH, as defined by JARUS SORA
[3] Other means are still possible
[4] An FTS is also at the base of PDRAs S-01 and S02 as detailed in Regulation (EU) 2019/947. The means of compliance provided by this document for the FTS provide the possibility for applicants to substantiate compliance with the following requirement applicable to both PDRAs: Provide means for the remote pilot to terminate the flight of the UA, which shall: a) be reliable, predictable and independent from the automatic flight control and guidance system; this applies also to the activation of this means; (b) force the descent of the UA and prevent its powered horizontal displacement; The "means to reduce the

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EASA has therefore decided to define a means of compliance focused on the adoption of an FTS, and has opted for a public consultation of such means of compliance, due to its generic nature. The MoC is presented together with 2 methods for the determination of the allowed maximum population density in adjacent areas. The consultation refers also to these methods.

1. Structure of the document and general approach

The document presents a method to determine compliance with Light-UAS 2511 based on:

- Determination of the maximum allowed density of population in adjacent areas, i.e. Dpop-adj-max (chapter 2)
- MoC for the FTS (chapter 3)

In order to ensure that the SORA TLOS is achieved on adjacent areas, Light-UAS 2511 (b) is assessed quantitatively with regard to ground risk. This is done by means of the equation[5] which links Dpop-adj-max (maximum acceptable population density in adjacent areas), Ac (expected crash area of the UA), TLOS (not to exceed probability of fatality on ground: 10^{-6} / FH), Pexit (probability / FH that the UA breaches in adjacent areas).

Precisely:

- TLOS is known
- Ac is conservatively provided based on characteristics of the UA (solution 1) or determined (solution 2)
- Pexit is the target value of this MoC (10^{-4} / FH)[6]
- Dpop-adj-max follows as a result

If enhanced SORA step 9 is triggered, it is possible to apply this method proceeding through the following steps:

1. Check that the operation may not entail a peculiar ground risk in adjacent areas whose nature is not captured by this MoC[7]. If such risk is possible, the operator should refer to the competent authority for operational authorization. If not, proceed to step 2
2. Check that the adjacent airspace is such that a breach of the UA beyond the ground buffer with a probability of 10^{-4} / FH can be considered acceptable by the competent authority issuing the operational

effect of the UA impact dynamics" (also mentioned in the PDRA) are addressed in the form of "option" in chapter 4 this MoC, as this MoC to Light-UAS 2511 (b) does not necessarily need such means. Chapter 4 aims at ensuring no detrimental effect of these means on safety. Regarding their performance in terms of capability of reducing kinetic energy, if the objective is the increase of Dpop-adj-max, it is taken into account in chapter 2 (assuming it can be demonstrated that these means operate even when the FTS has not worked appropriately). However, specific performance objectives for the PDRA, if any, are not herein addressed.

[5] P(loss of containment/FH) ≤ TLOS / (Dpop-adj-max*Ac) with Dpop-adj in people/m^2 and Ac in m^2. It is assumed that, once containment has been lost, it will not be re-gained and the UA will finally crash outside the ground buffer in the adjacent areas.

[6] It should be noted that this target value is provided implicitly by a SAIL IV, with no need of additional containment means.

[7] For example, the existence of specific infrastructure in the adjacent areas, or carriage of dangerous goods.

authorisation. If considered acceptable[8], proceed to step 3. If not acceptable refer to the competent authority issuing the operational authorization.

3. Utilise either method 1 or method 2 to derive the maximum Dpop-adj-max (chapter 2)
4. Ensure that Dop-adj[9] for the operation is below Dpop-adj-max as determined in step 3. If it is not, change or adjust the area of operation, recheck assumptions, or do not apply this MoC and refer to the competent authority. If it is, proceed to step 5
5. Apply the MoC on the FTS (chapter 3)

Regarding the operation of multiple UA in the same airspace, although these operations (in particular "drone swarms"[10]) are not in the scope of SORA[11], some Member States are gaining operational experience. Therefore it is proposed to consider them included in the scope of this MoC (focused on enhanced containment) as long as the UA maximum dimension is below 1 m. The limitation in dimension could be re-address in further revisions of the MoC.

2. Assessment of ground risk posed to adjacent areas

In the specific category of operation, the SORA provides the possibility to take into account ground risk mitigation means M2 based on reduced crash area and / or reduced transmitted KE[12]. M2 can contribute a "- 1" or "- 2" in the determination of the final ground risk class (GRC)[13], or provide no contribute if not applied. M2 is assessed for the operational volume and ground risk buffer, however it might be fully or partially applicable also on adjacent areas (defined herein as $M2_{adj}$), depending on the specific technical means and justification. Applicability in adjacent areas (and therefore whether $M2_{adj}$ has a value of 0, -1 or -2) should be assessed by the operator / applicant, taking into account that a breach in adjacent areas / volumes implies by definition that 1) control has been lost and 2) the FTS, although segregated from the UA as required by this MoC (refer to chapter 3), has not functioned as expected.

For correct understanding of the results obtained from method 1 and method 2 it is highlighted that:

- For both methods the formula of footnote 5 applies, recombined to obtain Dpop-adj-max
- Both methods assume that operation is not lost at a rate higher than 10^{-2} /FH. Although a SAIL I could in theory be allowed to have worse performances, the assumption is considered reasonable for the scope of this MoC (also with regard to most consumer products currently on the market). The rate of

[8] It should be noted that, where the competent authority for operational authorization would consider more appropriate to adhere to SORA step 9, for which Pexit = 10^{-4}/FH is applied to the operational volume, the authority could still require that the activation of the FTS is performed sufficiently before the outer perimeter of the operational volume is reached, such that termination would lead to a crash within the operational volume (the single failure criteria is considered met by means of the segregated FTS).

[9] This refers to the "at risk" population in adjacent areas. If the MTOM is below 25 Kg, sheltering assumption could be possible, as long as they are agreed with the authority authorizing the operation. This document does not provide further guidance to determine the "at risk" Dpop-adj. Such guidance could be derived from future JARUS WG6 proposals regarding SORA "step 9". Until this guidance will be published in the AMC and GM to Regulation 2019/947, EASA will be available for discussion / consultations with competent authorities and operators.

[10] Swarms operation are usually authorized only on ground control area. This document address only the technical containment aspect.

[11] Currently considered not addressing the operation of multiple UA in the same airspace

[12] Specific design can decrease the probability to cause a fatality in case of collision with people.

[13] Crash area reduction and reduction of the probability of fatality can be used together to provide the "-1" or "-2" contribute

loss of control of the operation and the reliability ensured for the FTS by this MoC contribute to the obtainment of, at least, Pexit ≤ 10^{-4} /FH

- Mitigation means M2 on adjacent areas are taken into account in different ways by method 1 and method 2, as method 2 explicitly incorporates the determination of the specific Ac of the UA

2.1 Method 1 to derive Dpop-adj-max

If $M2_{adj} = 0$

- UAdim[14] ≤ 1 m and cruise speed ≤ 25 m/s[15]: Dpop-adj-max = 1500 people / Km^2
- UAdim ≤ 3 m and cruise speed ≤ 35 m/s: Dpop-adj-max = 100 people / Km^2

$M2_{adj} = -1$; [16]

- UAdim ≤ 1 m and cruise speed ≤ 25 m/s: Dpop-adj-max = 15000 people / Km^2
- UAdim ≤ 3 m and cruise speed ≤ 35 m/s: Dpop-adj-max = 1500 people / Km^2

$M2_{adj} = -2$

Dpop-adj-max not limited (it has been proved that the statement "it can be reasonably assumed that a fatality will not occur" from Annex B to SORA is applicable also on adjacent areas).

If this method cannot be used, the remaining option is to select method 2.

2.2 Method 2 to derive Dpop-adj-max

Determine the contribute to $M2_{adj}$ provided solely by a reduction of transmitted kinetic energy (if any): $M2_{adj\text{-}ke}$

- Possible values of $M2_{adj\text{-}ke}$: 0, -1

Determine the crash area of the UA on adjacent areas: Ac

Dpop-adj-max[17] = $(10^4/Ac)*(10^{-M2adj\text{-}ke})$ people/Km^2

For $M2_{adj\text{-}ke} = -2$ Dpop-adj-max not limited.

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[14] Maximum dimension of the UA

[15] The indications of method 1 derive from the use of crash areas (Ac) considered by JARUS WG SRM. Even if the proposal is not publicly consulted yet, it is considered by EASA state-of-the-art. Should JARUS public consultation lead to different conclusions, this MoC may be updated.

[16] A small drone UA of, e.g., 30 cm maximum dimension, should be able to gain a "-1"

[17] The consultation paper was initially published on 13/12/2021 with a typo in the formula: "1000" was wrongly written instead of "10^4". This has been corrected on 15/12/2021 but the issue number of the consultation paper has remained is1

Means of Compliance MOC Light-UAS.2511-01

Means of Compliance with Light-UAS.2511 Containment

3. Introduction

The following chapters provide the prescriptions for an FTS system considered adequate to provide, for the UA, a Pexit ≤ 10^{-4} / FH.

3.1 General requirements

The FTS must be segregated from the UAS flight control system architecture. Such segregation needs to be simply verifiable and comply with the following paragraphs.

The FTS can be manually or automatically activated. In the case of manual activation, the system will include a ground and an air (i.e.: on-board) segment.

3.2 Segregation of the air segment

The air segment of the FTS should be fully and clearly segregated from the UAS flight control system architecture and any other elements of such architecture whose failure may induce a loss of control, unless demonstrated that the failure of such elements may only lead to crash in the operational volume or ground buffer. For example, the FTS air segment may use the same power supply of the UA, as a loss of a power supply could be considered a failure leading to a crash in the operational volume. In such a case erroneous operation of onboard power supply (out of range voltage, inverted polarity) should be demonstrated to not result in loss of containment and loss of the FTS.

If the FTS is activated from ground, the receiver of the FTS signal installed onboard should be independent from the receiver utilized for command and control.

If the FTS is automatically activated, its activation should be triggered by systems which are not utilized for the control of the UA operation within the operational volume. For example, positioning information utilized to trigger the FTS should be provided by different systems with respect to the ones utilized during normal operation of the UA.

3.3 Segregation of the ground segment

The unit(s) utilized to trigger the FTS should be fully segregated from the Command Unit (CU) utilized for UA control during normal operation. The segregation should be such that, if CU operation would be lost or function erroneously, the FTS would be fully unaffected.

3.4 Frequency and frequency diversity

The frequency band utilized by the FTS should be separated from the frequency band utilised for UA control. The FTS frequency should also not be superimposed with frequencies intensely utilized in the area of operation, or it should be proven that in such case no interference would be possible such to cause erroneous FTS activation.

3.5 FTS Performance

Adequate performance of the FTS should be checked by test as in the following.

FTS initial tests.

Proper functioning of the FTS needs to be checked with dedicated laboratory tests, focused on the FTS function.

Ground integration tests after installation of the FTS on the UA

These tests need to demonstrate proper activation of the containment means as installed on the UAS and that the desired effect on the UAS is obtained. Effect of the possible payload (in terms of FTS integration, antenna masking) should be considered. If the FTS, during real operation, is activated from ground, ground test should be such to already test the maximum operational distance of the UA from the antenna transmitting the command of flight termination. The ground FTS unit needs to be connected with the antenna as in the real operational case.

Flight test

Flight tests need to be carried out in low risk scenarios (typically: a test location which is controlled and with very low risk in adjacent areas). Flight tests are not considered necessary for very small UAS[18], since in this case ground risk is anyway contained and antenna masking effects are not expected.

Flight tests need to demonstrate proper activation of the on-board segment of the FTS, however, a representative non-destructive configuration may be arranged (e.g. digital recording of the FTS signal which would normally interrupt power connection to engines when FTS is actuated, avoiding that such signal actually commands power interruption during tests). It should be demonstrated that each activation from ground, respectively each test case in which the FTS is supposed to be automatically actuated, would result in a correct flight termination.
During the tests, all geometries UA – ground antenna expected during operation would need to be tested at the maximum expected distance. The FTS should never be subject of inadvertent activation.

End-to end activation tests performed in laboratory

These tests address the capability of the termination means to ensure its potential operation for the life cycle of the UA. The number of activations (triggering of the termination means and observation of proper operation) should be equal to the number of expected operations of the UAS for its entire life (accounting for pre-flight checks, maintenance check, return to service check) multiplied by a scattering factor of 2. The lapse of time in which such tests are performed will depend on the organization on the test (i.e. the activations can be performed in a rapid sequence, considering that the unit might need to rest long enough to avoid adverse effects). The tests should be carried out utilizing the UA that has been subject to flight tests (when such tests have been carried out) with FTS installed, utilizing the same FTS activated in flight.

3.6 Flight Manual Procedure

[18] A threshold of 900 g is proposed

Proper procedures should be established to ensure that the FTS will be operated appropriately and it will work as intended throughout the life of the installed system.

At least one on-ground test of the FTS installed on the UAS needs to be carried out before each UAS operation, with method and timing as indicated by the flight manual. This test is dedicated to minimize the possibility of latent failures. If the test fails the FTS needs to be replaced before next flight, and re-tested.

3.7 Maintenance Instruction

Proper maintenance instructions should be established to ensure that the FTS will work as intended throughout the life of the installed system.

Maintenance instruction should be established in order to record the in-service reliability of the FTS. This check is dedicated to verify that the reliability target is met during the life cycle of the system. The check consists in the application of the formula below whenever an FTS failure during operation is observed:

(Number of FTS failure at fleet level) x 4.7[19] x (Average operation time) / (Fleet total flight time) < 1E-2

In case the above condition is not met at any point in time of the fleet life, this needs to be reported to the authorizing authority as the FTS would not feature the expected performance.

3.8 Prescriptions for ground buffer definition

The extension of the ground buffer should be such that any termination event would end with the crash of the UA within the ground buffer and not outside. In order to determine such extension, the following factors needs to be considered:

- T: Human and system latencies in the activation of the FTS
- D1: Distance travelled by the UA during time T
- D2: distance travelled by the UA after termination is effectively triggered onboard

Conservatively and as a simple solution:

- T = 3 sec
- D1 = V*T
- V = maximum velocity declared as part of the operational authorization and including worst expected wind conditions (intensity and direction)
- D2 to be determined on the base of the trajectory after termination
  - Velocity vector at termination: horizontal, oriented perpendicularly to the operational volume and at the maximum height of the operational volume.
  - Velocity at termination: V (as above)
  - For rotorcrafts / multirotors: ballistic trajectory with no drag considered
    - D2: projection of the ballistic trajectory on ground, perpendicular to the operational volume

[19] This scatter factor accounts for uncertainties due to a small sample size

- For fixed wing, the distance travelled after termination should be derived as far as possible from tests (carried out in safe scenario) and never be smaller than the one that would be calculated for rotorcraft / multicopters.
  - D2: derived from tests

3.9 FTS Manual

Limits and conditions should be reflected in the operations/maintenance manual of the FTS.

4 Means to reduce impact dynamics (optional)

This MoC does not necessarily require integration in the FTS of *means to reduce UA impact dynamics*[20] (typically a parachute). If such combination is intended, it should be ensured that they do not negatively impact the safety of the operation and the correct operation of the FTS. Correct integration of these *means* would require flight tests to verify correct deployment when triggering the FTS. Such tests could be integrated with the tests above prescribed for the FTS. During the test campaign it should be proved that the means have never been inadvertently activated.

Regarding their performance in terms of capability of reducing kinetic energy, where the objective is the increase of Dpop-adj-max, it is taken into account in chapter 2 (assuming it can be demonstrated that these means operate even when the FTS has not worked appropriately). Specific performance objectives in the PDRA frame, if any, are not herein addressed.

[20] Referred to by the published PDRAs