SUBJECT : **Containment**

REQUIREMENTS incl. Amdt. : **Special condition Light-UAS Medium Risk 01, point Light-UAS.2511**

ASSOCIATED IM/MoC : Yes☐ / No ☒

ADVISORY MATERIAL : **N/A**

INTRODUCTORY NOTE AND IDENTIFICATION OF ISSUE:

EASA received several applications for design verification projects (DVP) focused on enhanced containment (SORA step#9). In the frame of EASA DVPs, SC Light UAS is utilized as design verification basis and Light-UAS 2511 applies for containment[1]:

Light-UAS.2511 Containment

(a) No probable failure of the UAS or any external system supporting the operation must lead to operation outside the operational volume

(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 (risk) 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 address the UAS containment. A flight termination system (FTS) is a system which upon its triggering terminates the flight. By its nature this is an emergency measure, not a contingency measure[2]. Its scope is to ensure that an UAS out of control will not breach into adjacent areas with undefined trajectory but, instead and preferably, is terminated, and its crash / debris areas will be strictly kept within the ground risk buffer.[3]

[1] Requirement 2511 is not driven by the SAIL (i.e. low/medium/high risk) therefore it is not affected by the applicability of the SC to medium risk operations.

[2] A contingency measure is put in place when the UA exits the flight geography with the scope to make the UA flying back within the flight geography. An emergency measure is put in place when the contingency measures were ineffective with the scope of avoiding that the UA enters the adjacent area.

[3] 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 effect of the UA impact dynamics*" (also mentioned in the PDRA) are addressed in the form of "option" in chapter 4 this MoC, 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.

This MoC is meant for a declaration toward the competent authority issuing the operational authorisation for operations up to SAIL II. It provides the possibility, for UAS leveraging FTS, to substantiate, with a simple design checklist and a set of tests, the FTS performances. This MoC does not address the design of the specific UAS with regard to its probability of leaving the operational volume, however it provides a logic according to which a maximum probability can be determined on the basis of the SAIL. Due to the specific FTS design on which this MoC is based, this allows to determine in a simple way the maximum probability of exit from the ground buffer.

Where better performances are needed (either for the operational volume or for the ground risk buffer) the applicant will have to provide evidences beyond this MoC and apply to EASA for a Design Verification Report (DVR)

1. Scope and general approach

This MoC defines a simple set of prescriptions that allow, upon successful compliance demonstration, to reasonably consider that the probability of failure of the installed FTS is below 10^{-2} /Flight Hour (FH) (**$P_{FTSfail} < 10^{2}$ /FH**). Together with the performance of the UAS operation (as represented by the SAIL) and with a design checklist ensuring FTS segregation from the UAS, the probability per flight hour that the UAS may leave the ground risk buffer and exit in adjacent areas / volumes can be deduced [4]. This is explained in the following for a typical SAIL II operation:

— for SAIL II the probability of loss of control / FH is less than 10^{-2} (Ploc < 10^{-2}/FH);

— a loss of control may lead to a crash in the operational volume or an attempt to exit the operational volume[5]. Without specific analysis on the UAS design, it is considered appropriate to assume that the probability that a loss of control would lead to an exit from the operational volume ($P_{UAexitOV}$) is at least 10 times smaller than the probability that it would lead to a crash in the operational volume. Therefore for a SAIL II a **$P_{UAexitOV} < 10^{-3}$ /FH** is assumed;

— when such event occurs, the FTS is triggered to ensure that the crash would still be kept within the ground risk buffer. As this MoC prescribes an FTS segregated[6] from the UAS, the probability that the UAS would exit the ground risk buffer and enter adjacent areas (**$P_{UAexitGB}$**) is obtained as:

$P_{UAexitGB} = P_{UAexitOV} * P_{FTS(fails)} < 10^{-3} * <10^{-2} = <10^{-5}$ /FH.

The application of this MoC for a SAIL II operation substantiates therefore **$P_{UAexitGB} < 10^{-5}$ /FH.**

For SAIL III, **$P_{UAexitOV} < 10^{-4}$ /FH** and compliance with this MoC would substantiate **$P_{UAexitGB} < 10^{-6}$ /FH** . However it should be considered that for SAIL III and above the UAS would be assessed with EASA design verification including the FTS, not only with regard to containment.

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[4] It is considered that an exit from the ground risk buffer would always determine a crash in adjacent areas or, in much fewer and extreme cases, a collision with manned aircraft.

[5] Or, in much fewer cases, a mid-air collision in the operational volume.

[6] Throughout this document "segregated from the UAS architecture" means segregated from the UAS flight control system architecture and from any other element of such architecture whose failure may induce a loss of control, unless such failure would only lead to crash in the operational volume or ground risk buffer.

Regarding Light-UAS.2511 (b)(2) and (b)(3), they can be considered met on the basis of the segregation of the FTS from the UAS architecture.

Applicability of this MoC:

— UAS operated in an operation in the specific category classified up to SAIL II according to SORA;

— UA dimension: recommended for UAS whose characteristic dimension is equal to or less than three (3) meters, in consideration of the limited performance attributed to the FTS. Higher dimensions can be accepted by the competent authority when the kinetic energy or speed are sufficiently low (typically below 34 kJ or 35 m/s respectively)

— UA design: no specific restrictions. For lighter-than-air, normally the ground risk is considered smaller than for heavier-than-air (with equal UA dimension and scenario)[7]. However, the prescriptions to determine the ground risk buffer as indicated in 2.5 are not applicable for lighter-than-air and the criteria to determine such buffer would have to be re-determined in agreement with the authority;

Declaration:

— The nature of this MoC[8] is such that the authority issuing the operational authorisaiton may accept a declaration of compliance.

Means of Compliance with Light-UAS.2511 Containment

2. Introduction

The following chapters provide a design checklist and a set of tests. Their application and successful passing can be utilized to credit an FTS installed on a UAS with a probability of failure < 10-2 / FH.

Where this MoC is used for declaration, the documentation identified in the next paragraphs should still be prepared and kept available for oversight by the authority issuing the operational authorisation or in case the authority requires a DVR issued by EASA.

2.1 Design checklist general requirements

The FTS should be segregated from the UAS flight control system architecture. Such segregation needs to be simply verifiable and comply with paragraphs 2.1.1, 2.1.2 and 2.1.3.

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

[7] This does not prevent the application of this MoC for lighter than air.
[8] Simple analysis of UAS design and a set of tests.

The remote pilot should have means to detect if the FTS is not available due to the failure of any of the elements contributing to its proper functioning.

A design checklist document should be made available and include:

— a high level description of the FTS architecture;

— the FTS installation on the UAS;

— assessment as per chapters 2.1.1, 2.1.2, 2.1.3 with evidence of compliance with each of these chapters;

2.1.1 Segregation of the air segment

The air segment of the FTS[9] should be segregated from the UAS flight control system architecture and from any other element of such architecture whose failure may induce a loss of control, unless such failure would only lead to crash in the operational volume or ground risk buffer. For example, the FTS air segment may use the same power supply of the UAS, 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 not result in loss of containment and loss of the FTS[10].

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 UAS operation within the operational volume. For example, positioning information utilized to trigger the FTS should be provided by different systems (not implying different technology[11]) with respect to the ones utilized during normal operation of the UAS.

2.1.2. Segregation of the ground segment (where applicable)

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

2.1.3 Frequency and frequency diversity

When using radio frequencies for the initiation of flight termination, the frequency band utilized by the FTS should be separated from the frequency band utilised for UAS control[12].

[9] Elements of the FTS installed onboard the UA.

[10] Where this MOC is used in declarative way and not complemented by design verification, the only exception to full architectural segregation should be with regard to power supply.

[11] The need of technology diversity is not considered proportionate in consideration of the limited performance attributed to the FTS on the basis of this MoC.

[12] Should cellular technology be utilized for both C2 and FTS, utilization of different providers is recommended

Where the specific operational volume includes emitting sources of high power radio frequencies[13], the frequencies used by the FTS should not be superimposed with such frequencies.

The flight manual (see chapter 2.3) should provide the relevant information on the frequency bands and avoidance of areas which could cause interference.

2.2 Tests

Adequate performance of the FTS should be verified with the following set of tests as per 2.2.1 to 2.2.4.

A test procedures and result document should be made available to the authority and cover such set of tests.

The documentation should contain date and time of test and test configuration, including FTS and utilised test equipment. Where any test is not passed (FTS not activated, not correctly activated or erroneously activated), the document should record the root cause analysis and investigation of the failure and the change of FTS and/or test equipment configuration that may have been necessary on the basis of such investigation. The series of tests shall not be restarted without the failure event having been recorded and analyzed. Tests shall be considered passed only when bench, ground, flight and end-to-end tests executed consecutively as per chapters below will have been passed. Any failure will require analysis of the root cause, possible modification of the system, justification of such modification and recording in the documentation, re-execution of tests starting from bench tests.

2.2.1 Bench tests on FTS

These tests should be performed on the uninstalled FTS in a controlled environment.

Where manually activated, the operator should trigger the termination function with the ground unit and observe that the correct termination signal is received by the FTS receiver [14].

Where automatically activated, correct activation of the termination signal should be tested providing as input to the FTS those conditions which would cause its triggering in flight[15].

The applicant should perform a number of tests considered adequate on the base of the FTS complexity. At least ten (10) activation tests should be performed[16]. Bench tests are considered passed when the full set of tests is passed consecutively.

2.2.2 Ground integration tests after installation of the FTS on the UAS

These tests need to demonstrate proper activation of the FTS as installed on the UAS and that the desired effect on the UAS is obtained. If the FTS is activated from ground during real operation, the tests should be such to

[13] This would be for example the case in which a UAS is operated near large antennas which are evident from simple oversight of the operational area.
[14] Typically it would be necessary to observe that the signal determining cut of the power to motors is correctly activated.
[15] Where FTS activation would be determined on the base of the position of the UAS or an elaboration of such position, this information should be provided as input to the FTS to cause its activation.
[16] Where FTS activation would be determined on the base of the position of the UAS or an elaboration of such position, this information should be provided as input to the FTS to cause its activation

test the maximum operational distance of the UAS 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.

Where automatically activated, correct activation of the termination signal should be tested providing in input to the FTS those conditions which would cause its triggering in flight. In this case, the activation should be checked for a set of conditions covering uniformly the whole activation envelope, while limiting the granularity of such checks.

Where the FTS deploys a parachute, it is possible to not install the parachute; it is sufficient to ascertain that proper termination of flight would be triggered and that the signal causing parachute deployment is correctly received (without actually causing parachute deployment).

The number of tests performed should be adequate to the complexity of the FTS as installed on the UAS. At least ten (10) activations should be performed. Ground tests can be considered passed when the full set of tests is passed consecutively.

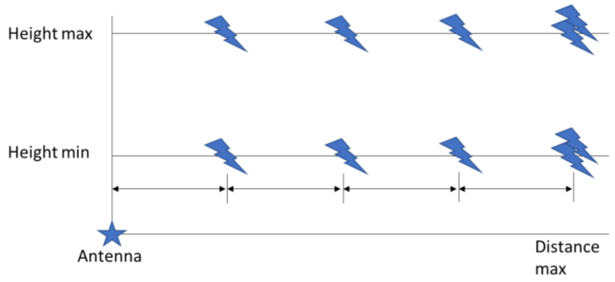
2.2.3 Flight test

Flight tests need to be carried out in low risk scenarios (typically: a VLOS operation in a test location over a controlled ground area, where the probability of encountering another aircraft is negligible and with very low risk in adjacent areas). Flight tests are not considered necessary for UAS with MTOW < 900 grams, unless they are used in lieu of the ground tests.

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.
The following minimum scenarios should be tested:

- UAS flying straight and levelled towards or away to / from the antenna transmitting the termination signal, at the minimum and maximum height expected during the operation (excluding climb and descent segments). At least 10 activations should be triggered:
  - 5 at minimum height, 2 of which testing the maximum distance of operation at that height, the other 3 with approximate equal distribution as depicted below;



— 5 at maximum height, 2 of which testing the maximum distance of operation at that height, the other 3 with approximate equal distribution as above;

— UAS flying straight and levelled in a direction perpendicular to the one of the tests above, same heights as above, same distribution as above;

In case of automatic FTS activation, the conditions / scenario set for activation should lead to automatic termination approximately with the distances and patterns as above.

2.2.4 End-to end activation tests

These tests aim to assess the proper functioning of the FTS system integrated on a particular UAS throughout the entire life of the UAS.

The tests should be carried out using the same FTS-UAS combination that has been subject to the tests specified in 2.2.2 and 2.2.3.

The number of activations (triggering of the FTS and observation of proper operation) should be equal to the number of expected activations of the FTS for its entire life (accounting for pre-flight checks, maintenance checks, return to service checks). The lapse of time in which such tests are performed will depend on the organization of the tests (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 information on these maximum number of activations should be provided in the maintenance manual.

2.3 Flight Manual

The following should be reflected in the UAS flight manual , either as supplement of the manual or integrated:

— Limits and conditions for the FTS, including its frequency band;

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

— A procedure requiring at least one pre-flight check (on-ground) of the FTS installed on the UAS, which needs to be carried out before the first flight of the day on a given site of operation. This check is dedicated to minimize the possibility of latent failures. If the check fails the FTS needs to be replaced before flight, and re-checked. When the FTS is associated with means to reduce impact dynamics (i.e. a parachute), the deployment of such means can be avoided for the pre-flight check provided that all other elements in the chain contributing to proper functioning of the FTS are checked;

— The minimum extent of the ground risk buffer, defined according to point 2.5, should be specified in the flight manual.

2.4 Maintenance Instruction

Maintenance instructions should be established to ensure that the FTS will work as intended throughout the life of the installed system. These should include the necessary actions to be taken after reaching the maximum expected number of activations in accordance with 2.2.4.

As part of maintenance, the in-service reliability of the FTS should be tracked by recording the following data:

— Number of FHs accumulated by the UAS with FTS installed;

— In case of FTS activations failures during pre-flight checks record the FH accumulated by the UAS at time of failed activation;

— In case of FTS activations failures during flight, keep record of:

  — FH accumulated by the UAS at time of failed activation;

  — attempted activation distance between CU and UAS (where applicable);

  — specific location of the operation;

  — presence or not of high power emitters in the operational volume.

— In case of FTS activations during flight keep record of:

  — if activation was commanded or un-commanded;

  — FH accumulated by the UAS at time of activation;

  — distance between the CU and UAS (where applicable);

  — specific location of the operation;

  — presence or not of high power emitters in the operational volume.

If the failure probability observed in service is higher than 10^{-2}/FH (accounting for statistical uncertainty), the operator should report to the competent authority.

2.5 Prescriptions for ground risk buffer definition

The minimum extension of the ground risk buffer should be specified in the flight manual and its value should ensure that any termination event would end with the crash of the UAS only within the ground risk buffer. In order to determine such extension, the following factors need to be considered:

— T: Human and system latencies in the activation of the FTS;

— D1: Distance travelled by the UAS during time T (projected on ground);

— D2: distance travelled by the UAS after termination is effectively triggered onboard (as projection on ground of its trajectory).

Conservatively and as a simple solution:

— T = 3 sec;

— V = maximum UAS cruise speed, or maximum speed declared as part of the operational authorization complemented, for UAS beyond 1 m characteristic dimension, by possible maximum acceleration due to Flight Control System (FCS) failure determining an increase of speed during the latency of 3 sec. Worst expected wind conditions (intensity and direction) should also be considered;

— D1 = V*T;

— D2:

  — For rotorcraft / multirotors apply any of the following options:

    — Compute D2 as projection of a ballistic trajectory on ground, with a maximum of 0.8 drag. The projection should be perpendicular to the operational volume all along the perimeter of such volume. Velocity vector at termination: horizontal, oriented perpendicularly to the operational volume and at the maximum height of the operational volume. Modulus computed according to the above guidance for V;

    — Compute D2 as projection on ground of a glide trajectory with 9 degree incidence angle (same V in modulus and direction);

    — Determine D2 on the basis of tests (V in modulus and orientation as above defined)

  — For Fixed wing apply any of the following options:

    — Determine D2 on the basis of tests (V as above defined);

    — Compute D2 as projection on ground of a glide trajectory with 9 degree incidence angle (V as above defined);

  — When a parachute is deployed as part of the FTS:

    — D2 estimated as (maximum wind considered for the operation)x(height at termination)/(speed of descent with parachute). As a correction should be considered to account for speed at termination, for simplicity D2 as calculated above should be increased of 10%;

    — Determine D2 with tests (taking into account worst environmental conditions and maximum height of operation).

Ground risk buffer = D1 + D2.

Operational considerations might affect ground risk buffer and require a different one with respect to what above assessed, where so established by the competent authority for operational authorization.

3 Means to reduce impact dynamics (optional)

This MoC does not necessarily require integration in the FTS of means to reduce UAS impact dynamics[17] (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.

This MoC does not address the performance of such means in terms of capability of reducing kinetic energy .

[17] Referred to by some published PDRAs.