Joint Authorities for Rulemaking of Unmanned Systems

JARUS guidelines on SORA

Annex D

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Tactical Mitigation
Collision Risk Assessment

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Annex D: Tactical Mitigation - Collision Risk Assessment

1 Introduction-Tactical Mitigation

The target audience for Annex D, is the UAS operator who wishes to apply Tactical Mitigation Performance Requirement (TMPR), Robustness, Integrity, and Assurance Levels for their operation.

Annex D provides the tactical mitigation(s) used to reduce the risk of a Mid Air Collision (MAC). The TMPR is driven by the residual collision risk of the airspace. Some of these tactical mitigations may also provide a means of compliance with ICAO Annex 2 section 3.2, codified in 14 CFR 91.113, “See & Avoid,” SERA 3201, and additional requirements by various states.

The Air Risk Model has been developed to provide a holistic method to assess the risk of an air encounter, and to mitigate the risk that an encounter develops in a Mid Air Collision. The SORA Air Risk Model guides the operator, competent authority, and/or Air Navigation Service Provider (ANSP) in determining whether an operation can be conducted in a safe manner. This Annex is not intended to be used as a checklist, nor does it provide answers to all the challenges of Detect and Avoid (DAA). The guidance allows an operator to determine and apply a suitable mitigation means to reduce the risk of a Mid-Air Collision (MAC) to an acceptable level. This guidance does not contain prescriptive requirements but rather objectives to be met at various levels of robustness.

2 Principles

Mitigation of the risk that an encounter develops into a Mid Air Collision is a highly dynamic, variable, and complicated process. To simplify the process, the Air Risk Model takes a more qualitative approach to arrive at an initial aggregated airspace risk assessment. After an assessment of the initial, unmitigated risk of an encounter, and optional application of strategic mitigations, this Annex assigns a performance requirement on the UAS operation to mitigate the remaining collision hazard (residual airspace risk).

3 Scope, Assumptions and Definitions

See Annex C for scope, and assumptions

See Annex G and/or I for definitions

4 Knowledge of terms and definitions

To understand this section, the following SORA definitions need to be understood:

- Atypical/Segregated vs. Other Airspace (see Annex G)
- AEC (see Annex C and G)
- Initial ARC (see Annex C, G, and I)
- Residual ARC (see Annex C, G, and I)
- ICAO conflict management (see ICAO Doc. 9854, section 2.7)
- Strategic Mitigation (see Annex C and G)
- Tactical Mitigations and feedback loops (see Annex G)
- VLOS and BVLOS (see Annex I)

5 Tactical Mitigation Performance Requirement (TMPR) Assignment

A Tactical Mitigation is a mitigation applied after takeoff and for the air risk model it takes the form of a "mitigating feedback loop." This feedback loop is dynamic in that it reduces the rate of collision by modifying the geometry and dynamics of aircraft in conflict, based on real time aircraft conflict information. For more information on Tactical Mitigations and feedback loops see Tactical Mitigation definition in Annex G.

SORA Tactical Mitigations are applied to cover the gap between the residual risk of an encounter (the residual ARC) and the airspace safety objective. The residual risk is the remaining collision risk after all strategic mitigations are applied.

5.1 Two Classifications of Tactical Mitigation

There are two classifications of Tactical Mitigations within the SORA, namely:

1. VLOS, whereby a pilot and/or observer use human vision to detect aircraft and take action to remain well clear and avoid collisions from other aircraft.
2. BVLOS, whereby an alternate means of mitigation to human vision, as in machine or machine assistance[1], is applied to remain well clear and avoid collisions from other aircraft. (e.g. ATC Separation Services, TCAS, DAA, UTM, U-Space, etc.)

5.2 Tactical Mitigation Performance Requirement (TMPR) using VLOS

Originally the regulations for "See and Avoid" and "Avoid Collisions" of ICAO Annex 2 section 3.2 (codified in 14 CFR 91.111, 113, 181, SERA 3201, and other regulations) assumed a pilot was onboard the aircraft. With unmanned aircraft this assumption is no longer valid as the aircraft is piloted remotely.

Under VLOS the pilot/operator accomplishes "see and avoid" by keeping the UAS within their Visual Line-of-Sight (VLOS). The UAS remains close enough to the remote operator/observer to allow seeing and avoiding another aircraft with human vision unaided by any device other than, perhaps, corrective lenses. VLOS is generally considered an acceptable means of compliance with the "remain well clear" and "avoiding collisions" requirements of ICAO Annex 2 section 3.2., 14 CFR 91.111, 113, 181, SERA 3201, etc.

VLOS generally provides sufficient mitigation for cases where the requirements for tactical mitigations are low, medium, and high. Different states may have other rules and restrictions for VLOS operations (e.g. altitudes, horizontal distances, times for relaying critical flight information, operator/observer training, etc). In some situations the competent authority and/or ANSP may decide that VLOS does not provide sufficient mitigation for the airspace risk, and may require compliance with additional rules and/or requirements. It is the operators' responsibility to comply with these rules and requirements.

The operator should produce a documented VLOS de-confliction scheme, explaining the methods that will be applied for detection and the criteria used to avoid incoming traffic. If the remote pilot relies on

[1] For the purposes of this dissection, systems like Air Traffic Control (ATC) Separation Services would be considered machine assisted.

detection by observers, the use of communication phraseology, procedures, and protocols should be described. Since the VLOS operation may be sufficiently complex a requirement to document and approve the VLOS strategy is necessary before authorization and approval by the competent authority and/or ANSP.

The use of VLOS as a mitigation does not exempt the operator from performing the full SORA risk analysis.

5.3 Tactical Mitigation Performance Requirement (TMPR) using BVLOS

Since VLOS has operational limitations, there was a concerted effort to find an alternate means of compliance to the human "see and avoid" requirements. This alternate means of mitigation is loosely described as "Detect and Avoid (DAA)." DAA can be achieved in several ways, e.g. through ground based detect and avoid systems, air based detect and avoid systems, or some combination of the two. DAA may incorporate the use of varying sensors, architectures, and even involve many different systems, a human in the loop, on the loop, or no human involvement at all.

Tactical Mitigation Performance Requirement (TMPR) provides tactical mitigations to assist the pilot in detecting and avoiding traffic under BVLOS conditions. The TMPR is the amount of Tactical Mitigation required to further mitigate the risks that could not be mitigated through Strategic Mitigation (residual risk). The amount of residual risk is dependent on the ARC. Hence, the higher the ARC, the greater the residual risk, the greater the TMPR.

Since the TMPR is the total performance required by all tactical mitigation means, tactical mitigations may be combined. When combining multiple tactical mitigations, it is important to recognize that the mitigation means may interact with each other, depending on the level of interdependency. This may negatively affect the effectiveness of the overall mitigation. Care must be exercised not to underestimate the negative effects of interactions between mitigation systems. Regardless whether mitigations or systems are dependent or independent, when acting on the same event unintended consequences may occur.

5.3.1 Tactical Mitigation Performance Requirement (TMPR) Assignment Risk Ratio

The SORA TMPR is based on the findings of several studies. These studies provide performance guidance using Risk Ratios. Table 1 shows the SORA TMPR Risk Ratio Requirements derived from those studies. For more information on risk ratios and risk ratios assignments please see Annex G.

Air-Risk Class	Tactical Mitigation Performance Requirement (TMPR)	TMPR System Risk Ratio Objectives
ARC-d	**High Performance**	**System Risk Ratio ≤ 0.1**
ARC-c	Medium Performance	System Risk Ratio ≤ 0.33
ARC-b	Low Performance	System Risk Ratio ≤ 0.66
ARC-a	No Performance Requirement	No System Risk Ratio guidance; although operator/applicant may still need to show some form of mitigation as deemed necessary by the CAA

Table 1- TMPR RR Requirements Table

Table *2* of this Annex provides TMPR Qualitative Criterion as a qualitative means of compliance to help operators translate the risk ratio quantitative values found in table 1 into system qualitative functional requirements. Table 3 provides TMPR Integrity and Assurance Objectives guidance for compliance with the objectives of Table 1.

For the purpose of this assessment the objectives of Table 1 take precedence over the guidance provided in Tables 2 and 3.

5.3.2 TMPR Qualitative Criterion Table

Table *1* below, shows more qualitative criteria for the different functions and levels of the TMPR. The qualitative criteria are divided into five sub-functions of DAA namely: Detect, Decide, Command, Execute, and Feedback Loop. For more information please see Annex G.

	Function	TMPR Level				
		VLOS	No Requirement (ARC-a)	Low (ARC-b)	Medium (ARC-c)	**High (ARC-d)**
Tactical Mitigation Performance Requirements (TMPR)	Detect[1]	No Requirement	No Requirement	The expectation is for the applicant's DAA Plan to enable the operator to detect approximately 50% of all aircraft in the detection volume[2]. This is the performance requirement in absence of failures and defaults. It is required that the applicant has awareness of most of the traffic operating in the area in which the operator intends to fly, by relying on one or more of the following: • Use of (web-based) real time aircraft tracking services • Use Low Cost ADS-B In /UAT/FLARM[3]/Pilot Aware[3] aircraft trackers • Use of UTM Dynamic Geofencing[4] • Monitoring aeronautical radio communication (i.e. use of a scanner)[5]	The expectation is for the applicant's DAA Plan to enable the operator to detect approximately 90% of all aircraft in the detection volume[2]. To accomplish this, the applicant will have to rely on one or a combination of the following systems or services: • Ground based DAA /RADAR • FLARM [3/6] • Pilot Aware [3/6] • ADS-B In/ UAT In Receiver[6] • ATC Separation Services[7] • UTM Surveillance Service[4] • UTM Early Conflict Detection and Resolution Service[4] • Active communication with ATC and other airspace users[5]. The operator provides an assessment of the effectiveness of the detection tools/methods chosen.	A system meeting RTCA SC-228 or EUROCAE WG-105 MOPS/MASPS (or similar) and installed in accordance with applicable requirements.

[1]For an in depth understanding of the derivation, please see Annex G. Detection should be done with adequate precision for the avoidance manoeuvre to be effective.

[2]The detection volume is the volume of airspace (temporal or spatial measurement) which is required to avoid a collision (and remain well clear if required) with manned aircraft. It can be thought of as the last point in which a manned aircraft must be detected, so that the DAA system can performance all the DAA functions. The detection volume in not tied to the sensor(s) Field of View/Field of Regard. The size of the detection volume depends on the aggravated closing speed of traffic that may reasonably be encountered, the time required by the remote pilot to command the avoidance manoeuvre, the time required by the system to respond and the manoeuvrability and performance of the aircraft. The detection volume is proportionally larger than the alerting threshold.

[3]FLARM and PilotAware are commercially available (trademarked) products/brands. They are referenced here only as example technologies. The references do not imply an endorsement by JARUS or the authors of this document for the use of these products. Other products offering similar functions may also be used.

[4]These refer to possible future applications of automated traffic management systems for unmanned aircraft in an UTM/U-space environment. These applications may not exist as such today.

[5]If permitted by the authority. May require a Radio-License or Permit.

[6]The selection of systems to aid in electronic detection of traffic should be made considering the average equipage of the majority of aircraft operating in the area. For example: In areas where many gliders are known to operate, the use of FLARM7 or similar systems should be considered whereas for operations in the vicinity of large commercially operated aircraft, ADS-B IN is probably more appropriate. In areas where aircraft are known not to These refer to possible future applications of automated traffic management systems for unmanned aircraft in an UTM/U-space environment. These applications may not exist as such today. A subscription to these services may be required.

[7]The selection of systems to aid in electronic detection of traffic should be made considering the average equipage of the majority of aircraft operating in the area.

	Function	TMPR Level				
		VLOS	No Requirement (ARC-a)	Low (ARC-b)	Medium (ARC-c)	High (ARC-d)
Tactical Mitigation Performance Requirements (TMPR)	Decide	No Requirement	No Requirement	The operator must have a documented de-confliction scheme, in which the operator explains which tools or methods will be used for detection and what the criteria are that will be applied for the decision to avoid incoming traffic. In case the remote pilot relies on detection by someone else, the use of phraseology will have to be described as well. Examples: • The operator will initiate a rapid descend if traffic is crossing an alert boundary and operating at less than 1000ft. • The observer monitoring traffic uses the phrase: 'DESCEND!, DESCEND!, DESCEND!'.	All requirements of ARC 2 and in addition: 1. The operator provides an assessment of the human/machine interface factors that may affect the remote pilot's ability to make a timely and appropriate decision. 2. The operator provides an assessment of the effectiveness of the tools and methods utilized for the timely detection and avoidance of traffic. In this context timely is defined as enabling the remote pilot to decide within 5 seconds after the indication of incoming traffic is provided. The operator provides an assessment of the failure rate or availability of any tool or service the operator intends to use.	A system meeting RTCA SC-228 or EUROCAE WG-105 MOPS/MASPS (or similar) and installed in accordance with applicable requirements.

	Function	TMPR Level				
		VLOS	No Requirement (ARC-a)	Low (ARC-b)	Medium (ARC-c)	High (ARC-d)
Tactical Mitigation Performance Requirements (TMPR)	Command	No Requirement	No Requirement	The latency of the whole command (C2) link, i.e. the time between the moment that the remote pilot gives the command and the airplane executes the command must not exceed 5 seconds.	The latency of the whole command (C2) link, i.e. the time between the moment that the remote pilot gives the command and the airplane executes the command must not exceed 3 seconds.	A system meeting RTCA SC-228 or EUROCAE WG-105 MOPS/MASPS (or similar) and installed in accordance with applicable requirements.

	Function	TMPR Level				
		VLOS	No Requirement (ARC-a)	Low (ARC-b)	Medium (ARC-c)	**High (ARC-d)**
Tactical Mitigation Performance Requirements (TMPR)	Execute	No Requirement	No Requirement	UAS descending to an altitude not higher than the nearest trees, buildings or infrastructure or ≤ 60 feet AGL is considered sufficient. The aircraft should be able to descend from its operating altitude to the 'safe altitude' in less than a minute.	Avoidance may rely on vertical and horizontal avoidance manoeuvring and is defined in standard procedures. Where horizontal manoeuvring is applied, the aircraft shall be demonstrated to have adequate performance, such as airspeed, acceleration rates, climb/descend rates and turn rates. The following are suggested minimum performance criteria:[10] • Airspeed: ≥ 50 knots • Rate of climb/descend: ≥ 500 ft/min • Turn rate: ≥ 3 degrees per second	A system meeting RTCA SC-228 or EUROCAE WG-105 MOPS/MASPS (or similar) and installed in accordance with applicable requirements.

[10] Low End Performance Representative (LEPR) performance requirments for RTCA SC-228 Study 5

	Function	TMPR Level				
		VLOS	No Requirement (ARC-a)	Low (ARC-b)	Medium (ARC-c)	**High (ARC-d)**
Tactical Mitigation Performance Requirements (TMPR)	Feedback Loop	No Requirement	No Requirement	Where electronic means assist the remote pilot in detecting traffic, the information is provided with a latency and update rate for intruder data (e.g. position, speed, altitude, track) that support the decision criteria. For an assumed 3 NM threshold, a 5 second update rate and a latency of 10 seconds is considered adequate (see example below).	The information is provided to the remote pilot with a latency and update rate that support the decision criteria. The applicant provides an assessment of the aggravated closure rates considering traffic that could reasonably be expected to operate in the area, traffic information update rate and latency, C2 Link latency, aircraft manoeuvrability and performance and sets the detection thresholds accordingly. The following are suggested minimum criteria: • Intruder and ownship vector data update rates: ≤ 3 seconds.	A system meeting RTCA SC-228 or EUROCAE WG-105 MOPS/MASPS (or similar) and installed in accordance with applicable airworthiness requirements.

Table 1; TMPR Qualitative Criterion Table

5.3.3 Effects of Aircraft Equipage on Tactical System Performance

The performance of a tactical mitigation is affected by the equipage of both the UAS and threat aircraft, on an encounter by encounter basis. A tactical mitigation mitigates encounter risk using a set of sub-functions of the detect and avoid routine, namely see/detect, decide, command, execute, and feedback loop. Equipage that aids these sub-functions increases the overall performance of the tactical mitigation system.

The following example illustrates how equipage of both the UAS and threat aircraft effects the overall tactical performance. Given a threat aircraft equipped with a transponder, it is easier for other aircraft to detect and track the threat aircraft. In this case the UAS can equip with a system able to detect and track transponders. However a UAS that mitigates risk by locating the threat aircraft by detecting their transponder (e.g. through TCAS II/ACAS-II), cannot use the same approach to mitigate the risks posed by an aircraft without a transponder.

Tactical Mitigation equipage is not homogeneous within the airspace. Different airspaces have a different mix of equipage. General aviation aircraft tend to be less well equipped than commercial aircraft. There will be differences in the mix of general aviation/commercial aircraft from one location/airspace to another. Based on aircraft equipage, a specific tactical system (e.g. FLARM, ACAS, etc.) could mitigate the risk of a collision in some airspaces and not in others.

Therefore, the operator needs to understand the effectiveness of their tactical mitigation systems within the context of the airspace in which they intend to operate and select systems used for tactical mitigation accordingly. A TCAS II/ACAS-II equipped UAS will not mitigate all encounter risks in an area where sailplanes equipped with FLARM are known to operate.

5.4 TMPR Robustness (Integrity and Assurance) Assignment

Table *2* below lists the recommended requirements to comply with the TMPR Integrity and Assurance Assignment.

Tactical Mitigation Integrity		**LEVEL of INTEGRITY**			
		TMPR: N/A (ARC-a)	**TMPR: Low (ARC-b)**	**TMPR: Medium (ARC-c)**	**TMPR: High (ARC-d)**
TMPR	Criteria	Allowable loss of function and performance of the Tactical Mitigation System: < 1 per 100 Flight Hours (1E-2 Loss/FH)	Allowable loss of function and performance of the Tactical Mitigation System: < 1 per 100 Flight Hours (1E-2 Loss/FH)	Allowable loss of function and performance of the Tactical Mitigation System: < 1 per 1,000 Flight Hours (1E-3 Loss/FH)	Allowable loss of function and performance of the Tactical Mitigation System: < 1 per 100,000 Flight Hours (1E-5 Loss/FH)
Robustness of Tactical Mitigation Systems	*Comments / Notes*	*The requirement is considered to be met by commercially available products. No quantitative analysis is required.*	*The requirement is considered to be met by commercially available products. No quantitative analysis is required.*	*This rate is commensurate with a probable failure condition. These failure conditions are anticipated to occur one or more times during the entire operational life of each aircraft.*	*A quantitative analysis is required.*

Tactical Mitigation Assurance		LEVEL of ASSURANCE			
		TMPR: N/A (ARC-a)	**TMPR: Low (ARC-b)**	**TMPR: Medium (ARC-c)**	**TMPR: High (ARC-d)**
TMPR	Criteria	No Assurance Required.	The operator is declaring that the Tactical Mitigation System and procedures will mitigate the risk of collisions with manned aircraft to an acceptable level.	The operator provides evidence that the tactical mitigation system will mitigate the risk of collisions with manned aircraft to an acceptable level.	The evidence that the tactical mitigation system will mitigate the risk of collisions with manned aircraft to an acceptable level is verified by a competent third party.
Robustness of Tactical Mitigation Systems	*Comments / Notes*				

Table 2; TMPR Integrity and Assurance Objectives

6 Maintenance and Continued Airworthiness

DAA maintenance and continued airworthiness requirements are addressed in the SAIL requirements, please refer to Annex E.