NATO STANDARD

AEP-107

SENSE AND AVOID SYSTEM PERFORMANCE BASED STANDARD

Edition A, Version 1

DECEMBER 2021

NORTH ATLANTIC TREATY ORGANIZATION

ALLIED ENGINEERING PUBLICATION

Published by the
NATO STANDARDIZATION OFFICE (NSO)

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NORTH ATLANTIC TREATY ORGANIZATION (NATO)

NATO STANDARDIZATION OFFICE (NSO)

NATO LETTER OF PROMULGATION

14 December 2021

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Major General, GRC (A)
Director, NATO Standardization Office

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CHAPTER 1 INTRODUCTION

1.1. TERMS AND DEFINITIONS

For the purposes of this document, the following terms and definitions apply.

1.1.1. Definitions

Acceptable Means of Compliance (AMC)	This illustrates a means, but not the only means, by which a regulation can be met and a regulated entity may decide to show compliance by other means. Hence only an authority can agree an alternative to the published Acceptable Means of Compliance. Acceptable Means of Compliance are strongly recommended practices and a justification will be required to the authority if they are not followed. The burden of proof that a regulation is satisfied rests entirely with a regulated entity when alternatives are proposed to the authority. (EMAD 1, 10 OCT 2017)) Note: Use of the terms 'shall' and 'must' within AMC does not preclude the use of alternative means of compliance and apply only if a given AMC is used to demonstrate compliance with the applicable requirement.
Active Surveillance	Surveillance that requires signal transmission from the surveillance equipment.
Airspace Reservation	A defined volume of airspace normally under the jurisdiction of one aviation authority and temporarily reserved, by common agreement, for exclusive use by another aviation authority. (ICAO Doc 9426)
Automatic	The execution of a predefined process or event that requires UAS crew initiation. (STANAG 4671, STANAG 4703)
Availability (data link)	The long-term ratio of the data link actual RF channel operation time to scheduled RF channel operation time. (STANAG 4671)
Catastrophic (failure condition)	Failure conditions that are expected to result in at least uncontrolled flight (including flight outside of pre-planned or contingency flight profiles/areas) and/or uncontrolled crash. Or Failure conditions may result in a fatality to UA crew, ground staff, or third parties. (STANAG 4671)
Command and Control Data Link	A data transmission used for control of the UA that transmits UA crew commands from the UCS to the UA (uplink) and UA status data from the UA to the UCS (downlink).
Communication system	A means that allows ATC communication between the UA crew in the remote control station and the air traffic control service. (STANAG 4671)
Cooperative Aircraft	Aircraft that contain operable equipment for the purposes of identification, e.g. transponder, ADS-B.
Data Link (UAS)	A wireless communication channel between one or more UCS and one or more UA, or between multiple UA. UAS data link data exchange may include but is not limited to exchange of command and control or payload data between UA and UCS. A UAS data link may consist of:

	(1) Uplink – Transmittal of UA crew commands from the UCS to the UA. (2) Downlink – Transmittal of UA status data from the UA to the UCS. (STANAG 4671)
Detect and Avoid	The capability to see, sense or detect conflicting traffic or other hazards and take the appropriate action. (ICAO Annex 2)
Degraded Mode	State of the UAS that reflects a loss of accuracy, capability, or performance in response to a failure of a component or system. (STANAG 4671)
Effective Maximum Range (data link)	Measure of data link coverage over a horizontal distance that is a function of frequency, availability, bit error rate, climate area and altitude.
Electromagnetic Compatibility (EMC)	The ability of equipment or a system to function in its electromagnetic environment without causing intolerable electromagnetic disturbances to anything in that environment. (AAP-06)
Electromagnetic Environment (EME)	The totality of electromagnetic phenomena existing at a given location. (AAP-06)
Electromagnetic Interference (EMI)	Any electromagnetic disturbance, whether intentional or not, which interrupts, obstructs, or otherwise degrades or limits the effective performance of electronic or electrical equipment. (AAP-06)
Electromagnetic Vulnerability (EMV)	The characteristics of a system that cause it to suffer degradation in performance of, or inability to perform, its specified task as a result of electro-magnetic interference. (AAP-06)
Emergency Recovery Capability	Procedure that is implemented through UA crew command or through design means in order to mitigate the effects of critical failures with the intent of minimising the risk to third parties. This may include automatic pre-programmed course of action to reach a predefined and unpopulated forced landing or recovery area. (STANAG 4671)
Enabled/Disabled function	Function that is available but can be activated or not by the UAS crew.
Error	An omission or incorrect action by the UAS crew or ground staff, or a mistake in requirements, design, or implementation.
Failure	An occurrence, which affects the operation of a component, part, or element such that it can no longer function as intended, (this includes both loss of function and malfunction). Note: Errors may cause failures or be the result of failures, but are not considered to be failures.
Failure Conditions	A condition having an effect on the UAS, UAS crew, ground staff or third parties, either direct or consequential, which is caused or contributed to by one or more failures or errors considering flight phase and relevant adverse operational or environmental conditions or external events. (STANAG 4671)
False alert	Situations where the system alerts based on a false track – i.e. a track that is not an aircraft. (AEP-101) Examples of SAA false alerts: Tracks from birds, clutter, not filtered and causing alerting.
Field of Regard	The total angle where detections can be made by the system. (AEP-101)

Flight Control System	The flight control system comprises sensors, actuators, computers and all those elements of the UAS, necessary to control the attitude, speed and flightpath of the UA. (STANAG 4671)
Flight Envelope Protection	A system that prevents the UA from exceeding its designed operating limits. (STANAG 4671)
Flight Termination System	A system to immediately terminate UA flight. (STANAG 4671)
Forced Landing	A condition resulting from one or a combination of failure conditions that prevents the UA from normal landing on its planned main landing site, although the flight control system is still able to maintain the UA as controllable and manoeuvrable. (STANAG 4671)
Function	Intended behaviour of the UAS based on a defined set of requirements regardless of implementation. It may be further broken down to the lowest defined level of a specific action of a system, equipment, and UA crew that, by itself, provides a completely recognizable operational capability (e.g. an airplane heading is a function). One or more systems may contain a specific function or one system may contain multiple functions. (derived from SAE ARP4754A and FAA AC 23.1309-1E)
Guidance Material (GM)	Guidance Material provides additional explanation to assist the application of the requirement and/or explain the Acceptable Means of Compliance.
Hazardous	Failure conditions that either by themselves or in conjunction with increased crew workload, are expected to result in a controlled-trajectory termination or forced landing potentially leading to the loss of the UA where it can be reasonably expected that a fatality will not occur. Or Failure conditions for which it can be reasonably expected that a fatality to UAS crew, ground staff, or third parties will not occur. (STANAG 4671)
Latency (data transfer)	Delay in time between the sending of a unit of data at one end of a connection, until the receipt of that unit at the destination. (STANAG 4671)
Latent	A failure is latent until it is made known to UAS Crew or ground staff.
Latent Failures	An existing fault that has not yet been recognized by the UA crew or ground staff (BSI, BS 4778-3.2 1991; IEC 50-191, 1990).
Line of Sight	A visually unobstructed straight line through space between the transmitter and receiver. In communications, a direct propagation path that does not go below the radio horizon. (STANAG 4671)
Link Budget	The allocation of the maximal acceptable total loss of a radio link between attenuations, gains and operating margins. Link Budget calculation considers the gain and loss factors associated with the antennas, transmitters, transmission lines and propagation environment used to determine the maximum distance at which a transmitter and receiver can successfully operate. (STANAG 4671)
Major	Failure conditions that either by themselves or in conjunction with increased crew workload, are expected to result in an emergency landing of the UA on a predefined site where it can be reasonably expected that a serious injury will not occur. Or

	Failure conditions which may result in injury to UAS crew, ground staff, or third parties. (STANAG 4671)
Malfunction	Failure of a system, subsystem, unit, or part to operate in the normal or usual manner. The occurrence of a condition whereby the operation is outside specified limits.
Means of Compliance (MoC)	The techniques that will be used to demonstrate the compliance of the type design against each certification requirement identified in the Certification Basis. (EMAD 1) In this document, following means are defined: • Analysis (includes experience, similarity, proof of design) • Simulation • Inspection • Test (includes lab, ground, flight)
Minor	Failure conditions that do not significantly reduce UAS safety and involve UAS crew actions that are well within their capabilities. These conditions may include a slight reduction in safety margins or functional capabilities, and a slight increase in UAS crew workload. (STANAG 4671)
Must	Used to indicate a mandatory requirement (see also “shall”). (STANAG 4671)
Non-cooperative Aircraft	Aircraft that do not contain operable equipment for the purposes of identification.
Nuisance alert	Situations where an alert is issued but the situation is otherwise safe (AEP-101) Examples of SAA nuisance alerts: alerting logic taking into account (sensor, flight path prediction) uncertainty may also issue warnings for encounters that are safe but cannot be assessed as safe by the implemented logic.
Operational Envelope	Defines boundaries in terms of speed, altitude and load factor within which the UAS must be capable of operating in order to accomplish its missions. (derived from MIL-F-8785C)
Passive Surveillance	Surveillance that does not employ signal transmission from the surveillance equipment.
PBCS/PBN (RCP, RNP, RSP)	Communication, Surveillance and Navigation based on performance requirements for aircraft operating in a designated airspace. Note: This PBS assumes that the airspace is also specified in terms of performance based communication, navigation and surveillance. If not, the UAS shall be equipped with the CNS equipment as required for operations in the designated airspace.
Permissible Envelope	Permissible: Encompass all regions in which operation of the UAS is both allowable and possible. Defines boundaries in terms of speed, altitude and load factor. (derived from MIL-F-8785C)
Resolution manoeuvre	Any manoeuvre to remain well clear from or avoid collision with another airspace traffic.

Risk Ratio	The ratio of the risk of collision with SAA to the risk of collision without SAA. (AEP-101)
RLP	Required link performance of data links, in terms of bandwidth, update rates, availability, integrity and continuity of service.
Sense and Avoid	Detect and Avoid of other aircraft in flight for unmanned aircraft systems. (AEP-101) Note: SAA only addresses the sense and avoid of other aircraft in flight, rather than additional hazards, such as birds, terrain, obstacles, weather, and aircraft on the ground.
SAA Equipment	Technical components developed and integrated for the specific SAA function. (AEP-101)
SAA system	An integrated composite of people, products, and processes that provide the SAA capability, which is to sense and avoid other aircraft in flight and thus protect against mid-air collisions. (derived from AOP-15) Functionally, an SAA system at its highest level consists of: the UAS itself, the operator, the human machine interface (HMI), surveillance, alerting and guidance, monitoring, and system support elements. (AEP-101)
Shall	Used to indicate a mandatory requirement (see also “must”).
Should	Used to indicate a preferred, but not mandatory, requirement.
Situational awareness (S/A)	S/A is the knowledge of the elements in the operational environment allowing to make well informed decisions; for the UA Operator such as: • respond to ATC queries • monitor traffic in the UA surrounding airspace • monitor erratic SAA system data • monitor resolution manoeuvres
Suppressed function	Function that is made unavailable, e.g. by the SAA equipment.
Surveillance data	Traffic information used for S/A and required by the SAA system to determine resolution manoeuvres.
UA Control Station (UCS)	A facility or device from which a UA is controlled and/or monitored for all phases of flight. (STANAG 4671)
UA Crew	One or more qualified people responsible for monitoring and controlling the flightpath, flight status, and functions of one or more UA. Includes the UA Operator and also all support crewmembers responsible for operating on-board systems (e.g. payload). (STANAG 4671)
UA Operator	The UA crew member in the UA Control Station tasked with overall responsibility for operation and safety of the UAS. Equivalent to the pilot in command of a manned aircraft. (ATP-3.3.8.1/STANAG 4671)
UAS eligibility criteria	Criteria that need to be reviewed for compliance in order for the UAS type to be eligible for an operational approval.
Uncontrolled Crash	A condition resulting from one or a combination of failure conditions that prevents the flight control system from maintaining the UA controllable and manoeuvrable until impact on the ground. (STANAG 4671)
Uncontrolled Flight	A condition resulting from one or a combination of failure conditions that result in loss of UA control and/or manoeuvrability. Uncontrolled flight

	includes flight outside of pre-planned or contingency flight profiles/areas. (STANAG 4671)
Unmanned Aircraft (UA)	An aircraft that does not carry a human operator and is operated remotely using varying levels of automated functions. (AAP-15) Moreover, a UA: • Is capable of sustained flight by aerodynamic means, • Is remotely piloted or automatically flies a pre-programmed flight profile, • Is reusable, Is not classified as a guided weapon or similar one shot device designed for the delivery of munitions. (STANAG 4671)
Unmanned Aircraft System (UAS)	A system whose components include the Unmanned Aircraft (UA), the UA control station and any other UA System elements, equipment and personnel necessary to enable flight such as a command and control data link, communication system and take-off and landing element. There may be multiple UA, UCS, or take-off and landing elements within a UAS. (derived from AAP-06 and STANAG 4671)
Verification / Validation	Verification is the process for determining whether or not a system or system element fulfills the requirements or specifications established for it. (derived from ISO/IEC 15288) Validation is the assessment of a system to meet the operational needs of the user in its intended environment. (derived from ISO/IEC 15288)
Workload	The amount of work assigned to or expected from a person in a specified time.

1.1.2. Acronyms

ACAS	Airborne Collision Avoidance System
ACNS	Airborne Communications, Navigation and Surveillance
ADS-B	Automatic Dependent Surveillance - Broadcast
AGCAS	Automatic Ground Collision Avoidance System
ALS	Acceptable Level of Safety
ALT	Altitude
AMC	Acceptable Means of Compliance
AoA	Angle of Attack
ARES	Airspace Reservation/Restriction
ATC	Air Traffic Control
ATS	Air Traffic Service
C2	Command and Control
CA	Collision Avoidance
CAT	Catastrophic
CFIT	Controlled Flight Into Terrain
CNS	Communication, Navigation, Surveillance
CPA	Closest Point of Approach
CS	Control Station
CV	Collision Volume
DAA	Detect And Avoid
DAL	Development Assurance Level
E3	Electromagnetic Environmental Effects
FCS	Flight Control System
FDAL	Function Development Assurance Level
FH	Flight Hours
FL	Flight Level
FOR	Field of Regard
FMS	Flight Management System
GA	General Aviation
HAZ	Hazardous
HF	Human Factor
HMI	Human Machine Interface
HW	Hardware
IAS	Indicated Airspeed
ID	Identification/Identifier
IDAL	Item Development Assurance Level
iSMT	Initial Shared Mission Trajectory
KIAS	Knots Indicated Airspeed
LOA	Level Of Automation
MAC	Mid Air Collision

MAJ	Major
MOC	Means of Compliance
MMS	Mission Management System
MTBF	Mean Time Between Failure
NMAC	Near Mid Air Collision
PBS	Performance Based Standard
PBCS	Performance Based Communication and Surveillance
PBN	Performance Based Navigation
POD	Probability of Detection
RCP	Required Communication Performance
RLP	Required Link Performance
RNP	Required Navigation Performance
RR	Risk Ratio
RSP	Required Surveillance Performance
RTSP	Required Total System Performance
RWC	Remain Well Clear
S/A	Situational Awareness
SAA	Sense And Avoid
SW	Software
TAS	True Airspeed
TCDS	Type Certificate Data Sheet
UA	Unmanned Aircraft
UAS	Unmanned Aircraft System
WC	Well Clear

1.2. BACKGROUND

1. NATO's objective is for military UAS, operated by an Alliance member, to be able to operate across borders in another NATO nation, with similar procedures as in existing multilateral agreements for manned military aircraft. However, several barriers have prevented similar acceptance and access as manned military aircraft, including airworthiness and SAA. In 2018, NATO first published a guidance and recommended practice SAA standard (AEP-101) to provide foundational concepts for the development and certification of SAA systems. This standard extends the guidance and recommended practice in AEP-101 to include certification requirements and the associated acceptable means of compliance (AMC). AEP-101 remains valid and provides amplifying guidance material—it is referenced specifically when applicable and appropriate.

2. Given the diverse current and anticipated SAA technologies and architectures, this standard is performance-based rather than prescriptive. Performance based requirements are non-prescriptive in that they are architecture and technology agnostic. Therefore, performance-based requirements enable greater flexibility, although the requirements and means of compliance must be comprehensively defined. The requirements and AMC are defined at the boundary between the SAA function and the environment. Requirements at this level are considered to define the required total system performance (RTSP), consistent with ICAO performance-based concepts[1]. The level at which requirements are defined is depicted by the boundary in Figure 1-1. Specifying requirements at the RTSP level provides the maximum amount of technology and architecture flexibility, while ensuring total system performance in the ATM environment. However, standardizing the RTSP requires the applicant to demonstrate compliance of the total system function, including components that may not be considered SAA specific equipment, such as the communications link and operator response. Additionally, interfaces can only be standardized at the SAA function boundary, which may include the interface with collision avoidance systems on intruder aircraft.

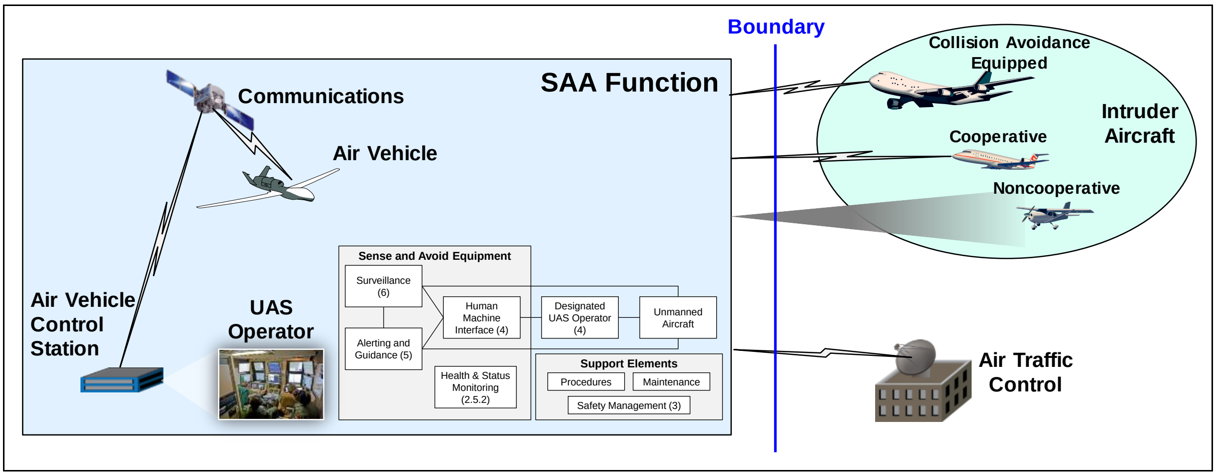

Figure 1-1: Specification Level for Performance Based Requirements

3. NATO is not the sole organization developing SAA standards. Of specific note are high-level ICAO DAA standards that are under development and industry prescriptive DAA standards that have been published or are in the development cycle—e.g., by RTCA, EUROCAE, ASTM. It is not the purpose of this document to replace or substitute for any of

[1] ICAO Doc 9883 First Edition dated 2009 – Manual on Global Performance of the Air Navigation System

these standards. Rather, this standard provides high-level requirements consistent with the ICAO standards under development and a means to demonstrate compliance of specific SAA systems, to include prescriptive DAA standards. This standard is necessarily a military standard; however, SAA systems on military UAS must operate in a civil environment. Therefore, the relationship to civil standards enables military operations, in addition to the standard being largely applicable to civil operations.

4. The primary anticipated use of this standard is by the applicant and appropriate certification, airworthiness, and operational approval authority. The standard will serve as a certification basis for the SAA equipment that can be tailored by the certification authority. It will also provide evidence within the airworthiness approval of the installed SAA equipment. Lastly, the standard will provide assurance to the operational approval authority that the system has been appropriately validated in the applicable operational environment.

5. Special note must be taken of the initial NATO approval of this standard by a Standardization Recommendation (STANREC): thus, this standard is non-binding, is employed on a voluntary basis, and does not require commitment of Allies to implement the standard[2]. It is anticipated that this standard will transition to Standardization Agreement (STANAG) ratification when further validated by nations and industry; therefore, please convey any feedback, lessons learned, or other validation information to the custodian reported in the covering STANREC. The standard is being published at this stage because several nations have expressed interest in early use.

1.3. PURPOSE AND SCOPE

1. This document provides certification requirements to be complied with in order to certify an SAA system and performance metrics to be demonstrated in order to approve SAA system equipped UAS operations in a designated airspace. The certification requirements are defined for the SAA system and are made up of functional requirements and installation/integration requirements into the UAS. The performance requirements are defined for an SAA equipped UAS operating in its intended environment.

2. This performance-based standard (PBS) is SAA system, UAS and airspace agnostic. It supports:

a. The airworthiness certification of an SAA system (Chapter 3)
    a. Generic functional requirements independent of the intended UAS airspace of operations (Section 3.2)
    b. Functional requirements to be further specified for the intended UAS airspace of operations (Section 3.2)
    c. Installation & integration requirements (Section 0)

b. The operational approval through the demonstration of the airspace safety performance metrics achieved by the SAA system equipped UAS, appropriately validated in the designated operational environment. (Chapter 2)

[2] NATO AAP-03 Directive for the Production, Maintenance, and Management of NATO Standardization Documents, Edition K Version 1, 2018

3. Requirements as part of the PBS stated as *shall* and *must* are considered as an imperative when citing this STANREC as a certification basis. Requirements stated as *should* are considered to be recommendations.

4. Performance metrics are a quantitative definition of the required airspace safety level performance and dictate the specification of the functional requirements for the intended UAS airspace of operations.

5. *Is* criteria are used for specific UA features, external to the SAA system, in order for the UAS to be eligible for the operational safety demonstration.

6. Note that references are defined in the text when necessary. If a reference to a specific document version is necessary, the version is explicitly defined; otherwise, the most recent version of the reference should be used.

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CHAPTER 2 SAA SYSTEM SAFETY PERFORMANCE DEMONSTRATION

2.1. BACKGROUND

1. An operational approval authorizes an operator to carry out defined UAS operations with an SAA system equipped UAS in the designated operational environment. The operational approval is the top-level approval for UAS operations and consists of airworthiness, continued airworthiness (type certificate scope) and flight operations elements.

2. This section only addresses the SAA system safety in the airspace performance demonstration, which is only one criteria to be met for granting an operational approval. Additional criteria such as procedures, training and in-service support must be defined for an operational approval as a prerequisite for seamless airspace integration.

2.2. AIRSPACE SAFETY PEFORMANCE METRICS & THRESHOLDS

2.2.1. Airspace Safety Performance Metrics

1. The following three metrics, their associated airspace safety severity classes, and thresholds shall be used to quantify the level of SAA system equipped UAS safety performance in the designated airspace(s), for both the initial safety demonstration and safety monitoring during operations. Quantitative thresholds are defined in Section 2.2.2.

Table 2-1: Airspace Safety Performance Metrics

Performance Metric	Airspace Safety Severity	Threshold
Mid Air Collision	Catastrophic	N1
NMAC (collision volume infringement)	Hazardous	N2
Well clear volume infringement	Major	N3

2. The safety demonstration is conservatively based on a number of collision volume (CV) infringements considered as NMAC. From this figure, the real number of collisions may be estimated based on the ratio of MAC/NMAC by taking the “metal” to “air” volume ratio. This probability of collision in the CV is sometimes called providence and may vary for different categories of traffic, based on the traffic size, shape, and the collision geometry.

3. The airspace safety severity classification is based on the airspace safety classification scheme (see GM.0001) and provides a risk reference system for the events defined as a performance metric. Depending on the severity, each metric requires a specific safety threshold.

4. For initial safety demonstration the metrics are expressed per encounter or as a risk ratio, for safety monitoring during operations they are expressed per UAS FH and in relation to encounters (see Section 2.6). The derivation of thresholds [per flight hour, FH^{-1}] from risk ratios shall be defined (see GM.0002).

2.2.2. Nominal RR thresholds

The following are thresholds for the N2 and N3 metrics, expressed as logic risk ratios (RR). The risk ratio is the ratio of the risk of collision with SAA to the risk of collision without SAA (see AEP-101 Ed. A Ver. 1 Chapter 3 for risk ratio guidance material). These logic risk ratio thresholds reflect the nominal performance: nominal conditions are broadly defined as the system, including all subsystems, operating within specified performance and the specified operational environment, and all equipment properly functioning—i.e., no equipment degradations or failures. If different reference volumes are used, the risk ratio may need to be adapted accordingly. Note that these thresholds are for the full SAA capability—e.g., not only the CA or RWC alerting and guidance for the NMAC and WC risk ratios, respectively.

Table 2-2: N2 & N3 Nominal Thresholds†

<table>
<tr><th>Intruder Equipage and Reference Volume</th><th>Nominal NMAC RR (N2)</th><th>Nominal WC RR (N3)</th></tr>
<tr><td>Reference volume</td><td>NMAC Volume:
500 ft horizontal,
±100 ft vertical</td><td>Well Clear volume:
RTCA DO-365 volume††</td></tr>
<tr><td>System with coordinating and responding Collision Avoidance</td><td>≤ 0.04*</td><td rowspan="2">≤ 0.4**</td></tr>
<tr><td>Transponder equipped (appropriate mix of Mode C, S, ADS-B per airspace)
(based on all encounters, not limited by SAA system FOR)</td><td>≤ 0.18*</td></tr>
<tr><td>Non-cooperative
(based on all encounters, not limited by SAA system FOR)</td><td>≤ 0.3‡</td><td>≤ 0.5**</td></tr>
</table>

†These thresholds align directly with current ICAO RPAS Panel recommendations (RPASP/12-WP/4), and are based on the general perspective that SAA must be at least as safe as existing applicable systems: specifically, ACAS and manned aircraft see-and-avoid.

*ICAO Annex 10 Vol IV, Ed. 5, 2014, Section 4.4.3.

‡A Candidate Approach For Deriving Top-Level Sense And Avoid (SAA) System Requirements (Part 1) - Adam G. Hendrickson – US Army RDECCOM Technical Report RDMR-TM-15-01, November 2015.

**The system must have some efficacy at mitigating losses of well clear; these values are approximately the square root of the collision avoidance (NMAC) risk ratios.

††The RTCA DO-365 well clear volume is defined as $\tau_{mod} = 35\,s, HMD = 4000\,ft, DMOD = 4000\,ft, and\ h = 450\,ft$ where $\tau_{mod} = \frac{-(r^2 - DMOD^2)}{r\dot{r}}$, r is the range, $\dot{r}$ is the range rate, HMD is the projected horizontal miss distance at closest approach, DMOD is the distance modification, and h is the vertical separation (see RTCA DO-365 Appendix C for more details).

2.2.3. Off-Nominal Thresholds

Following are thresholds for the N2 and N3 metrics, expressed as system risk ratios. These thresholds encompass the nominal and off-nominal performance and are the logic risk ratio requirements inflated by the greater of 1/3 the logic risk ratio or 0.04. The following table applies this inflation factor to Table 2-2. Off-nominal, or abnormal, conditions may include the system, including any subsystem, operating outside of the specified performance, operating outside of the specified operational environment, or equipment degradations or failures: namely, degraded/loss of command and control data link and SAA equipment failures. If the off-nominal risk is left unbounded, then the system may not satisfy anticipated total risk reduction performance in operation.

Table 2-3: N2 & N3 Combined Nominal and Off-Nominal Thresholds

<table>
<tr><th>Intruder Equipage and Reference Volume</th><th>System CA RR (N2)</th><th>System WC RR (N3)</th></tr>
<tr><td>Reference volume</td><td>NMAC Volume: 500ft horizontal, +/-100 ft. vertical</td><td>Well Clear volume: RTCA DO-365 volume.</td></tr>
<tr><td>System with coordinating and responding Collision Avoidance</td><td>≤ 0.08</td><td rowspan="2">≤ 0.53</td></tr>
<tr><td>Transponder equipped (appropriate mix of Mode C, S, ADS-B per airspace) (based on all encounters, not limited by SAA system FOR)</td><td>≤ 0.24</td></tr>
<tr><td>Non-cooperative (based on all encounters, not limited by SAA system FOR)</td><td>≤ 0.4</td><td>≤ 0.67</td></tr>
</table>

The likelihood of some off-nominal conditions can be quantified while for others the likelihood is unquantifiable. For example, it is typically possible to quantify the failure likelihood of equipment or the availability of a C2 link, but it may not be possible to quantify the likelihood of hazardously misleading information or unobserved conditions, such as civil aircraft operating beyond airspace speed limits. See AEP-101 Ed. A Ver. 1 Section 3.2 for guidance material.

2.3. DESIGNATED OPERATIONAL ENVIRONMENT CHARACTERIZATION

1. The operational environment, or airspace, characterization is required in each type of airspace in order to assess the suitability of the SAA system in its operational environment but also to derive subsystem requirements.

2. Airspace characterization encompasses:

   a. Traffic characterization (to assess sensor specifications compliance)

   b. Encounter characterization (to be used for fast time simulations)

   c. Traffic densities characterization (to be used for sensor specifications and risk ratio evaluation against a TLS)

   d. Airspace classification characterization

   e. Atmospheric conditions characterization

   f. UAS operations characterization

2.3.1. Traffic characterization

1. The traffic to be encountered in the intended airspace of operations shall (2301) be characterized in order to define the SAA surveillance sensors minimum performance required to detect and track such traffic at the required distance and time to ensure at least collision avoidance and/or well clear separation.

2. The traffic should be divided into cooperative and non-cooperative traffic. Within these categories, traffic groups/classes should be defined.

2.3.2. Encounter characterization

1. The encounters used in the fast time simulations (for risk ratios demonstration) shall (2302) be representative of the traffic flight path geometries and dynamics in the intended airspace of operations and the UAS usage. Each flight path that may result in an alerting of the UAS (for RWC or CA) is considered to be an encounter.

2. Sufficient traffic data shall be recorded in order to develop the encounters model. If insufficient data is available (due to limited coverage in time or area), this data shall be completed by realistic flight paths.

3. Encounter representations (or models) need to consider encounter differences due to traffic and/or ATM considerations (e.g. ATC separation provided).

2.3.3. Traffic densities characterization

Traffic densities and distribution of traffic categories within the intended airspace of operations shall (2303) be known because:

a. Traffic densities affect the encounter rate (ambient risk) when estimating the level of safety (note that the encounter rate also depends on factors such as the airspace organization).

b. Maximum traffic density defines the maximum number of traffic to be detected/tracked simultaneously by a sensor.

c. The encounters used in simulation shall be representative of the traffic categories/groups distribution (e.g. percentage of non-cooperative and cooperative traffic).

2.3.4. Airspace Classification

The structure of the intended airspace of operations shall (2304) be characterized, mainly by defining the airspace boundaries (altitude and area) and the mandatory CNS equipment and operating procedures (ATS provision: separation, information) that may affect SAA performance (e.g. surveillance sensor, ATC radio).

2.3.5. Atmospheric conditions characterization

1. The UAS shall (2305) be certified to operate in certain environmental conditions specific to the intended area of operations (see e.g. MIL-HDBK-310) which will affect the SAA equipment performance (e.g. ice accretion of unprotected areas like antennae, turbulence) and qualification (see e.g. MIL-STD-810 or RTCA DO-160).

2. The SAA sensors performance shall be characterized for the atmospheric conditions applicable to the intended type of operations:

  a. For operations in VMC (defined through horizontal and vertical distance to clouds or visibility of the surface, and visibility), this will require at least rain rate 4 mm/h.[3] Local rain shower conditions may require a higher rain rate, but in a reduced portion of the FOR. A smaller rain rate requirement may be possible if the UAS crew is informed on the rain rate prevailing in the area of operations and may avoid these areas.

2.3.6. UAS operations characterization

The UAS usage shall (2306) be characterized by parameters that affect SAA, meaning:

  a. the mission time distribution (%) in the airspace structure as defined under 2.3.4. or corresponding altitude layers

  b. the mission time distribution (%) between loiter, transit flights (cruise, climb and descent) in the airspace structure and their associated distribution in speed, turn rates and ROC/ROD

2.4. UAS ELIGIBILITY CRITERIA

A UAS must be eligible to operate in a designated airspace. Eligibility criteria determine if an airworthy UAS is capable of operating in a designated airspace. The UAS eligibility criteria related to the SAA capability are limited to the UAS SAA system airworthiness and UAS capabilities that may affect the probability of another traffic being able to sense and avoid the UAS (e.g. lights, paint scheme, CNS equipment).

[3] Probabilistic Parameterizations of Visibility Using Observations of Rain Precipitation Rate, Relative Humidity, and Visibility, Gultepe & Milbrandt, Journal of applied meteorology and climatology, Jan 2010

Table 2-4: UAS Eligibility Criteria

Criteria ID	Criteria title	Criteria	Review of compliance
2400	**UAS ELIGIBILITY**		
2401	SAA system certification	The SAA system complies with the requirements as listed in Chapter 3.	Inspection of UAS standard (e.g. TCDS)
2402	ACNS compliance	The UAS is qualified to the RCP, RNP and RSP level required for operations in the designated airspace.[4]	Inspection of UAS standard (e.g. TCDS)
2403	UAS lighting	The UA is equipped with the lights (e.g. navigation, position, strobe, anti-collision, landing, taxi) required for the intended type of operations and meteorological conditions (e.g. VMC, IMC, day/night)	Inspection of documentation (drawings)
2404	UAS paint scheme (conspicuity)	The UA has a paint scheme that is similar in terms of visible signature to a traffic of similar dimensions that may be encountered in the designated airspace of operations.	Inspection of documentation (drawings)
2405	Compliance with flight rules (IFR/VFR)	The UA is equipped with minimum equipage requirements imposed by the intended flight rules within the designated airspace classification it flies in	Inspection of UAS standard (e.g. TCDS)

2.5. OPERATIONAL SAFETY PERFORMANCE DEMONSTRATION

1. The operational safety performance demonstration shall take into account the UAS assumed operations and associated distribution of flight profiles, configurations and predicted reliability (including degraded performance), and designated airspace (as characterized). Representative data must be used for operational safety performance demonstrations. Representative data shall accurately reflect the performance of the simulated item. If this is not feasible, conservative performance can be modelled to account for data inaccuracy.

2. The demonstration should rely mainly on statistical evidence brought by simulations to be validated by tests (e.g. flight tests) for specific scenarios. However, the applicant is to propose a compliance demonstration that fulfils the performance requirements. Additional

[4] RNP indirectly affects the SAA performance as it defines the navigation data performance (primarily accuracy, integrity & OPMA) that will be available to the (cooperative) surveillance sensors.

guidance concerning the operational safety performance demonstration is provided in the AMC.

Table 2-5: Operational Safety Demonstration

Req. ID	Req. title	Requirement
2500	**OPERATIONAL SAFETY DEMONSTRATION**	
2501	Risk ratio demonstration, nominal conditions	The NMAC and well clear risk ratios for nominal conditions shall be demonstrated against the mandatory thresholds in Table 2-2.
2502	RR demonstration, abnormal conditions	The NMAC and well clear risk ratios incorporating abnormal conditions and degraded performance shall be demonstrated. The risk ratios should be evaluated against the thresholds in Table 2-3.
2503	RR demonstration, encounter sets	The encounters and traffic used in simulations shall be representative of those likely to be encountered by the UA in the UAS designated airspace of operations.
2504	RR demonstration, dynamic model	The UAS dynamic model used in simulations shall be representative of the UAS and cover the complete UAS operational or permissible envelopes
2505	RR demonstration, timing model	The latencies and processing times affecting the SAA system performance used in simulations shall be representative of the UAS configurations.
2506	RR demonstration, operator model	The operator response model used in the simulations shall be representative of the operator qualified for the UAS type.
2507	RR demonstration, surveillance model	The surveillance sensors performance models (in terms of FOV/FOR, accuracy, detection/tracking range, latencies, update rates and POD) used in the simulations shall be representative of the SAA surveillance sensors as installed in the UAS and for the atmospheric conditions specified.
2508	ACAS interoperability	The SAA system manoeuvres (automatic or guided) shall be interoperable with any other ACAS already approved in the designated airspace of operations.
2509	Operational validation	The SAA system equipped UAS safety performance shall be validated in operational conditions.

2.6. OPERATIONAL SAFETY MONITORING

1. The safety metrics collected during operational safety monitoring shall be expressed in relation to UAS fleet hours but also in relation to encounters for monitoring (this is consistent with the traditional practice of MIL-STD-882, or similar national guidance, for military systems).

2. The encounters shall be characterized, for example:

a. Alert frequency (numbers of RWC or CA manoeuvres recommended/initiated by the SAA system) and types (e.g. horizontal manoeuvre, combination/blended manoeuvre)

b. Encounter types (e.g., relative encounter geometry, airspace class)

c. Intruder categories (cooperative, non-cooperative)

3. The UAS fleet usage shall be characterized, for example:

d. Day/night

e. Altitude layers (e.g. above or below FL100)

f. Airspace classes (e.g. controlled, uncontrolled)

g. Manoeuvres characteristics (turn rates, climb rates, etc.) consistent to the encounters characteristics.

4. The monitoring will support continuous validation of the assumptions used for initial demonstration. Monitoring of health and performance metrics specific to the SAA system (e.g. number of tracks produced, split tracks, types of traffic detected within FOR, MTBF, etc.) and to the UAS functions supporting SAA (e.g. C2 link loss) will support continuous validation of airspace characterization (e.g. densities) and/or assumptions used for initial demonstration (e.g. C2 link availability).

Table 2-6: Operational Safety Monitoring

Req. Nr	Req. title	Requirement
2600	**OPERATIONAL SAFETY MONITORING**	
2601	Safety monitoring	The SAA system shall record event data to support safety metrics (N1-N3) monitoring.
2602	SAA system performance monitoring	SAA health & performance metrics shall be recorded and monitored.

CHAPTER 3 SAA SYSTEM CERTIFICATION REQUIREMENTS

3.1. BACKGROUND

1. The SAA system certification requirements are made of functional requirements (Section 3.2) and installation/integration requirements into the UAS (Section 3.3). The functional requirements ensure that the SAA system is appropriate to its intended functions. The installation and integration requirements ensure that the SAA system is properly installed, functions properly and does not negatively affect safe flight. The certification requirements support the issuance of UAS type certificates (initial certification) as well as changes to those certificates.

2. The resulting installed SAA system equipped UAS performance associated to the SAA system functions needs to be verified (certified in case of a verification by a State authority) and specified as input data or models to be used in the airspace safety demonstration (Chapter 2).

3.2. FUNCTIONAL REQUIREMENTS

Table 3-1: Functional Requirements

Req. ID	Req. title	Requirement
3200	**SAA HIGH-LEVEL FUNCTIONAL REQUIREMENTS**	
3201	Required functions	The SAA system shall provide the following functions: - Traffic Surveillance - Alerting for remain well clear and collision avoidance - Guidance and resolution manoeuvres - Support functions (Status reporting and recording)
3202	Recommended functions	The SAA system should provide guidance for resolution manoeuvres.
3203	Traffic categories and densities conditions	The SAA system shall provide the required function(s) and specified performances for categories and densities of traffic for the intended airspace of operations.
3204	Atmospheric conditions	The SAA system shall provide the required function(s) with the performances applicable for the atmospheric conditions to be encountered in the intended area of operations.
3205	Reliability	The reliability of each individual item of the SAA system and in combination shall be specified for the intended operational conditions.
3206	External systems dependency	The residual performance level of the SAA system in case of external systems unavailability (e.g. GNSS denied environment) shall be specified by the applicant.

3207	DAL related to Airspace safety	The SAA system functions that may impact airspace safety shall be assigned a development assurance level (DAL) that corresponds to the hazard severity in accordance with airspace safety regulations.
3208	Security	The SAA system shall be resistant against cyber security threats to be expected within the intended environment.
3220	**TRAFFIC SURVEILLANCE**	
3221	Traffic Surveillance detection 1	The detection of traffic shall be a at a range and time with an accuracy that allows the operator to manoeuvre its UA in order to remain well clear from any other traffic considering the operating rules to be specified.[5]
3222	Traffic surveillance detection 2	The detection of the collision threat shall be at a range and time with an accuracy that allows a collision avoidance manoeuvre that results in a safe avoidance.
3223	Sensor combination	The SAA system shall function with any individual sensor or a combination thereof. Allowable sensor combinations shall be defined by the applicant with corresponding performance level for each combination.
3224	Active sensors	If the SAA system incorporates active sensors, the SAA system shall not degrade performance of interoperable systems installed in other traffic or ground infrastructure.
3225	Data monitoring	The accuracy, integrity, availability and continuity of the data processed by the SAA system from ownship or from traffic shall be monitored and controlled.
3226	Insecure surveillance data validation	Surveillance data obtained through insecure means (lacking basic security measures[6]) or where integrity cannot be monitored shall be validated by a second means.
3227	Traffic criticality levels	The SAA system shall assign a priority level to each traffic tracked.
3240	**ALERTING**	
3241	RWC alerting	The SAA system shall issue a timely caution level alert if the UA is expected to infringe the well clear volume of any traffic.
3242	CA alerting	The SAA system shall issue a timely warning level alert if the UA is expected to enter the collision volume of any traffic.

[5] Such operating rules could be the additional time required for ATC coordination
[6] Basic data security measures are encryption and authentication

3260	GUIDANCE AND RESOLUTION MANOEUVRES[7]	
3261	RWC guidance	The SAA system should provide timely guidance to the operator for commanding resolution manoeuvres to remain well clear of any traffic.
3262	CA guidance	The SAA system should provide timely guidance to the operator for commanding resolution manoeuvres to avoid collisions.
3263	Automatic CA manoeuvre	The SAA system should perform automatic collision avoidance manoeuvres if the operator has not been able or is unable to command resolution manoeuvres in a timely manner.
3264	Right of Way	The SAA system guidance or automatic manoeuvres should take into account the right-of-way rules.
3265	Terrain and obstacle avoidance	The SAA system guidance or automatic resolution manoeuvres shall take into account terrain and obstacle clearance if the UAS operations are intended to take place in terrain proximity.
3266	Airspace Reservations	The SAA system guidance or automatic resolution manoeuvres should take into account (prohibited) airspace reservations.
3267	Clear of conflict	The SAA system shall report to the operator clear of conflict when both RWC and CA alerting criteria are no longer met.
3280	**SUPPORT FUNCTIONS**	
3281	Health and Status Monitoring	The SAA system individual items shall report their status (e.g. on, off, degraded, failed) and any additional associated data (e.g. type of failure, failed components, performance degradation) required for SAA system status monitoring.
3282	SAA system data recording	The SAA system shall record SAA data, and have the capacity of at least the max UAS flight endurance.

[7] If 3202 "Recommended functions" is to be implemented in an SAA system, requirements under subsection 3260 "Guidance & Resolution Manoeuvres" are considered mandatory

3.3. SAA SYSTEM UAS INSTALLATION & INTEGRATION REQUIREMENTS

Req. ID	Req. title	Requirement
3300	**SAA SYSTEM UAS INSTALLATION & INTEGRATION REQUIREMENTS**	
3301	SAA system environmental qualification	The SAA system equipment shall be qualified for the environmental, including EME, conditions as specified for the UAS.
3302	Non Interference	The SAA system shall not interfere with any UAS function required for safe flight or safe operations in the designated airspace (e.g. E3).
3303	UAS installation	Each item of installed SAA system equipment shall be installed according to limitations specified for that equipment and function properly when installed.
3304	Field Of Regard (FOR)	The FOR of the on-board SAA system surveillance shall be specified by the applicant for all sensors in combination and for each individual sensor as installed in the UAS.
3305	UA envelopes	All resolution manoeuvres commanded by the SAA system (automatic manoeuvre execution or manually through manoeuvre recommendation) shall be within the operational or permissible UA envelopes of the approved configurations (e.g. external stores).[8]
3306	Completion	The UAS should return to the last commanded flight and mission mode after the SAA system has terminated the automatic CA resolution manoeuvre. The behaviour shall be predictable in such conditions. Note: automatic manoeuvres in certain environments, such as the terminal environment, may require different behaviour.
3307	Human Factors (HF)	HF considerations shall be validated for the design and certification of the SAA system items that interacts with the operator (HMI, e.g. display, commands and controls, audio system).
3308	Traffic display (SA)	The SAA system shall display traffic information to the operator.[9]
3309	SAA Command and control interface	The SAA system shall provide to the operator the interface required to command and control SAA manoeuvres.
3310	SAA System Health and Integrity Monitoring	The SAA system shall provide to the operator SAA system status and associated data for monitoring.

[8] The SAA system resolution manoeuvre (automatic or recommended) may be outside the operational or permissible envelope. In this sense it would be the operator/FCS as part of the SAA system to limit the response.
[9] Traffic information provides the operator with a picture of the traffic situation surrounding the UAS. It assists the operator in self-separation duties.

3311	SAA system specific equipment control	The SAA system shall provide to the operator an interface to control SAA system equipment, including each surveillance sensor (power on, off or any required equipment settings).
3312	Function enabling/disabling	The SAA system shall provide the operator an interface to enable and disable all SAA functions either individually or in logical groups.
3313	Function output suppression	The SAA system shall allow the operator and optionally the UAS to suppress SAA alerts, guidance, and automatic response.
3314	SAA system data link	The SAA system data link shall be qualified to the RLP that supports the required SAA system functions and associated specified performance.
3315	SAA system UAS safety impact	The SAA system functions that may impact UAS safe flight shall be demonstrated to have an acceptable hazard probability in accordance with the approved UAS Certification Basis.
3316	DAA Interoperability and Compatibility	The SAA system shall work together coherently, effectively, and efficiently with other DAA systems in the UAS (e.g. AGCAS) so as to fulfil the DAA requirements. .

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CHAPTER 4 ACCEPTABLE MEANS OF COMPLIANCE & GUIDANCE MATERIAL

DEFINITIONS

Acceptable means of compliance	This illustrates a means, but not the only means, by which a regulation can be met and a regulated entity may decide to show compliance by other means. Hence only an authority can agree an alternative to the published Acceptable Means of Compliance. Acceptable Means of Compliance are strongly recommended practices and a justification will be required to the authority if they are not followed. The burden of proof that a regulation is satisfied rests entirely with a regulated entity when alternatives are proposed to the authority. (EMAD 1, 10 OCT 2017)) For requirements without corresponding AMC, it is expected that the applicant proposes a means of compliance to the certifying authority for approval and demonstrates that this means of compliance provides compliance with the requirement. Note: Use of the terms 'shall' and 'must' within AMC does not preclude the use of alternative means of compliance and apply only if a given AMC is used to demonstrate compliance with the applicable requirement.
Guidance Material	Guidance Material provides additional explanation to assist the application of the requirement and/or explain the Acceptable Means of Compliance.

4.1. SYSTEM SAFETY PERFORMANCE DEMONSTRATION

GM.0001
Airspace Safety Classification Similar to STANAG 4671 USAR 1309 that defines (airworthiness) safety objectives for the functions of the UAS that are essential to the safe flight and landing, safety objectives should be set for the operations in the intended airspace—e.g., to specify development assurance levels. The SAA system shall be designed to reduce the risk to people (in this context third parties) to a level acceptable by the authority. The risk to people is limited here to the air risk, meaning the risk for crews and passengers of other aircraft operating in the same airspace as the UA. The risk for people on ground (ground risk due to UA crash) is addressed by the airworthiness safety (see STANAG 4671 USAR 1309) and beyond the context of this standard. A failure condition in the context of this AMC is defined as a condition having an effect on the separation between the UA and any other traffic during airborne or on ground

operations, either directly or consequentially, which is caused or contributed to by one or more failures, considering flight phase, relevant operational conditions (e.g. ATC environment) and considering the probability of encountering another traffic (external event).

A distinction is made between a reduction in separation where the crew or ATC (whoever is responsible for separation) is fully controlling the situation and where the crew and ATC are not. Fully controlling means that the encounter traffic position and intention are known at each instant by the UA crew or ATC.

Risk reference system (derived from ESARR4):

Risk	Severity (ATM classification)	Failure condition
MAC	Catastrophic (accidents)	Failure conditions that are expected to result in a collision with another aircraft
Severe reduction in separation (more than half of the required separation) without crew or ATC fully controlling the situation (may ultimately end into an NMAC)	Hazardous (serious incidents)	Failure conditions that either by themselves or in conjunction with increased crew workload, are expected to result in a large reduction of separation or ultimately in a NMAC
Severe reduction in separation (a separation of less than half of the required separation) with crew or ATC controlling the situation (e.g. major RWC infringement) Large reduction in separation (a separation of more than half the separation minima) without crew or ATC controlling the situation (e.g. minor WC infringement)	Major (major incidents)	Failure conditions that are expected to result in a severe reduction in separation with crew or ATC controlling the situation or a large reduction in separation without crew or ATC controlling the situation.
Increased workload of the ATC due to UA deviating from ATC clearance Large reduction in separation (a separation of more than half the separation minima) with crew or ATC fully controlling the situation	Minor (significant incidents)	Failure conditions that are expected to result in an increased ATC workload or in a large reduction of separation with crew or ATC fully controlling the situation

The acceptable level of safety (ALS) is to be set by the authority for the defined airspace. This level of safety needs to be shared amongst all aircraft flying in the same airspace and same time plus all actors performing their services in that airspace. Indicators of safety levels can be the MAC statistics* or ATM incidents statistics. Alternatively, target level of safety for specific actors (like ATM) may be set : ESARR4 assumes for example a maximum tolerable probability of ATM directly contributing to an accident of a Commercial Air

Transport aircraft of 1,55 *10– 8 accidents per Flight Hour (accident includes here MAC, collision on ground between two aircraft, Controlled Flight Into Terrain (CFIT), …)

The SAA system is therefore not designed to achieve by itself any specific target level of safety (TLS) but rather contributes to the airspace level safety (see also Figure 4-1 and Figure 4-2 in GM.0002 for further discussion of SAA system contribution).

*see for example Determination and Evaluation of UAV Safety Objectives, Clothier & Walker (2006)

GM.0002

Evaluation of SAA Risk Ratio against Target Level of Safety (TLS)

National Authorities may require evidence that the air traffic integration of a UA will not degrade the current level of airspace safety. This is generally done based on absolute criteria such as the TLS approach. However, SAA system performance is preferably measured as a risk ratio, as this approach excludes safety performance aspects outside the scope of the SAA system (e.g. ATC system). GM.0002 provides a method for authorities to evaluate a SAA system equipped UAS in the ATM system against a TLS.

The TLS approach is an absolute criteria expressed as an event per unit of exposure. Relating this to the airspace safety performance metrics defined in Section 2.2.1, the TLS approach defines maximum allowable rates of occurrence per FH for events such as a MAC or NMAC in the designated airspace. These rates may be dependent on the applied airspace safety classification scheme (see GM.0001).

Evaluating an SAA system equipped UAS against a TLS requires the definition of all the factors contributing to an event from occurring. The SAA system is only one of those contributors to evaluate against the absolute measure, and it is often difficult to ascertain the contribution of the other contributors.

For a collision to occur, there must be at least two aircraft present: the UAS and the intruder. Without any mitigation measures, two aircraft on colliding trajectories will eventually cause a MAC. One way to frame the safety assessment is a bow-tie diagram, which accounts for all contributing factors that prevent a possible MAC.

The top event depicted in the middle of the example bow-tie diagram (Figure 4-1) is an imminent collision incident, which occurs when the collision volume has been breached. The mitigation measures are part of the ATM conflict management and are either performed by the host UAS, the intruder traffic or the ATC. Barriers to the left of the top event are preventative barriers and related to separation provision. Barriers to the right are mitigating barriers related to collision avoidance. The SAA system supports both preventative and mitigating barriers.

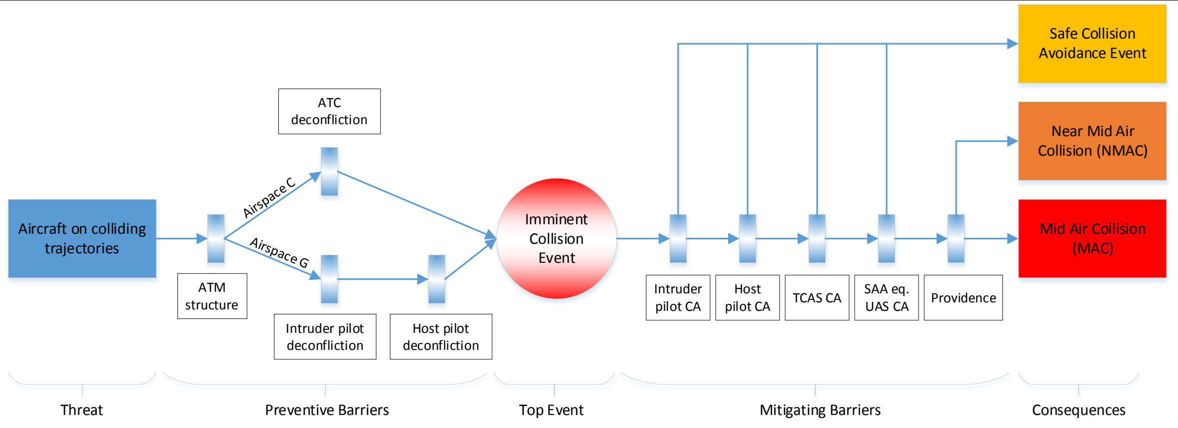


Figure 4-1: Bow-Tie Diagram Illustrating Contributors and Mitigating Measures

The bow-tie diagram shows multiple barriers, which can be combined to define the SAA system efficacy. These are based on the required function of an SAA system (Req. 3201). The SAA system efficacy as a single contributor is shown in the following event tree diagram for cooperative traffic in controlled airspace. Based on the required airspace safety performance metrics, this value is expressed as a risk ratio, providing a direct measure of SAA system efficacy.

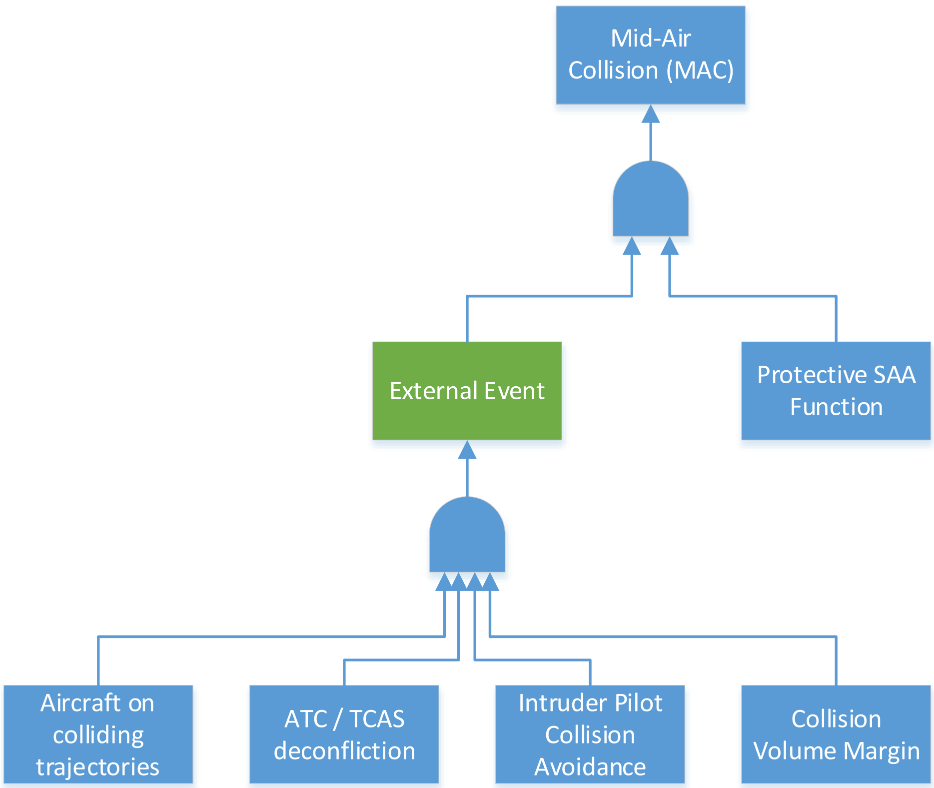


Figure 4-2: Event Tree Diagram for Cooperative Traffic in Controlled Airspace

The product of the rate of occurrence of an external event and the risk ratio of the SAA system efficacy provides a rate of occurrence for the top event, which can then be evaluated against a TLS. The contributors to the external event depend on the operational environment as defined in Section 2.3.

Note that the bow-tie diagrams, event trees, or other tools used within a probabilistic risk assessment may be more complex to consider additional risk contributors. See also AEP-101 Ed. A Ver. 1 Section 3.2.1 for further guidance material.

4.2. DESIGNATION OF OPERATIONAL ENVIRONMENT CHARACTERISTICS

AMC.2301

Traffic Characterization

The applicant shall identify the traffic to be encountered in the intended airspace of operations and categorize the traffic in accordance with the types defined herein. The physical characteristics of the traffic should be used in the SAA system design (e.g. to specify the sensors performance requirements in terms of traffic detection) and SAA performance verification (e.g. tracking performance against individual traffic with maximum turn rate values).

For each traffic category, the relevant parameters are:

Cooperative	Non-cooperative
- Dimensions - Speed range: TAS shall be used; operational limitations shall also be considered (for example 250 KIAS below FL100); speed 0 means hovering (helicopter) - Rate of climb (ROC) / Rate of descent (ROD) - Turn rates - (N)VFR/IFR approved and associated equipment that may affect SAA performance (e.g. lighting, ATC Com)	
- Surveillance sensor specifications / standard - Typical installation (e.g. losses, obstructions)	- Characteristics required for surveillance sensor detection: Radar: RCS [m^2] at radar bandwidth, IR sensor: IR [m^2] at wavelength range Other sensor types to be defined.

Each traffic has its key attributes (e.g. physical properties, abilities, and equipage) that directly affect the probability of detection (physical properties, equipage) and their probability of encounters (quantity in airspace). Note that small unmanned aircraft that are intended to operate outside of the traditional ATM system are not expected to be avoided by the SAA system, so are not addressed here.

The traffic characterization is especially important for non-cooperative traffic. Beside the physical property relevant for the individual type of sensor (e.g. RCS), traffic airspeeds expressed in TAS need to be defined, considering that:

- A maximum of 250 kts IAS is applicable below FL 100
- ADS-B out may be mandatory for traffic* > 5700 kg and TAS > 250 kts, respectively at or above FL 100

It can be derived that 250 kIAS is the max speed for a cooperative traffic operating below FL 100**.

The selection of key attributes to be considered is under the responsibility of the applicant and depends on the SAA system architecture and the type of traffic to be encountered (cooperative or non-cooperative).

The following sections provide some supporting data for the traffic characterization.

a. Traffic Equipage:

Description	Equipage		
	Radio	XPDR	ACAS II
Hot air balloon	×	×	×
Glider	(×)	(×)	×
Powered air sports	×	×	×
Airship	✓	✓	×
Helicopter	✓	✓	×
Non-pressurised GA	✓	✓	×
Pressurised GA	✓	✓	×
Airliner / Cargo AC	✓	✓	✓
Military Fighter	✓	✓	×
Unmanned aircraft	✓	✓	×

Note: Gliders carriage of equipment is marked as (x) as it is highly variable across nation states and on a voluntary basis.

b. Traffic Typical Performance:

The following table give typical performance data of specific traffic categories (the data has been extracted from radar data):

Traffic Category	Altitude	Turn Rate [°s^{-1}]		Vertical Rate [ft/min]				Ground Speed [kts]	
				ROC		ROD			
		95%	99%	95%	99%	95%	99%	95%	99%
VLA&UL	all	7	12	1100	2500	1200	2200	122	136
CS22	all	13	17	1100	2600	1100	2300	111	125
CS23	pA>FL100	6	12	1400	2600	1500	3100	154	211
	all	6	11	1500	2800	1600	3600	176	277
CS25	pA>FL100	3	5	3400	4300	2100	2900	289	308
	all	3	4	3400	4200	2400	3200	441	487
Cooperative	pA>FL200	1	2	2300	3100	2400	3300	510	551
7000	all	7	13	1300	2800	1500	3000	141	188
Helicopter	all	8	15	1500	2800	1700	3400	136	151

c. RCS for Radar based SAA Systems:

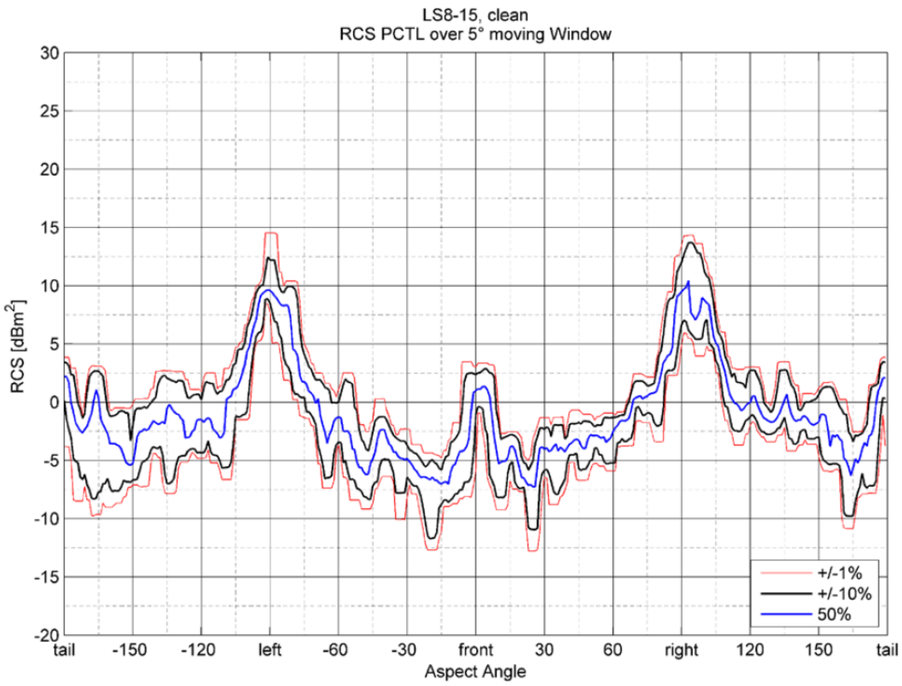
RTCA DO-366 distinguishes 3 categories of traffic for RCS:

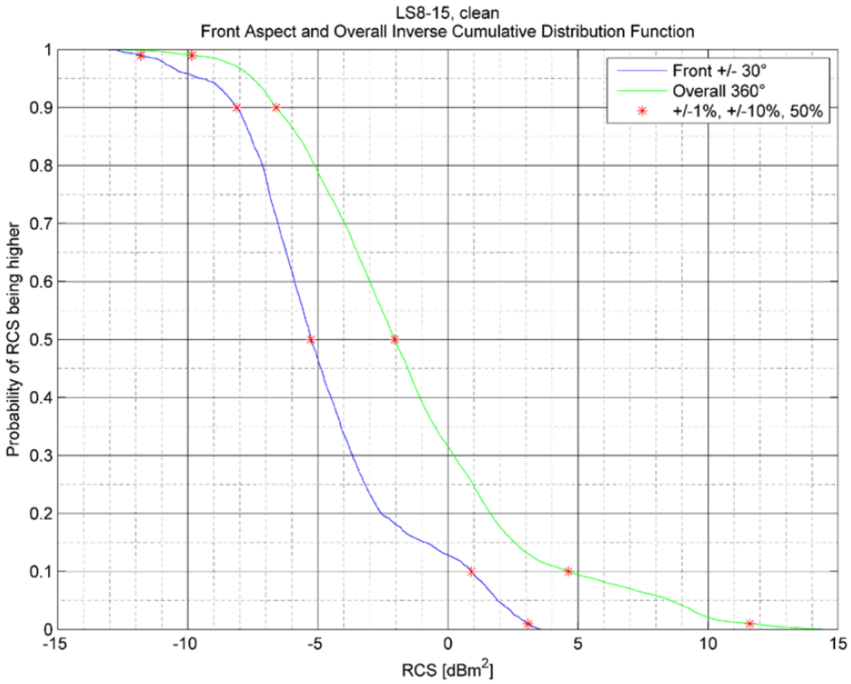
Traffic	Typical RCS [m^2]	Typical TAS [kts]	Comment
Small size	1	< 100	RTCA DO-366 assumes that an RCS of 1 m^2, equivalent of an average adult human, can be used as lower limit for small size aircraft RCS. This may not be conservative.
Medium size	2	< 130	
Large size	4	< 170	Large size traffic are usually cooperative. 10 m^2 RCS may be used in combination with 250 kIAS below FL100.

Within the small size category, sailplanes/gliders need a particular attention due to their low RCS. The following table gives some typical RCS values and reference measurements:

Traffic	Typical RCS [m^2]	Ref. measurements 50% percentile [dBm^2, -180° – +180°]	Typical TAS [kts]	Comment
Paraglider	0.25		20	Max speed 40 TAS
Small gliders	0.25		120	
Sailplane/Gliders	0.5	-2 (LS-8, [1]) 2.6 (Duo Discus, [1])	150	Max speed 150 IAS
GA, SEP	3	4.1 (Robin DR400, [1])	120	Max speed 120 IAS
GA, MEP	3	3 (DA-42, [1])	120	
SET (low perf)	3		120	Max speed 120 IAS
SET (high perf)	5***		250	
Helicopter	10		110	0 (hovering)

RCS values are 50% percentile value (median), given for the front sector of a traffic [-30 – +30°]. There is a strong dependency with aspect angle. The applicant shall consider encounter scenarios at aspect angles with min values (for example hereafter crossing at 30° aspect angle). In the verification of the sensor performance, specific encounters with minimal values at specific aspect angles shall be flight tested.





	Probability	99%	90%	50%	10%	1%
RCS [dBm²]	Front	-11.8	-8.1	-5.3	0.9	3.0
	Overall	-9.8	-6.6	-2.0	4.6	11.6

RCS measurement in C-Band of sailplane

Reference [1]: armasuisse FT report 2303, RCS measurements (C-band)

* Note that regulations implementing ADS-B mandates differ between NATO member states. For reference, Commission Regulation (EU) No 1207/2011 lays down requirements including the ADS-B mandate in Europe, 14 CFR 91.225 and 91.227 lays down ADS-B requirements in the US.

** State aircraft, in particular the military, and certain other operators, may be approved to operate outside of the VFR flight rules, most notably operating above 250 KIAS below FL100, by exception, and may also have special characteristics. It is not an expectation that the system, including sensors, is designed to these exceptions; however, the SAA system should still function against such operations, and performance degradation is acceptable. In general, the Flight Safety Management System (SMS) should provide information through the flight planning process and procedures to aid deconfliction for traffic that may be operating outside of the rules. Typical exceptions are:

- non-cooperative stealth aircraft (RCS <0.25 m2)
- parachute and free fall (not to be confused with paraglider)
- aircraft performing very high energy manoeuvres—e.g., aerobatics, high ROC/ROD and turn rates
- Military aircraft that do not comply with civilian requirements (e.g. high speeds and no ADS-B out)

*** Representative of non-cooperative traffic with high TAS between medium and large size operating below FL 100. For example, RCS of PC-12 is 4.4 dBm2 (median, all aspects, [1]).

AMC.2302
Encounter Characterization For fast time simulations, encounters are broadly defined as a multi-aircraft proximity events of interest to the SAA system, that could or should result in the SAA system alerting, or that could result in another event of interest, such as a loss of well clear or NMAC. The intruder and ownship characteristics and relative encounter geometry are key characteristics that must be accounted for because they will affect SAA system performance. For example, higher aircraft speeds typically require greater surveillance ranges, while higher intruder speed relative to ownship will reduce the ability of ownship to induce a separation. Unanticipated manoeuvres will also challenge an SAA system, so the frequency and magnitude of such manoeuvres must be accounted for. Additionally, frequent manoeuvres, such as those consistent with loitering missions, may affect the sensor field of regard orientation and the tracking accuracy. A variety of aircraft encounter sets may be used in system verification and validation, briefly (see AEP-101 Ed. A Ver. 1 Section 5.4 for further guidance): - Encounter model: realistically captures the distribution of aircraft encounters for risk ratio simulation evaluation. See AMC.2503. - Stressing model: comprehensively and systematically evaluates all potential algorithm states; such a model is intended to have possible aircraft and encounter characteristics but not necessarily be realistic. - Scenario specific: realistic encounters capturing a distinct type of operation where SAA performance should be assessed. - Operational data: direct use of observed surveillance data in SAA simulation. It is not typically possible to use such data to estimate the frequency of NMAC or losses of well clear, but it is typically possible to estimate operational suitability metrics of interest to UAS operators, other airspace users, and the ATM system. Stressing encounter sets should be used for system verification and validation. Specific operational scenarios of special interest to the SAA system should be identified by the authority, applicant, and operators. Encounter sets for such identified scenarios should be developed and used for system verification and validation. Operational data should be collected and used in system verification and validation to evaluate operational suitability. For all encounter sets used in system verification and validation, the sets shall be modified as necessary to represent own aircraft (UAS) characteristics. For all encounter sets used in system verification and validation, the future airspace environment should be considered and incorporated. For all encounter sets used in system verification and validation, statistical confidence shall be calculated and provided with summary point estimates for all metrics.

AMC.2303

Traffic Density Characterization

The traffic density assumptions from RTCA DO-185B (2.2.1.2.1)/ICAO Annex 10 Vol 4 (4.3.2) may be used for the combination of both cooperative and non-cooperative aircraft. Specifically, this is 0.3 aircraft per square nautical mile in lower altitudes and 0.06 aircraft per square nautical mile in higher altitudes. Lower altitudes can be considered below 10,000 ft MSL, while higher altitudes are above 10,000 ft MSL.

RTCA DO-185B specifies that there is a threshold range below which the density is assumed to be proportional to the geographical area and above which the density is assumed to be proportional to the range; this specification may be used when identifying the number of aircraft within a given range of interest. If the range of interest (R) is above this threshold (R_O), then the number of aircraft given the traffic density (ρ) can be computed as ($\rho \pi R_O R$); if the range is below the threshold, then the density can simply be computed as ($\rho \pi R^2$). RTCA DO-185B defines R_O to be 5 NM for lower altitudes and 10 NM for higher altitudes.

Angular field of regard limitations may be used to reduce the number of aircraft derived from the traffic density.

Traffic density characterization using operational surveillance data should be performed to either (as applicable): derive the traffic densities for the intended operational environment, or to validate the use of the RTCA/ICAO traffic density values.

Traffic density characterization should consider the future airspace environment, over the anticipated lifetime of the SAA system.

Traffic density may be considered per unit volume rather than per unit area. This may be especially beneficial when the sensors have a limited elevation field of regard.

AMC.2304

Airspace Classification

This AMC is part of the operational environment characterization. The applicant shall do all calculations above for the specific airspace classification the RPA is flying in. The RPA shall remain at any time within the individually derived safe distances for well clear and collision avoidance. The generic airspace classification definition in accordance with ICAO Annex 11 Appendix 4-1 (Characteristics, Services, Restrictions) below describes the ATM structure used in the bow tie diagram figure 4.1 The applicant shall also complementary refer to the possibility of national exclusions (certain airspace classes are undefined) or exemptions (e.g. Airspace G in CH to 2000ft AGL).

Airspace Classes in Accordance with ICAO Annex 11, Appendix 4:

Class	Type of flight	Separation provided	Service provided	Speed limitation*	Radio communication requirement	Subject to an ATC clearance
A	IFR only	All aircraft	Air traffic control service	Not applicable	Continuous two-way	Yes
B	IFR	All aircraft	Air traffic control service	Not applicable	Continuous two-way	Yes
	VFR	All aircraft	Air traffic control service	Not applicable	Continuous two-way	Yes

C	IFR	IFR from IFR IFR from VFR	Air traffic control service	Not applicable	Continuous two-way	Yes
	VFR	VFR from IFR	1) Air traffic control service for separation from IFR; 2) VFR/VFR traffic information (and traffic avoidance advice on request)	250 kt IAS below 3 050 m (10 000 ft) AMSL	Continuous two-way	Yes
D	IFR	IFR from IFR	Air traffic control service, traffic information about VFR flights (and traffic avoidance advice on request)	250 kt IAS below 3 050 m (10 000 ft) AMSL	Continuous two-way	Yes
	VFR	Nil	IFR/VFR and VFR/VFR traffic information (and traffic avoidance advice on request)	250 kt IAS below 3 050 m (10 000 ft) AMSL	Continuous two-way	Yes
E	IFR	IFR from IFR	Air traffic control service and, as far as practical, traffic information about VFR flights	250 kt IAS below 3 050 m (10 000 ft) AMSL	Continuous two-way	Yes
	VFR	Nil	Traffic information as far as practical	250 kt IAS below 3 050 m (10 000 ft) AMSL	No	No
F	IFR	IFR from IFR as far as practical	Air traffic advisory service; flight information service	250 kt IAS below 3 050 m (10 000 ft) AMSL	Continuous two-way	No
	VFR	Nil	Flight information service	250 kt IAS below 3 050 m (10 000 ft) AMSL	No	No
G	IFR	Nil	Flight information service	250 kt IAS below 3 050 m (10 000 ft) AMSL	Continuous two-way	No
	VFR	Nil	Flight information service	250 kt IAS below 3 050 m (10 000 ft) AMSL	No	No

* When the height of the transition altitude is lower than 3 050 m (10 000 ft) AMSL, FL 100 should be used in lieu of 10 000 ft.

The ICAO classification scheme for the airspace as existing today will be valid or the relevant changes applied in the future for manned aviation will apply and UAS will adapt to it. While there are presently discussions ongoing with respect to the future integration of UAS and changes to the classification scheme, no decisions have been made at the time of release of this standard. Consequently, it is proposed that the applicant is to still use the official ICAO classification scheme as published in Annex 11.

AMC.2305

Atmospheric Conditions Characterization

The applicant shall characterize the atmospheric conditions in which the SAA equipped UAS will operate and achieve the required performance in terms of airspace safety.

Atmospheric conditions affect the performance of the SAA sensors (primarily non cooperative) but possibly also the types and densities of traffic to be encountered (especially VFR traffic). Both aspects shall be taken into account in the verification of the required safety levels.

Atmospheric conditions prevailing for SAA use may not necessarily cover the complete environmental conditions in which the UA shall operate, allowing different types of operations in different environments. MIL-HDBK-310 or STANAG 2895 may help by defining the climatic conditions prevailing in the area of operations. For environmental qualification of the SAA system, see AMC.3301.

For Air Traffic Integration purposes, it is recommended to derive the atmospheric conditions applicable to SAA from the VMC/IMC minima (all airspace users apply the same conditions). VMC/IMC conditions are meteorological conditions expressed in terms of visibility, distance from cloud and ceiling, equal to or better to specified minima (ICAO Annex 2). These conditions make sense in the scope of see and avoid (*visual* conditions) but cannot be directly used for SAA and need to be converted or quantified differently: Visibility into rain rate and clouds into LWC (Liquid Water Content) and MVD (Mean Volume Diameter) metrics.

Rain rate:
Visibility is defined in ICAO Annex 2. Several probabilistic models of visibility are available in the literature* and can be used to derive the rain rate associated to a specified visibility.

Visibility minima for VMC are specified to be:

	Flight visibility	Rain rate, using 95% curves**
At and above FL 100	> 8 km	3 mm/h
Below FL 100 and above 3000 ft AMSL or above 1000 ft AGL, whichever is the higher	> 5 km	10 mm/h
At and below 3000 ft AMSL or 1000 ft AGL, whichever is the higher	> 5 km, may be reduced to 1500 m	37 mm/h

Note that these are recommended minimum values, considered for likely encounters with civilian traffic adhering to speed limits as listed in AMC.2304. The authority may impose a margin, for example to take into account variations of visibility in the FOR of the SAA (e.g. local shower limited to some azimuth degrees in the FOR). A correlation between measured rain rates and the presence of VFR traffic in an airspace may further be used to define the minimum required rain rate.

Clouds:
VFR traffic must maintain minimum separation from clouds (1500 m horizontally / 300 m vertically or clear of clouds at or below 3000 ft AMSL or 1000 ft AGL, whichever is the higher).

Clouds may be quantified through their LWC and MVD and their effect on sensors performance vary greatly (no detection with EO/IR sensors). A low detection probability through clouds or a track loss due to clouds may impose very short reaction times which may be incompatible with the SAA performance. In this case, these encounters with traffic in proximity of clouds shall be specifically addressed.

Only typical values*** for medium altitude clouds (susceptible to be encountered during flight) are given here:

	Clouds (cumulus, stratus)
MVD	< 20 µm
LWC	<0.3 g/m3

If the SAA system incorporates sensors that have degraded performance detection through clouds, and if this degraded detection is required to achieve the required RR, the MVD and LWC conditions used for simulations and encountered during flight tests shall be quantified.

*	For example "Probabilistic parametrization of visibility using observations of rain precipitation rate, relative humidity and visibility", Gultepe & Milbrandt, 2009
**	From Gultepe & Milbrandt, 2009, VIS [km]=-863.26*PR[mm/h]^0.003 + 874.19
***	Source for LWC data: Thompson, Anne (2007). "Simulating the Adiabatic Ascent of Atmospheric Air Parcels using the Cloud Chamber". Department of Meteorology, Penn State Source for MVD data: 20mu typical cloud droplet size, "size of aerosols, raindrop and clouds droplets", UCAR, 2007

AMC.2306

UAS Operations Characterization

The encounters used in the fast time simulations shall be representative of the UAS usage based on the profiles to be flown across the operational envelope including both nominal and evasive action. The profiles shall encompass the whole range of the airspace structure to be flown in. To represent the flight profile will require details, including a suitable percentile range, of:

- Turn rate [°/s] at different altitudes
- Roll angles [°] used
- Airspeed IAS [kts] or TAS throughout the profiles
- Vertical rate (ROC/ROD [ft/min]) distributions as functions of altitude layers
- Horizontal and vertical accelerations across the altitude ranges
- Altitude changes (>100 ft)
- IAS changes (> 4kts)
- Heading changes
- Representative time in airspace classes

The flight profile used in the simulations should be representative of the intended mission profiles.

The profiles should be based on proven performance from flight trial data. If sufficient data are not available, it is recommended that the usage characteristics be derived from the operational data of an already operational comparable UAS performing the same type of mission.

The profiles should be representative of the UA operating with the SAA system installed to ensure the performance is representative of the platform configured with a SAA system.

The operational usage shall be later monitored for compliance with the usage assumed in the initial UAS operations characterization.

4.3. UAS ELIGIBILITY CRITERIA

The operational environment depends on national regulation and differs for the types and classes of airspace it is located in. Thus, there is no common internationally agreed definition available. The applicant shall make a thorough analysis of the intended operational environment, and comply with the rules and requirements set in order to not create an undue threat for the safe operation of flights within.

4.4. OPERATIONAL SAFETY DEMONSTRATION

AMC.2501
Risk Ratio Demonstration, Nominal Conditions Nominal conditions are broadly defined as the system, including all subsystems, operating within specified performance and the specified operational environment, and all equipment properly functioning—i.e., no equipment degradations or failures. The risk ratio shall be estimated in Monte Carlo simulations, where a large collection of realistic encounters is simulated with and without the SAA system response manoeuvres to evaluate safety metrics. The nominal risk ratios shall be estimated using a verified and validated simulation environment, including all individual components and input data. Verification and validation of the simulation shall be conducted or reviewed independent of the applicant. Applicable standards for modelling and simulation verification, validation, and accreditation should be used, such as MIL-STD-3022. The upper 95% confidence interval should be used when evaluating system performance against the risk ratio requirements. The confidence interval may be assessed using resampling of the simulation results—e.g., as in B. Efron (1982), "The jackknife, the bootstrap and other resampling plans", SIAM. All applicable equipment configurations on the ownship and intruder(s) shall be evaluated and assessed against the applicable risk ratio requirement (Table 2-2). The performance of the system, including all subsystems, shall be conservatively represented. Sensitivity analysis, where individual component parameters are varied to assess the effect on the risk ratio, should be used to evaluate and report the magnitude of conservatism. Additionally, such a sensitivity analysis can identify areas where risk can be further reduced. References for example simulations and models for estimating the nominal risk ratio include ICAO Annex 10 Vol IV Section 4.4 and RTCA DO-365 Appendix Q. These example simulations and models may not be directly applicable, so they must be assessed for applicability. See AMC.2503, AMC.2504, AMC.2505, AMC.2506, and AMC.2507 for specific components of the simulation environment.

AMC.2502
Risk Ratio Demonstration, Abnormal Conditions Abnormal, or off-nominal, conditions may include the system, including any subsystems, operating outside of the specified performance, operating outside of the specified operational environment, or equipment degradations or failures.

Each abnormal condition considered sufficiently likely shall be individually assessed to ensure that the system and/or environment condition does not pose an undo safety hazard. If such a hazard is identified, then additional measures may be required to protect against that hazard—e.g., through additional system monitoring functions. Specific abnormal conditions include, for example:

- Out of specified conditions: sensor measurement errors larger than specified, system latencies longer than specified, pilot response that is beyond specification.
- Operational environment: stressing intruders that are possible given aircraft and airspace constraints but are not representative (as in an encounter model), clutter beyond that specified, saturated spectrum environment.
- Degradations or failures: individual sensor failure (and combinations of sensor failures), degradation beyond end-of-life expectations, failure of command and control link.

An abnormal condition should be considered sufficiently likely for the purposes of individual assessment if its resulting risk ratio contribution may be more than 1% of the risk ratio requirements in Table 2-2. Abnormal conditions that result in an alternate procedure or transition to an alternate operational environment should be considered for the time of exposure—e.g., if a loss of a non-cooperative sensor dictates manoeuvring into an airspace with transponder requirements, then the time of exposure in the airspace with non-cooperative aircraft may be minimized and considered in the risk ratio estimation.

Abnormal conditions that can be estimated for their likelihood should be assessed against the thresholds specified in Section 2.2.3. Such conditions may include degradations or failures, or certain out of specified conditions, such as pilot responses considered outside of specification. Risk ratios that account for both abnormal and nominal conditions are considered system risk ratios. See AEP-101 Ed. A Ver. 1 Section 3.2 for guidance.

AMC.2503

Risk Ratio Demonstration, Encounter Sets

The encounter set(s) used to evaluate the risk ratio under nominal conditions shall be appropriate for the intended UAS operational environment and SAA system being proposed. Specifically, the encounter set should have the following properties:

- Relevance: the applicable aircraft operating rules, equipment, airspace classes, and altitudes are represented.
- Realism: the aircraft trajectories and encounter geometries are physically possible, typical, and appropriately distributed (including for the UAS ownship aircraft).
- Range: the encounter set must span the variables of interest for the operational environment and SAA system being proposed—e.g., the initial time of the simulation relative to closest approach must allow the SAA system time to track, alert, and provide guidance; additionally, the span of the horizontal and vertical separations must be sufficiently large to encompass events that result in the event being assessed (e.g., NMAC).
- Resolution: the range of the variables is appropriately discretized and the encounter set enables the requisite statistical significance.

The SAA system shall be evaluated in multi-intruder encounters. Contrary to single intruder encounters, it is typically not possible to build a model from observed multi-intruder encounters, because multi-intruder encounters are relatively infrequent. Thus, single-intruder encounters may be extended to form multi-intruder encounters; for example, see Billingsley et al., “TCAS Multiple Threat Encounter Analysis”, MIT Lincoln Laboratory Project Report ATC-359, 2009.

The SAA system shall be evaluated in the applicable operational environment using encounter sets representative of the airspace of NATO member states. Although it would be ideal to use encounter sets representative of all NATO member states, such data are often not available. Therefore, it should be suitable to evaluate the SAA system using a combination of U.S. and European models. An SAA system that is evaluated using encounter sets representative of only a subset of the airspace of NATO member states shall be declared limited as such.

For U.S. airspace, the following models are considered generally appropriate, however their assumptions should be validated for the SAA system and UAS under evaluation. There may be more recent versions of the models that should be considered.

- Harkleroad et al., “Uncorrelated Encounter Model of the National Airspace System, Version 2.0”, MIT Lincoln Laboratory Project Report ATC-349, https://apps.dtic.mil/sti/citations/ADA589697, 2013.
- Underhill et al., “Correlated Encounter Model for Cooperative Aircraft in the National Airspace System; Version 2.0”, MIT Lincoln Laboratory Project Report ATC-440, https://apps.dtic.mil/sti/citations/AD1051496, 2018.

Users of these models are encouraged to ensure applicability of the models, including establishing the currency of the models by reviewing appropriate documentation—e.g., at https://github.com/Airspace-Encounter-Models/.

At the time of publication of this standard, European airspace models suitable for evaluating SAA systems are under development; future revisions of this standard may reference specific European models and associated documentation.

AMC.2504

Risk Ratio Demonstration, UAS Dynamic Model

The UAS dynamic model used to evaluate the risk ratio under nominal conditions shall conservatively represent the accelerations and velocities in all three position dimensions—lateral, vertical, and longitudinal—and all three angular dimensions—pitch, roll, and yaw. Considering the angular components is especially important when there is a limited, aircraft body fixed field of regard or when angle of arrival measurements are used.

UAS platform dynamic responses may be considered within SAA development and validation in one of two ways: first, a representative dynamic model for a specific UAS or set of UASs can be included; or second, a generic dynamic model can be included, where minimum manoeuvre requirements are defined through sensitivity analysis.

If an SAA system is developed and validated using a generic dynamic model, the UAS dynamic response shall be demonstrated to satisfy the minimum manoeuvre requirements using flight test or a validated dynamic simulation for the UAS under consideration. The UAS dynamic response should satisfy the minimum requirements for at least 90% of the operational or permissible envelopes.

If an SAA system is developed and validated using a dynamic model of a specific aircraft, the model shall be validated through flight test. The model should be deemed conservatively representative for at least 90% of the representative flight test scenarios.

AMC.2505

Risk Ratio Demonstration, Timing Model

The timing of all subfunctions must be accounted for and controlled. Timing broadly consists of both processing periods and latency, each of which will affect SAA system performance differently: for example, a subfunction may have a large processing period relative to latency (e.g., the pilot acting on continuously updated displayed information, an M-of-N alert or track declaration filter where M events out of N total events are necessary before proceeding), or a subfunction may have a small processing period relative to latency (e.g., track information continuously transmitted on a long-range latent communications link). Furthermore, a subfunction may compensate for its latency or latency induced by other subfunctions—e.g., a tracker will often align and propagate tracks to a common time reference. Note however, that due to unanticipated aircraft accelerations and uncertainty regarding the actual latency, latency compensation is not perfect and such errors must be considered and accounted for. Total latency is the sum of the compensated and latency compensation error (RTCA DO-317C, Appendix J). See DO-365B Appendix E for an example of common latency contributions for DAA equipment.

The processing period for all subfunctions shall be conservatively represented in the risk ratio simulation.

The compensated latency and latency compensation error for all subfunctions shall be conservatively represented in the risk ratio simulation.

The processing period for all subfunctions shall be validated using component or integration tests as applicable.

The compensated latency and latency compensation error for all subfunctions shall be validated using component or integration tests as applicable.

Consistent with other simulation components, the minimum specification can be modelled or a higher fidelity model of the specific system can be used. In either case, the AMC requirements herein dictate that the simulation representation is conservative and validated.

AMC.2506

Risk Ratio Demonstration, Operator Model

The operator model (e.g. reaction time) used in the simulations shall be representative of the operator qualified for the UAS type.

Pilot model should be developed on a representative sample (i.e., various levels of experience) of operators for the system being evaluated. Human performance items (e.g., reaction times and manoeuvre decisions) can be recorded quantitatively and qualitatively. Reaction requirements could be verified against a specified reaction requirement (similar to TCAS). Distribution of response times (i.e., skewness) should be noted when the model is used for system simulations. Note: Relying on subject matter experts will likely not meet this recommendation.

GM.2506

ICAO Doc 9859, *Safety Management Manual*
FAA Human Factors Policy Order 9550.8
Guendel, R.E., Kuffner, M. P., Maki, D.E. (2017). A Model of Unmanned Aircraft Pilot Detect and Maneuver Decisions, Project Report ATC-434

AMC.2507

Risk Ratio Demonstration, Surveillance Model

Adopt one of two simulation approaches:

1. Simulate the performance in the specifications and then provide verification of the requirements;
2. Simulate up to the capabilities of the sensor and provide verification up to the level in identified capabilities.

Modelling of the minimum performance in specifications should be the goal and conservative values for performance attributes should be used for simulation. Where the capabilities of the individual sensor, including those inside the communication chain, is simulated (Option 2) then all relevant performance aspects of the sensor should be addressed providing full functional coverage. Where functional aspects of the sensors' operation are not used within the SAA system then their characteristics do not need to be representative However, a justification should be undertaken to explain why these aspects are not needed in simulation.

An example of Option 1 is defined in DO-365 Appendix Q.4.

AMC.2508

ACAS Interoperability

Interoperability for systems that act to mitigate collision risk is broadly defined as the capability of two or more systems to provide acceptable performance when encountering one another. For ACAS, this interoperability is provided through explicit coordination where ACAS equipment will communicate with other ACAS equipment to ensure complementary collision avoidance manoeuvres (resolution advisories). This is a robust interoperability mechanism that can be used by SAA systems to ensure complementary manoeuvres with intruder collision avoidance manoeuvres—i.e., an SAA system can be aware of intruder collision avoidance manoeuvres and modify guidance information accordingly, or an SAA system can coordinate collision avoidance guidance consistent with ACAS.

The interoperability of the SAA system with applicable intruder ACAS equipment shall be demonstrated in the risk ratio simulation, and the resulting risk ratio evaluated against the Table 2-2 requirement for an intruder system with coordinating and responding Collision Avoidance.

The SAA system should be compliant with EUROCAE ED-264, “Minimum Aviation System Performance Standards (MASPS) for the Interoperability of Airborne Collision Avoidance Systems (CAS)". There may be alternative means to provide interoperability—such as limiting vertical SAA manoeuvres when encountering aircraft with ACAS equipment (although ACAS equipment is being designed to additionally provide horizontal manoeuvres)—but such means must be fully validated. Regardless of the means of interoperability, ED-264 defines interoperability metrics that should be evaluated in the risk ratio simulation.

AMC.2509

Operational Validation

The UAS equipped with the SAA system to be qualified against this PBS should be operated at least for 300 FH in operational conditions in an airspace environment that is under ATM surveillance and control, meaning that each traffic inside this airspace can be detected, tracked and receive instructions for WC separation or ultimately collision avoidance.

This condition will possibly impose:

- the use of ATM sensors (e.g. ground based ATM radars), in order to detect and track intruders that may not have been detected by the SAA system,
- the use of ATC 2-way radio communications inside the airspace,
- an ATC coordination for traffic that cannot be detected by the ATM sensors but are part of the representative traffic to be detected by the SAA system (for example sailplanes, authorization based on predefined flight plans and with ATC radio contact)

The applicant shall demonstrate that:

- no NMAC has occurred within the duration of the operational validation
- no WC infringement has occurred or if any WC infringement has occurred during the 300 FH, this can be statistically justified
- the SAA system has performed as specified in the operational conditions encountered, especially detection/tracking performance against the operational traffic for the atmospheric conditions encountered and SAA system reliability,
- the operational validation has occurred in an environment reflecting the representative airspace the SAA equipped UAS is intended for,
- the flown UAS flight profiles are representative of the ones assumed in the safety simulations (similar distributions),
- the characteristics of the traffic encountered (e.g. speeds, ROC/ROD, turn rates) are compliant with the traffic characterization,
- the SAA system does not affect the UAS operations negatively (e.g. nuisance alerts, HMI accepted by the UAS operational crews)
- the UAS operations have been considered by ATC and other traffic to be operationally suitable (ATC feedback and possibly operational traffic feedback should be collected)

As an alternative, the applicant may choose to provide to the authority a report summarizing the topics listed above for the FH already flown in operational conditions. In this case, the FH per airspace class, day/night, and geographic area shall be detailed.

4.5. SAFETY MONITORING

AMC.2601
Safety Monitoring See AMC.3282.

AMC.2602
SAA System Performance Monitoring The SAA system health and performance should be recorded by an on-board data recorder and the data transmitted via the command and control data link should be recorded by a data recorder in the control station. Guidance on data recorders can be obtained from EUROCAE ED 112. In case that the UAS' certification basis includes provisions for flight data recorders, the same provisions shall apply for the recording of the SAA system health and performance data.

4.6. SAA HIGH LEVEL FUNCTIONAL REQUIREMENTS

AMC.3205
Reliability The SAA system reliability needs to be specified so that as part of the UAS integration it can be verified that the installed SAA system and each individual SAA item supports the safety objectives as defined in Section 2.2. The intended operational conditions, such as environmental conditions and usage, need to be considered. In order to show compliance with the reliability requirement 3205 the following analysis steps should be followed: a) For each individual item of the SAA system a Failure Mode and Effects Analysis (FMEA) must be performed. All individual failures must be analysed for their probability of failure and whether the internal tests of the SAA system can detect the failure. b) Individual failure probabilities should, as far as practically possible, be derived from test data and similar equipment already in service. Alternatively sources such as MILHDBK-217, MIL-HDBK-338, MIL-HDBK-978 or similar can be considered. c) Where items of the UAS are required to achieve SAA system functions, e.g. INS for position data or a flight control system to execute avoidance manoeuvres, those should be declared and the data of the UAS' system safety assessment should be used in the analysis. If the UAS' system safety assessment is not accessible, those items may be represented in the analysis using industry standard failure probabilities. d) The individual failure probabilities are combined using methods such as Fault Tree Analysis, Markov Analysis, or Dependency Diagrams. See SAE ARP 4761 as acceptable standard for this type of analysis, alternatively MIL-STD-1629A can be used for guidance. e) The resulting analysis shall show the Mean Time Between Failures (MTBF) for the identified failure modes, the criticality / consequences of the failure and whether the system can detect the failure.

GM.3207
DAL related to Airspace Safety The airspace safety performance metrics defined in Section 2.2.1 quantifies the required level of safety at the airspace level. Each metric application of an airspace safety classification scheme is provided in GM.0001. The SAA system functions contributes to safety performance at the airspace level, in the way that the system supports the airspace conflict management by reducing the risk of collision. The level of safety to be ensured by the SAA system defines the criticality of its functions. It follows the inverse proportionality of the airworthiness risk reference systems. The higher the criticality, the higher the level of rigor that must be applied to the development process in order to ensure that the system works as intended and that an acceptable level of safety is achieved. This level of rigor is defined as the DAL. The derivation of the DAL requirement for the SAA system due to airspace safety objectives is independent from the DAL requirement due to airworthiness safety objectives from airworthiness codes (e.g. STANAG 4671), because the safety assessment with a MAC as

top level hazard also needs to consider other airspace users. Both objectives (airworthiness and airspace) must be met. The SAA system may impose higher DAL to functions (FDAL) or items (IDAL) than the applicable airworthiness code compliance (e.g. STANAG 4671 USAR 1309) would have done (ex. data link).

While airworthiness certification codes (like STANAG 4671) may allow a lower development assurance for UAS classes with lower MTOM, this cannot be applied for DAL derived from airspace safety objectives due to the involvement of third party aircraft with an unknown number of passengers. A MAC is therefore considered a catastrophic failure condition, even if caused by a UA with lower MTOM, and is assigned an FDAL A in line with the airspace safety metric definition in Section 2.2.1 Table 2-1 and following the guidelines given in SAE ARP 4754:

Table 4-1: Airspace FDAL Assignment

Performance Metric	Airspace Safety Severity	Top-Level Function FDAL Assignment
MAC Mid Air Collision	CAT	A
NMAC (collision volume infringement)	HAZ	B
Well clear volume infringement	MAJ	C

Although an SAA system must protect the ATM environment against a MAC event, it does not necessarily have to be developed to the highest level of rigor (Level A). ARP 4754A allows a reduction of the FDAL by giving credit for external events, which in this case may be by giving credit to ATC separation or intruder pilot SAA.

The level of reduction in safety margin via FDAL reduction is dependent on the probability of the external event defined by the airspace safety performance metrics. This can be done for hazardous and catastrophic failures as illustrated in Figure 4-3. It also shows that the FDAL for a protective function of the highest two levels should at least be level C.

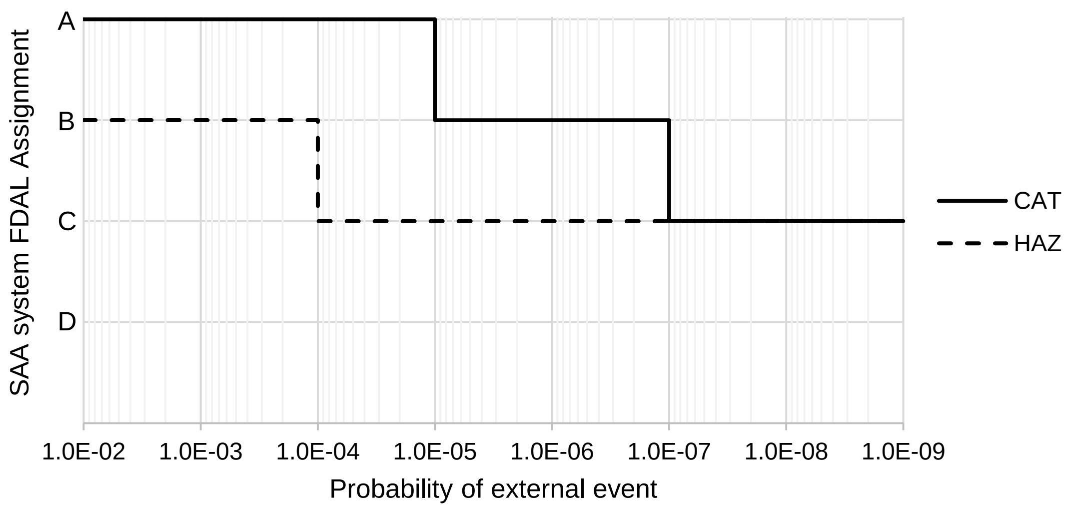


Figure 4-3: FDAL Reduction based on P(External Event) per SAE ARP 4754A

The FDAL reduction exercise is done for collision avoidance being the most critical function and is to follow the guidelines given in ARP 4754A, Section 5.2.4. Both traffic encounter scenarios (cooperative and non-cooperative) must be considered. The external event probability represented on the horizontal axis is the probability of a NMAC without any SAA system mitigation, called the unmitigated risk of collision. The calculation of the unmitigated risk of collision is based on the bow-tie diagram in Figure 4-1 and considers all MAC preventative and mitigating barriers except for the UAS SAA functions themselves. Also see MIDCAS report MIDCAS-T-0025 for example reference on the list of probabilities required to calculate the unmitigated risk of collision for cooperative and non-cooperative traffic in ATC controlled and uncontrolled airspace.

The applicant may consider a reduction in the MAC top-level function FDAL assignment to B for situations and environments (encounters) where ATC separation services are not required.

See also RTCA DO-178C and DO-254 as acceptable means to show evidence for DAL.

AMC.3208

Security

All SAA interfaces shall be assessed for their individual and collective security risk, and mitigations developed and employed as necessary. This assessment should consider the SAA level of automation.

The latest (or most appropriate) version of RTCA DO-326 should be used as a guideline, tailored to unmanned systems and in line with the UAS system safety objectives (as per the approved certification basis, e.g. STANAG 4671 USAR 1309).

4.6.1. Traffic Surveillance

AMC.3221 & AMC.3222
Traffic Surveillance Detection The analysis described in this AMC applies in principle to both requirement 3221 and requirement 3222. The difference is in the input variables of the remain well clear volume versus the collision volume, and any differences in SAA system variables and operational rules being imposed. For example, to remain well clear considers crew reaction time, system latency including UAS link and possibly ATC coordination. To remain outside the collision volume may on the other hand be based on an automatic avoidance manoeuvre, which removes such considerations; however, if the operator is still assumed to have a defined SAA role (e.g., override), an operator time allocation may be necessary. Based on airspace characterization as defined Section 2.3, the required traffic surveillance detection ranges will vary for the possible cooperative and non-cooperative encounters, and their associated atmospheric conditions. For each of these combinations, the maximum detection range required shall be calculated considered the following: - Ownship speed and heading; - Ownship sensor detection performance (e.g. Probability of Detection (POD)) and accuracy in given environment; - Intruder speed and heading; - Intruder cooperative equipment, if any, and their performance and accuracy in given environment; - Time elapsed between initial intruder detection and a track being established; - Ownship performance in initiating and executing avoidance manoeuvre, including maximum ROC/ROD, maximum turn rates, system latency and if not automatic, crew reaction time. The analysis may be based on a worst case combination of the above factors if justified to the certifying authority, or alternatively be a full probabilistic simulation. In either case, the analysis shall consider the airspace characterization as defined Section 2.3 and include variations in atmospheric conditions. As output of the analysis, the probability of the ownship ability to remain well clear and / or outside the collision volume shall be computed and compared with the safety objectives given in section 2.2. A 95% POD and the required accuracy shall be met at the required minimum detection range. The analysis should not assume any avoidance action on the side of the intruder, i.e. the intruder should be simulated as maintaining speed and heading. Although these methods (worst case or simulation) provide an estimate of the required traffic surveillance detection performance, the traffic surveillance detection must be sufficient to satisfy the nominal risk ratio. Industry best practices in numerical code and calculation verification shall be applied in conducting the simulation. The simulation accuracy shall be validated in flight tests with a number of intruders across the intended envelope and environmental conditions. Additionally the variability inherent to flight tests should be considered in determining the number of test points required, to avoid basing the validation effort on few individual data points that can be prone to large variability. Test data may be used to calibrate the simulation and improve the accuracy, however the simulation accuracy outside the test should be justified to the certifying authority.

AMC.3223
Sensor combination See AMC.2501 and 2502.

AMC.3224
Active Sensors Signal transmissions are tightly controlled by national and internal regulations. SAA active sensors should use frequency spectrum assignments appropriate for the intended use wherever practicable—e.g., aeronautical radionavigation services spectrum. Specifically, the 1030/1090 MHz frequencies that support most ATM surveillance applications are tightly controlled. Airborne active cooperative surveillance on 1030/1090 MHz should comply with RTCA DO-300A; if alternate means are employed, the spectrum impact on other ATM systems shall be fully analysed and tested (see the RTCA DO-300A appendices for guidance). Noncooperative active sensors should consider waveforms and automatic frequency switching to ensure performance while minimizing effects on other airborne and ground-based equipment (RTCA DO-366A includes one means). See AEP-101 Ed. A Ver. 1 Chapter 6 for guidance material.

AMC.3225
Data Monitoring The system provider or integrator may use different approaches to verify that satisfactory monitoring and control of data has been achieved. The system should consider the use of Built in Test (BIT) design methodologies and BIT coverage analysis to demonstrate system-wide data availability and data continuity and correctness. For computational functions the system should consider the implementation and verification of data consistency techniques such as cyclic redundancy checks (CRC), wrap-around monitoring and watch-dog functions. Where system functions have been identified as safety related then the software integrity used to support data processing integrity should consider compliance with RTCA DO-178. Where system functions have been identified as safety related then the integrity of the complex hardware used to support data processing should consider compliance with RTCA DO-254. SAA system architecture design and dissimilar solutions may be used where insufficient functional segregation would exist between data processing and the associated monitoring of that data if it were to be performed on the same processing hardware.

GM.3225
Maintaining the accuracy, integrity, availability and continuity of data presents different engineering challenges which may require a mixed or varied approach to design, and to Verification and Validation. For example, software development integrity may be addressed by DO-178 compliance. Processing hardware integrity elements may be covered by compliance to DO-254 to the appropriate Development Assurance Level (DAL). System designs are likely to included Power-up Built in Test (PBIT), Pre-flight Built in Test (PFBIT) together with various implementations of Initiated Built in Test (IBIT) to limit exposure to dormant failures and to ensure the continuity of valid data. Continuous Built in Test (CBIT) may be used in flight also. The use of BIT should be driven by Safety Analysis and reliability analyses. This analysis may be used to underpin the quantitative evidence supporting Integrity and Availability in particular. System architecture design can be used to ensure separation of data/command functions from their associated monitoring functions. This could be necessary where the system hardware used cannot support 'time and space' separation of data processing functions to the required DAL. Regarding Integrity: see also [1] RTCA DO-362, Appendix D, section D.5 (in particular D.5.2), D.7; [2] JARUS SORA 1.0, OSO#06 and PDRA-01; [3] ASD-STAN prEN4709-001 - Section 6.8.2.

AMC.3226
Insecure Surveillance Data Validation SAA performance relies on the integrity of the surveillance data, defined as the degree or level of confidence that the data provided meets the requirements of the SAA system. Any surveillance data that is not sufficiently protected against intentional alteration, whose integrity is not controlled or whose origin cannot be traced shall be considered as insecure and mitigation measures shall be placed to reduce the effects of using this data in the context of SAA. For example: - ADS-B In data is considered as insecure because it uses unencrypted automatic broadcast messages (public protocol, no authentication) that include the aircraft state information (position and velocity). ADS-B In vulnerabilities can be easily misused and may heavily affect SAA (ghost injection, flooding). - Proprietary non-certified and non-mandatory surveillance systems are commonly installed in European sailplanes, GA aircraft and miniature UAS. They are considered as insecure because they have no demonstrated design assurance and the integrity of the data transmitted or received is not controlled. The applicant shall identify all insecure surveillance data used by the SAA system and propose mitigation measures. The risks of using insecure surveillance data shall also be addressed in the Functional Hazard Analysis (FHA). Acceptable means of mitigation consists of validating the insecure data by a second independentmeans (or surveillance sensor here). For example, RTCA DO-365B requires

validation of ADS-B before being used to generate DAA warning level alerts or guidance (RTCA DO-365B 2.2.3.2.1.3.4/2.2.4.3.7.4). Surveillance sensor data may also be validated by a non-cooperative sensor like a radar or an EO/IR sensor. The validation technique shall consider aspects like validation rate (intervals between revalidation), validation validity and validation criteria: see DO-365A Appendix N for an approach to determining these criteria.

Situations differ in controlled and uncontrolled airspaces:

- In controlled airspaces, current mandatory traffic equipment ensures that a high percentage of validation is possible.
- In uncontrolled airspaces, tracks for specific traffic may only be validated with non-cooperative sensors. A certain percentage of unvalidated tracks may remain. Note that unvalidated means a track that has yet to be validated (or is not capable of being validated); this is contrasted with invalidated where a track has been determined to be invalid through the validation process.

As a consequence, unvalidated tracks need to be considered and should remain applicable for RWC and CA in certain conditions, to be agreed with the certifying authority.

The benefits of using a different symbology for unvalidated tracks (see for example ATSAW (Air Traffic Situational Awareness symbology)) should be considered, especially if different operating procedures are expected to result from the above situations—e.g. if the operator is expected to mitigate the risk of insecure data.

AMC.3227

Traffic Criticality Levels

The SAA system shall assign a priority level to each traffic tracked.

Operator acceptability should be validated in a simulation incorporating alerts as designated for traffic priority levels.

Automated priority levels can be assigned to traffic based on parameters derived from human-in-the-loop simulator testing and/or human performance modelling.

GM.3227

NATO UAS Human System Integration Guidebook
UK Ministry of Defence TLCM Handbook, 2010

4.6.2. Alerting

AMC.3241
RWC Alerting Alerting suitability and operator response shall be validated in a simulation incorporating the alerts. This simulation should quantify the frequency of nuisance alerts (situations where the SAA system alerts, but is otherwise safe). Level of caution should be evaluated based on aircraft and against human performance requirements to maintain well clear volume surrounding aircraft. Caution level of detail should consider mechanisms for drawing operator attention including colour, luminosity, location of caution on screen, and auditory cues. Additionally, information provided should facilitate appropriate response from operator without task saturation.

GM.3241
NATO UAS Human Systems Integration Guidebook UK Ministry of Defence TLCM Handbook, 2010 AEP-101 Ed. A. Ver. 1, Section 5.1 Vincent, M., & Jack, D. (2018, September). An evaluation of alert thresholds for detect and avoid in terminal operations. In 2018 IEEE/AIAA 37th Digital Avionics Systems Conference (DASC) (pp. 1-5). IEEE. MIL STD 1472H

AMC.3242
CA Alerting Alerting suitability and operator response shall be validated in a simulation incorporating the alerts. This simulation should quantify the frequency of nuisance alerts (situations where the SAA system alerts, but is otherwise safe). Level of warning should be evaluated based on aircraft and against human performance requirements to maintain collision volume surrounding aircraft. Warning level of detail should consider mechanisms for drawing operator attention including colour, luminosity, location of warning on screen, and auditory cues. Additionally, information provided should facilitate appropriate response from operator without task saturation.

GM.3242
NATO UAS Human Systems Integration Guidebook UK Ministry of Defence TLCM Handbook, 2010 AEP-101 Ed. A. Ver. 1, Section 5.1 Vincent, M., & Jack, D. (2018, September). An evaluation of alert thresholds for detect and avoid in terminal operations. In 2018 IEEE/AIAA 37th Digital Avionics Systems Conference (DASC) (pp. 1-5). IEEE. MIL STD 1472H

4.6.3. Guidance and resolution manoeuvres

AMC.3261
RWC guidance The SAA system should include a guidance logic that provides the preferred manoeuvres to be commanded by the UA crew in order to remain well clear from any surrounding traffic. (Guidance is only used for manoeuvres that shall be commanded by the crew located in the CS on the ground). Manoeuvre may be altitude, speed or heading changes or a combination thereof. Note that heading changes are commanded by the UA crew but track information may be used by the SAA processor and corrected with wind information for presenting heading to the UA crew. Preference* shall be given to a manoeuvre from a set of possible trajectories that ensures a minimum distance from terrain (if UA is being operated near terrain), has the highest probability of not infringing the protection volume, limits changes during the manoeuvre (especially multiple changes during the manoeuvre), is compatible with already operational ACAS systems and complies with the rules of the air**. Other avoidance criteria may be added. The logic shall take into account: - WC protection volume - Traffic and ownship predicted trajectories and associated accuracies - UAS status, performance (e.g. ROC, turn rate, speed) and limitations affecting the RWC manoeuvre - System latencies (including pilot reaction time) Each calculated possible RWC manoeuvre shall be evaluated for its compliance to the selected avoidance criteria. At the time a traffic is assigned the criticality level that requires a RWC manoeuvre, it shall provide the information associated to the preferred RWC manoeuvre to be transmitted and displayed to the UA crew: type of manoeuvre and manoeuvre specific information. The transmission and display shall be prioritized against tracks of lower criticality (which require no manoeuvre). Guidance information is heading, altitude or speed to be commanded by the UA crew, or any command particular to the RWC manoeuvre (e.g. lower levels like throttle commands, bank angles). Attention shall be given to the conversion of parameters used by the guidance logic (e.g. track) to the information displayed to the crew for commands (e.g. heading). The guidance shall be terminated when the UA has been navigated so that the encountered traffic is no longer of interest. Guidance shall be suppressed (or inhibited) if the logic is not able to calculate the avoidance manoeuvre (e.g. invalid input data). In this case, the suppression/inhibition status shall be also part of the information transmitted and displayed to the crew. The interfaces of the processing unit hosting the RWC guidance function shall be tested at unit level with real HW and SW (bit level testing, ICD verification).

The guidance logic implementation shall be then tested in a hybrid lab environment, including real units. Traffic data simulator and UAS dynamic model rovide the required inputs to the real equipment. The test cases shall exercise each type of RWC manoeuvre and their associated ranges (e.g. max altitude change).

During initial flight tests, traffic data may be injected artificially in order to activate RWC guidance and test it in open loop. Finally, closed loop tests with RWC manoeuvre commanded by UA crew shall be performed.

For additional guidance, see AEP-101 Ed. A Ver. 1, Section 5.2.

* Expressed through a quality criterion considering costs. Other data (e.g. UA attitude, wind estimation) may be required in accordance with the complexity of the guidance logic.
** see AMC.3264 for further discussion of the rules of the air.

AMC.3262

CA guidance

The SAA system shall include a guidance logic that provides the preferred manoeuvres to be commanded by the UA crew or an automated system* in order to avoid a collision with any surrounding traffic.

AMC.3261 is applicable with following adaptations:

- NMAC protection volume replaces the WC protection volume
- CA manoeuvre replaces RWC manoeuvre
- Compliance to the rules of the air* is not mandatory for a CA manoeuvre, considered as the last chance to avoid a collision

CA guidance may be used stand alone or in combination with RWC guidance. If used in combination with RWC guidance,

- the logic shall run in parallel and possibly calculate other possible trajectories than RWC trajectories (e.g. different weighted criteria, other UA performance)
- the transmission and display of CA manoeuvre information to the UA crew has highest priority and shall timely occur after RWC guidance, at the time a traffic transits to the criticality level requiring a CA manoeuvre.

* see AMC.3263 for further discussion of automatic manoeuvre execution.
** see AMC.3264 for further discussion of the rules of the air.

AMC.3263

Automatic CA Manoeuvre

The SAA system should include an avoidance logic that automatically commands the UA FCS to perform a collision avoidance manoeuvre, if the UA crew has not been able to command prior resolution manoeuvres (like RWC or CA guidance) in a timely manner (due to link loss, high system latencies or traffic late detection and tracking).

AMC.3262 is applicable with following adaptations:

- System latencies are reduced to the delay between the automatic avoidance processing unit and the FCS

Automatic CA may be used alone or in combination with RWC and/or CA guidance. If used alone, the automatic CA may be subject to a higher development assurance than when used in combination with RWC and CA guidance, the probability of having automatic CA being lower in combination.

If an automatic collision avoidance logic is implemented, the UA crew shall be able to:

- enable/disable the automatic CA function as part of the SAA system settings
- configure the SAA system so that the automatic CA function is enabled/disabled during link loss situations
- abort the automatic CA manoeuvre at any time during the manoeuvre and take over the command of the UA.

The unit hosting the automatic CA function shall directly interface the FCS unit:

- the CA logic should not command manoeuvre changes at a rate that may induce closed loop oscillations (< 1 Hz).
- the automatic CA information shall be transmitted with highest priority and rate (e.g. 10 Hz)
- the FCS should suppress automatic CA commands in the following situations:
  - SAA status declared inoperative or faulty
  - On ground operations
  - Critical flight phases like ATOL and emergency situations (e.g. engine power loss, stall escape)
- the FCS shall limit automatic CA commands to be within the permissible envelope

AMC.3264

Right of Way (RoW)

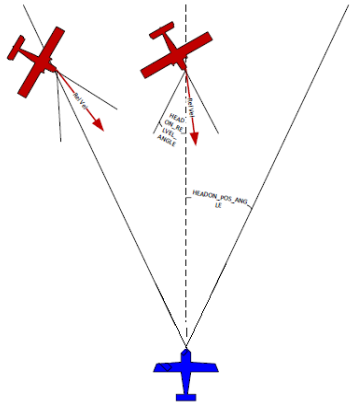
ICAO Annex 2 Rules of the Air (ROA) related to avoidance of collisions need to be interpreted in the context of UAS SAA, especially the RoW for head on, converging and overtaken/overtaking scenarios and if RWC guidance is only provided as a single manoeuvre recommendation.

Note that while RoW is often described in terms of heading of the respective aircraft, SAA systems may be expected to compare tracks instead. An intruder's heading may be estimated, however this is with variable accuracy and dependant on the on the sensor data available. While the SAA system internal comparison uses tracks, RWC and CA guidance given to the UA crew may then be presented in terms of heading change.

Head on:

The 3 following criteria shall be fulfilled in order to qualify an encounter as head on:

- the position of the traffic is within +/- 10° of the ground speed vector of the UA.
- the relative velocity vector of the traffic in regards to the UA is within +/- 10° of the vector connecting the traffic to the UA.
- the absolute track (ground course) difference between UA and traffic is greater than or equal to 90°.



UA Overtaking:

The 3 following criteria shall be fulfilled in order to qualify an encounter as UA overtaking:

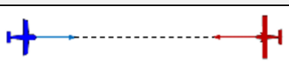
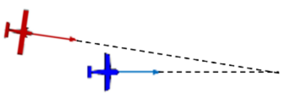
- the position of the traffic is within +/- 10° of the ground speed vector of the UA.
- the relative velocity vector of the traffic in regards to the UA is within +/- 10° of the vector connecting the traffic to the UA.
- the absolute track (ground course) difference between UA and traffic is less than 90°.

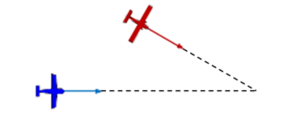
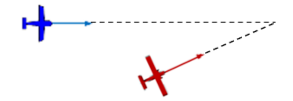
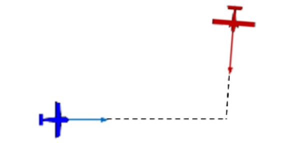
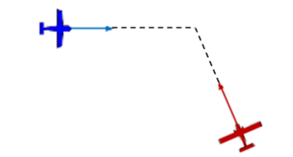
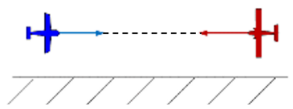
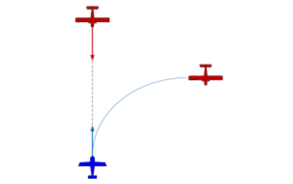
RoW compliance is a criteria for RWC manoeuvres, but is not mandatory for CA manoeuvres. For collision avoidance, any manoeuvre that maximizes the CPA with the possible constraints (e.g. terrain, multiple intruders) may be considered appropriate, regardless of RoW.

For encounters in proximity to terrain, terrain avoidance has priority and may induce manoeuvres not compliant with RoW. For encounters with multiple intruders, RoW may not be applied to all intruders.

For cases of the UA being overtaken or converging traffic where the UA has RoW and is not expected to manoeuvre, the SAA system shall regardless issue RWC guidance. The RWC guidance should not conflict with the RoW manoeuvre direction of the other aircraft to avoid the possibility of induced MAC.

The following table lists the ownship RWC manoeuvre, assuming the UAS SAA RWC guidance function has traffic data with sufficient quality to select a right turn within the possible trajectories. This might not be the case for all traffic (e.g. traffic with no bearing information). Note that vertical manoeuvres are not addressed and are generally considered to be acceptable.

Geometric Classification	Description	Ownship has RoW?	Intruder has RoW?	Ownship Manoeuvre Direction
Head-On		No	No	Turn right
UA Overtaken		Yes	No	If collision risk, manoeuvre to remain WC w/o consideration for ROW (preference to left)

UA Overtaking		No	Yes	Manoeuvre to the right
Left Oblique UA Overtaking		No	Yes	Manoeuvre to remain WC (left or right)
Right Oblique UA Overtaking		No	Yes	Manoeuvre to remain WC (left or right)
Intruder Converging from Left		Yes	No	If collision risk, manoeuvre to remain WC w/o consideration for ROW (left or right)
Intruder Converging from Right		No	Yes	Manoeuvre to remain WC (left or right)
Head-On with Terrain Right of UA		No	No	Terrain avoidance has priority, manoeuvre to remain well clear
Head-On with Second Intruder Right of UA		No	No	Manoeuvre to remain well clear

The implementation of the RoW in the RWC guidance logic is primarily verified through simulations. The Monte Carlo simulations shall include encounters with traffic (e.g. see and avoid /VFR traffic) that manoeuvre in accordance with the RoW to prevent loss of well clear (well prior collision). Additionally, flight tests shall verify that RoW is complied with for head on and overtaking encounters.

An encounter that requires compliance with RoW (e.g. head-on) may be erroneously not classified as head on if the SAA guidance relies on inaccurate traffic track information (e.g. due to poor performance of sensors). In this case, the RWC manoeuvre will not comply to RoW. The applicant shall assess and report the probability of RoW infringements for head on and overtaking encounters.

AMC.3265

Terrain and Obstacle Avoidance

An SAA system does not necessarily include a terrain and obstacle avoidance feature, however where operations in terrain proximity require such a feature the interaction between a) terrain avoidance and b) traffic avoidance algorithms must be considered. Depending on the type of operation and environment, terrain proximity not only limits downwards avoidance manoeuvres but also in lateral direction.

Terrain collision avoidance should take precedence over traffic avoidance and the rules of air, based on following considerations:

- The non-performance of a terrain avoidance manoeuvre will directly lead to a CFIT;
- The non-performance of a traffic avoidance manoeuvre will not necessarily end in a MAC, if the other traffic is able to avoid the UAS.

Nevertheless, these situations should be extremely rare and other considerations may influence the decision to prioritize terrain or traffic (e.g. no loss of life in a UAS crash).

Additionally, guidance or automatic resolution to maintain traffic separation should not directly lead to a situation where a follow-up manoeuvre to avoid terrain collision will be required. The rules of air should be followed, however there may be situations where it is safer to not comply with the right-of-way rules due to risk of a CFIT. Where it is judged to be safer to not follow the rules of air, the possibility of induced MAC should be considered and mitigated to the maximum extent possible (e.g. due to the intruder complying with the ROW and the ownship not).

Sample cases defining the avoidance prioritization and associated resolution manoeuvres, for example a head-on encounter geometry with terrain to the right, should be agreed with the certifying authority. Subsequently the ability to appropriately separate to terrain and traffic shall be shown by simulation (e.g. Monte Carlo simulation).

AMC.3266

Airspace Reservations

Staying clear of Airspace Reservation/Restriction (ARES) is an integral part to the FMS / MMS of UAS. For time based operations this is done by the flight planning process and for the trajectory based Operations (planned from 2030 to 2035) this is an integral part to the CDM process of trajectory planning for the Initial Shared Mission Trajectory (iSMT).

The SAA system should inhibit SAA responses into an ARES that must be avoided (where the penalty of intruding on the ARES significantly outweighs the potential degradation in SAA performance), and deprioritize SAA responses into an ARES that should be avoided (where the penalty of intruding on the ARES is roughly equivalent or less than the potential degradation in SAA performance).

The evasive action, if required, is to be performed in automatic mode or with pilot intervention.

Automatic mode:
The situation of an UA requiring evasive action to resolve a conflict situation is addressing the CA as well as the RWC function. Both functions of the SAA should use existing pertinent routine data links to the FMS / MMS (proven being airworthy) to get in real time the available data related to and to avoid the respective ARES. If the respective database is on board of the UA it (trajectory data including ARES data) should be taken from there, if that database is on the ground, the down and up linking capability (data link being airworthy) needs to be respected.

Pilot intervention:

The situation of an UA requiring evasive action to resolve a conflict situation is addressing the CA as well as the RWC function. The required information and guidance must be presented to the operator in an intuitive manner that supports the operator in the decision making process. This should make full use of HF research and guidance on the display of critical information—e.g., MIL-STD-1472, Def Stan 00-251. HSI should be considered throughout the requirements process when determining what information will be provided to the operator. The HMI should inform the operator when a traffic encounter is happening or is about to happen. Proper information of ownship and intruder traffic state is necessary regardless of the LOA used. For further guidance refer to AEP-101 Ed. A Ver. 1 (4.2.3.2).

The guidance function of the SAA HMI interface requires the development of pertinent algorithms depending on the LOA. It is important to fully consider and evaluate situations where the guidance may cause a conflict (here the infringement of ARES) that would not have otherwise occurred, often termed an induced conflict. Fast-time constructive simulation can be used to test many encounter geometries in a relatively short amount of time for characterization of induced conflicts.

As guidance requires more intensive verification and validation than alerting, verification and validation should be conducted throughout the design process when considering alternatives, developing requirements, and prototyping solutions. For further guidance refer to AEP-101 Ed. A Ver. 1 (5.2.2).

AMC.3267
Clear of Conflict Clear of Conflict is indicated to the UA crew when all RWC, CA guidance or automatic collision avoidance has been terminated, so that all surrounding traffic are no longer a well clear threat. Other indications may be provided when high alert levels clear but lower alert levels still persist or when alerts clear for a threat but persist for other traffic. The SAA avoidance function shall prevent clear of conflict indications that only last a limited time (intermittent clear of conflict is to be avoided). The clear of conflict situation shall be part of the message transmitted from the SAA processing unit to the CS. For example, avoidance information type (AMC 3261, 3262, 3263) data of the message may include a value for none or clear of conflict. The clear of conflict annunciation should be aural and visual.

4.6.4. Support functions

AMC.3281
Health and Status Monitoring Guidance on health and status monitoring for SAA systems can be obtained from Section 2.2.8 of DO-365. At least the following should be taken into account: - Each SAA subsystem should have its own health monitoring function to run in the background of its run-time environment and to determine its current operational status. - Each SAA subsystem should report its current operational status to the overall SAA system health monitoring function continuously (about every second). - During initiation, power-on, or before flight each SAA subsystem should perform a comprehensive set of tests to check hardware, software, and firmware, to evaluate that the components and functions of the subsystem will operate properly. - Any SAA subsystem that fails to report its operational status to the overall SAA system health monitoring function should be considered as failed.

AMC.3282
SAA System Data Recording Guidance on determining the data to be recorded can be obtained from Appendix 5 of ICAO ACAS Manual. However, the specifics of a SAA system must be taken into account. For each encounter that triggers an RWC alert the following SAA system data should be recorded: - Identifying information (date, time, encounter equipage, latitude, longitude, geographic altitude) - UA's own position (heading, altitude, altitude rate, height above ground) - Other aircraft's position (bearing, range, range rate, altitude, altitude rate)* - Description of the event (sequence of alert, severity, multi-aircraft encounter) For each encounter that triggers a CA alert the following SAA system data should be recorded additionally: - Time of minimum separation - Range at minimum separation - Relative altitude at minimum separation The SAA system data should be recorded for the whole flight. At least the data 90 seconds prior and 90 seconds after an indicated alert or caution must be recorded. The SAA system data should be recorded by an on-board data recorder and the data transmitted via the command and control data link should be recorded by a data recorder in the control station. Guidance on data can be obtained from EUROCAE ED 112. In case that the UAS' certification basis includes provisions for flight data recorders, the same provisions shall apply for the recording of the SAA system data.

* The applicant/authority will need to determine the number of aircraft to record simultaneously.

4.7. INSTALLATION & INTEGRATION REQUIREMENTS

AMC.3301
SAA System Environmental Qualification Tests according to standards and guidelines, agreed with the certifying authority, should be performed to show that the SAA system equipment is equivalent to the operating environmental conditions of the UAS.

GM.3301
SAA System Environmental Qualification The operating environmental conditions of the UAS may include: - natural climate (altitude, temperature, pressure, humidity, wind, rainfall rate, lightning, ice, salt, fog, fungus, hail, bird strike, sand and dust) - electromagnetic environmental effects (electromagnetic environment among all sub-systems and equipment, electromagnetic effects caused by external environment, electromagnetic interference among more than one UAS operated in proximity) - lighting conditions (e.g. day, night, dawn, dusk, mixed, etc.) The tests should also cover all effects on the equipment due to manoeuvres, gusts, taxiing, towing, storage and transportation (e.g. loads, vibrations etc.). The following standards and guidelines, including future amendments, may be used for testing, as agreed with the certifying authority: - MIL-STD-810H: Environmental Engineering Considerations and Laboratory Tests - STANAG 4370, Ed. 7: Environmental Testing (including the five related AECTP standards) - DO-160G / ED-14G: Environmental Conditions and Test Procedures for Airborne Equipment - MIL-STD-461G: Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment - MIL-STD-464C: Electromagnetic Environmental Effects, Requirements for Systems - AC 20-158A: The certification of Aircraft Electrical and Electronic Systems for Operation in the High-intensity Radiated Fields (HIRF) Environment - SAE ARP 541B / ED-84A: Aircraft Lightning Environment and Related Test Waveforms - SAE ARP 5414A / ED-91: Aircraft Lightning Zoning - SAE ARP 5416 / ED-105A: Aircraft Lightning Test Methods

AMC.3302
Non Interference Any adversely affection of the response, operation or accuracy of any equipment essential to safe flight or safe operation must be considered as an interference. During the certification of the UAS a safety assessment identifies the functions required for safe flight.

If the results of this assessment are not accessible, the identification of the UAS functions required for safe flight should be demonstrated by the approach as defined by SAE ARP 4761 based on iterative approach at UAS level, then at UAS subsystem level.

AMC.3303

UAS Installation

All installed SAA system equipment should function properly within the design usage spectrum of the UAS, as per the UAS certification basis for equipment function and installation (e.g. STANAG 4671 USAR.1301).

All installed SAA system equipment should have a statement that it has been designed, tested and manufactured in compliance with the applicable requirements (e.g. Declaration of Design and Performance (DDP) or equivalent) released by its manufacturer.

For installed SAA system equipment the UAS manufacturer should approve its technical specification in order to assess compatibility with UAS higher-level requirements.

AMC.3304

Field of Regard

The Field of Regard (FOR) is defined as the total angle within which the UAS' surveillance sensors are providing information to the UAS on possible intruders and is typically quantified in azimuth and elevation relative to the ownship axis. It is related to, but should not be confused with, the Field of Vision (FOV), which is the section within the FOR that is visible at a given instant and in the case of a moving or scanning sensor can be integrated over time to form the FOR. The UAS may include some feature to adjust or stabilize the FOR relative to changes in angle of attack (AoA) or roll angle along its longitudinal axis (bank angle).

An ideal FOR is spherical in shape, however optimizing the safety benefit afforded by the surveillance system with the related cost and performance penalty typically focuses on a FOR oriented towards the ownship velocity vector. Multiple factors external to the SAA influence this optimization and should be considered:

- Traffic characteristics;
- Encounter geometries, e.g. head-on, overtaking, climbing up from underneath, etc.;
- Application of Rules of Air;
- UAS usage, e.g. velocity, AoA and bank angle.

In addition to factors external to the SAA, various factors internal to the SAA and its installation must be considered:

- Sensor performance, such as resolution, FOV scan rate and time to establish track;
- Sensor stabilization features to counteract AoA and / or bank angle, if available;
- Installed performance due to sensor placement, sensor coverage and potential obstructions.

Taking these factors into account, the FOR shall be specified in azimuth and elevation with respect to the UA axes and verified by ground and flight test.

Note that SAA FOR limitations are to be considered as part of the risk ratio demonstration (AMC.2501 and AMC.2502).

AMC.3305

UA Envelopes

The UA performance limits information should be provided to the SAA system. The SAA system should check if the UA is capable of performing the resolution manoeuvre at these performance limiting conditions.

If the UA is not able to perform the resolution manoeuvre, the SAA system should adapt its resolution manoeuvre appropriately. If this adaption is not possible, an indication should be displayed to the operator.

The data exchange between the SAA system and the UA's flight control system shall be in a manner that the FCS is able to command the manoeuvre and to verify the integrity of the information prior to use. The UAS certification basis may include further provisions for the data received from components external to the UA's flight control system.

AMC.3306

Completion

This AMC addresses the criteria that must be considered after clear of conflict is declared and when returning back to the last commanded flight and mission mode as part of completing the resolution manoeuvre.

After the completion of a manoeuvre (RWC or CA guidance) and when "clear of conflict" is declared, the flight crew should select the appropriate UAS flight mode and:

If operating in controlled airspace under ATC control:
1) immediately return to their previously assigned clearance and advise ATC of near miss, avoidance manoeuvre and return to previously assigned clearance;
2) comply with any amended clearance issued and
3) report any deviation to ATC

If operating in uncontrolled airspace under own responsibility of traffic avoidance:
1) Return to planned route at UAS pilot's discretion, considering airspace restrictions.

In case of an automatic avoidance manoeuvre:
1) Return to flight mode that was active before initiating the automatic avoidance manoeuvre
2) The following setting should be adopted based on the flight mode:
   HDG / Rte: HDG value or route of previous flight mode.
   Coordinate: Previous flight mode with previous coordinate
   Hold: Hold established at UAS position where avoidance command terminates.

CAS:	CAS value of the previous flight mode.
ALT:	ALT value of the previous flight mode.

Note that it may be possible that multiple alerting and guidance levels exist simultaneously, and therefore residual alerts remain when the alert level is downgraded. Care must be taken that when returning to course alerts are not inadvertently ignored or induced.

See also ICAO PANS-OPS, Doc 8168, Volume I as reference on related ACAS procedures. Note also that RTCA DO-325 Appendix C and EUROCAE ED-224 define considerations for automatic execution of TCAS RAs that may be applicable, depending on the operational concept; additionally, RTCA DO-365B Appendix R describes considerations for the automatic execution of horizontal and vertical manoeuvres.

AMC.3307

Human Factors

Conduct human-in-the-loop testing with either the SAA system embedded in a full system simulation or operational testing environment. This human-system integration validation testing ensures safety of flight and system performance including human operators rather than solely relying on human performance models.

GM.3307

FAA Human Factors Policy Order 9550.8
NATO Human Experimentation with UAS Guidebook (*pending*)
NATO UAS Human Systems Integration Guidebook
EUROCONTROL (2007). The Human Factors Case: Guidance for Human Factors Integration
International Organisation for Standardization (1999). Human-Centred Design Processes for Interactive Systems: ISO 13407:1999.
United States Air Force (2008). Air Force Human Systems Integration Handbook.
ISO 9241-210:2019
AEP-101 Ed. A Ver. 1 Section 4.5

AMC.3308

Traffic Display (SA)

SAA system shall display traffic information to the operator to increase situation awareness throughout the operation. Situation awareness should be comparable to levels found in manned aircraft (including with TCAS/ATSAW.)

The system should consider RTCA DO-365A requirements (2.2.5) for the display of traffic information to the operator. The display of traffic information should consider the discernibility and legibility of the traffic information and should ensure that is it unambiguous. Display of traffic information should consider all operating environments within which the operator and control station display are working, or are likely to work in.

GM.3308
NATO UAS Human Systems Integration Guidebook UK Ministry of Defence TLCM Handbook, 2010 RTCA DO-365 Minimum Operational Performance Standards for Unmanned Aircraft Systems (Section 2.2.5).

AMC.3309
SAA Command and Control Interface Evaluate UI designs for utility of pre-population of manoeuvre guidance to facilitate speedier and more accurate decisions. Interface for UA manoeuvring shall be sufficient to respond to warnings and cautions provided by alerting systems and remain well-clear of surrounding traffic. Additionally, the SAA system shall provide protection (e.g., decision verification in UI) from inadvertent action that may be detrimental to safety and workload (e.g., disabling alerts/guidance or automation). The system should consider RTCA DO-365A requirements (2.2.5, 2.2.6, 2.2.7) for the SAA System command and control interface to the operator.

GM.3309
NATO UAS Human Systems Integration Guidebook UK Ministry of Defence TLCM Handbook, 2010 ISO 9241-210:2019

AMC.3310
SAA System Health and Integrity Monitoring System status shall be available to the operator at all times. Interfaces for consolidating system data (e.g., colour coding - red, yellow, green; auditory alerts) should be considered for improved human system integration. RTCA DO-365A requirements (2.2.8, 2.2.9) should be considered for the SAA system status and monitoring data provided. The presentation of all SAA system status and associated monitoring data should consider the discernibility and/or legibility of the information and should ensure that it is unambiguous. Provision of SAA status and associated monitoring data to the operator should consider all operating environments within which the operator and control station display are working. See also FAA Human Factors Policy Order 9550.8.

AMC.3311
SAA System Specific Equipment Control Task analysis shall be conducted to determine the breadth of control the user interface shall include for SAA system specific equipment control. User interface shall include only the components necessary to effectively control the SAA system. RTCA DO-365B (2.2.7) requirements should be considered for the SAA system sensor interface to the operator. For individual surveillance sensors, requirements specific to those sensors should be considered—for example, consideration could be given to the guidelines contained in RTCA DO-366, RTCA DO-260 and RTCA DO-317. This list of standards is not exhaustive and the applicant should undertake a study to identify the specific guidance relating to the surveillance sensors in their system. The applicant should be able to demonstrate that each surveillance sensor can be controlled individually by the operator through the interface and under all required combinations and sequences of required sensor management (for all in-air and on-ground conditions).

GM.3311
SAA System Specific Equipment Control See also: FAA Human Factors Policy Order 9550.8 NATO UAS Human Systems Integration Guidebook ISO 9241-210:2019 In consideration of the full control path, the SAA System should provide correct and timely information to the operator on the status of each surveillance sensor. The decision and intervention time required for the operator to receive the data, to process the data and to act on the data should be considered in the interface design. The Human Machine Interface (HMI) design is of particular importance when considering correct and timely control. It is important that surveillance sensors can be managed on the ground and in-hangar so that radiation hazards (RADHAZ) to ground personnel can be managed safely.

AMC.3312
Function Enabling/Disabling Task analysis shall be conducted to determine the critical functionality control necessary for the SAA system. User interface shall be developed to facilitate user response in emergency situations.

GM.3312
Function Enabling/Disabling See also: FAA Human Factors Policy Order 9550.8 NATO UAS Human Systems Integration Guidebook

UK MoD Def Stan 00-250, 2008
ISO 9241-210:2019

Providing an acceptable interface between the operator and the SAA System is important to ensure the correct and timely management and control of the SAA system functions. The implementation of the control and command interface influences the function of the SAA System and the UAS's performance, and has a direct influence on safe system operation.

The operator should have a clear and unambiguous understanding of the current state of all functions which can be enabled / disabled. Following an enable / disable request the operator should receive a timely confirmation that the status has changed.

The residual performance and capability of the SAA system following disabling of individual or grouped functions should be easily understood by the operator.

AMC.3313

Function Output Suppression

The operator must be able to manually suppress the SAA functions, for example during take-off or landing flight phases, in case of a SAA malfunction or due to overriding mission imperatives. An automatic suppression by the UAS may be considered by the UAS integrator where the execution of the collision avoidance manoeuvre is likely resulting in a hazardous condition for the UAS. This may be given in situations such as:

- Abnormal UAS conditions such as engine failure or fuel starvation;
- Continuous avoidance manoeuvres combined with link loss;
- Terrain avoidance, if this function is not integrated into the SAA system.

When a function is suppressed it shall be clearly indicated to the operator, visually and/or aurally, to avoid inadvertent suppression.

For manual suppression, a task analysis shall be conducted to determine the critical functionality control necessary for the SAA system. User interface shall be developed to facilitate user response in emergency situations. See also GM.3312 for guidance material.

If an automatic suppression logic is implemented it shall be justified to the certifying authority and be reflected in the operational safety performance demonstration.

AMC.3314

SAA System Data Link

Data link configurations will vary across UAS designs and the use of those data links to support SAA system functions will vary. It is not envisaged that a dedicated SAA system data link will be provisioned for in a UAS design. On this basis the SAA system may use allocated bandwidth on an existing conventional command and control data link for normal operation. Fail-over capability may be available on some UAS designs by using a secondary command and control data link or by repurposing a tactical mission data link for the transmission of essential flight critical tele-command functions including SAA. Where a conventional data link is not viable, then alternative means of data transmission may occur: for example, tele-command by SATCOM.

For each specific implementation of a UAS and its SAA system, the applicant should identify all of the data links and data link receive/transmit topologies which may be used as part of the SAA system's operation. Those identified data links together with their representative ground and air interfaces should be qualified to the RLP for SAA operation.

Where data links are provided by third parties, for example SATCOM services, then assurance should be sought from the service provider that the minimum specified performance is achievable under the range or operation and under the environmental conditions within which the data link is designed to operate. However, depending on the type of data link provisioned it may not be possible to meet the latency or bandwidth requirements for full SAA system performance (i.e. SATCOM services). Where third party data link performance cannot be guaranteed the applicant should be able to define the limitations which apply to SAA system use. The applicant should show that the achieved performance of the third party data link does not provide unwanted hazards in operation.

AMC.3315

SAA System UAS Safety Impact

Any SAA system function shall be assessed within a safety assessment to determine whether it affects the airworthiness of UAS for safe flight and landing. This assessment shall show compliance with the safety requirements of the UAS certification basis (e.g. STANAG 4671, USAR 1309) and should be performed by the same approach as for the system safety assessment of the UAS.

For software and complex electronic hardware the compliance should be shown for the functional development assurance level (FDAL) instead of hazard probability.

GM.3315

SAA System Safety

SAA system functions that may affect UAS safe flight may be:

- Provide situation awareness
- Provide flight path information

If a loss or a malfunction of a SAA system function results in a failure condition other than no safety effect on UAS level, this function affects UAS safe flight.

AMC.3316

DAA Interoperability and Compatibility

This AMC defines the criteria to be considered when the UAS incorporates multiple avoidance / awareness systems with conflicting functions. Such criteria are multi hazard handling (i.e. traffic, terrain, obstacles, weather, wake turbulence), prioritization, and threat override to ensure that the most critical and timely alerts are displayed to the pilot.

The term DAA (Detect and Avoid) is used in this context, SAA (sense and avoid) being historically limited to traffic detection and avoidance (see also AEP-101 Ed. A Ver. 1 Section 2.1 for further discussion of the terms).

The various DAA capabilities on the UAS, whether implemented in a single DAA system or in several systems, shall assure the most appropriate avoidance action is taken when two or more hazards are present at the same time.

In case of multiple hazard detection, the prioritization of hazards may vary according to the operational situation and may be supported by the DAA system and/or operational procedures. The following factors should be considered in the prioritization:

- The hazards criticality (warning preceding caution and advisory).
- The consequences severity (loss of life higher rated than loss of UA and UA damages).
- The probability of success for the mitigation actions (not performing terrain avoidance has no chance of success, not performing traffic avoidance has relatively little chance of success).

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