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Standard Specification for Detect and Avoid System Performance Requirements[1]

This standard is issued under the fixed designation F3442/F3442M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification applies to ~~unmanned~~uncrewed aircraft (UA) with a maximum dimension (for example, wingspan, disc diameter) ≤25 ft, operating at airspeeds below 100 kts, and of any configuration or category. It is meant to be applied in a "lower risk" ~~(low-~~[low- and medium-risk airspace as described by Joint Authorities for Rulemaking on Unmanned Systems ~~(JARUS))~~(JARUS)] airspace environment with assumed infrequent encounters with ~~manned~~crewed aircraft; this is typically in classes G and E airspace ~~(below~~[below about 1200 ft above ground level ~~(AGL)),~~(AGL)], Class B, C, D (below ~~about 400~~approximately 400 ft to 500 ft ~~AGL),~~AGL) below obstacle clearance surface (FAA Order 8260.3, as ~~amended),~~amended) or within low altitude authorization and notification capability (LAANC) designated areas below the altitude specified in the facility map.

1.1.1 Traffic encountered is expected to be mixed cooperative and non-cooperative traffic, instrument flight rules (IFR) and visual flight rules (VFR), and to mostly include low-altitude aircraft—including rotorcraft, small general aviation, crop dusters, ultralights, and light sport aircraft, but not transport category aircraft.

1.1.2 This includes, but is not limited to, airspace where nearly all aircraft are required[2] to be cooperative (for example, within the Mode C veil in the ~~U.S.).~~United States).

1.2 Ultimate determination of applicability will be governed by the appropriate civil aviation authority (CAA).

1.3 This specification assumes no air traffic control (ATC) separation services are provided to the UA.

1.4 While some architectures may have limitations due to external conditions, this specification applies to daytime and nighttime, as well as visual meteorological conditions (VMC) and instrument meteorological conditions (IMC). The system integrator shall document system limitation (that is, due to operating environments and/or minimum altitudes at which the air picture is no longer valid).

1.5 This specification is applicable to the avoidance of ~~manned~~crewed aircraft by ~~unmanned~~uncrewed aircraft systems (UAS), not UA-to-UA or terrain/obstacle/airspace avoidance (both to be addressed in future efforts). Likewise, birds or natural hazard (for example, weather, clouds) avoidance requirements are not addressed.

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[1] This specification is under the jurisdiction of ASTM Committee F38 on Unmanned Aircraft Systems and is the direct responsibility of Subcommittee F38.01 on Airworthiness.

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[2] Refer to 14 CFR § 91.215 and 14 CFR § 91.225 in the United States, or to the international equivalent for exceptions.

1.6 This specification does not define a specific detect and avoid (DAA) architecture[3] and is architecture agnostic. It will, however, define specific safety performance thresholds for a DAA system to meet in order to ensure safe operation.

1.7 This specification addresses the definitions and methods for demonstrating compliance to this specification, and the many considerations (for example, detection range, required timeline to meet well-clear, well clear, and near mid-air collision (NMAC) safety targets) affecting DAA system integration.

1.8 The specification highlights how different aspects of the system are designed and interrelated, and how they affect the greater UAS systemsystem-of-systems to enable a developer to make informed decisions within the context of their specific UAS application(s).

1.9 It is expected this specification will be used by diverse contributors or actors including, but not limited to:

1.9.1 DAA system designers and integrators,

1.9.2 Sensor suppliers,

1.9.3 UA developers,

1.9.4 Ground control station (GCS) Control Station designers,

1.9.5 UAS service suppliers, and

1.9.6 Flight control designers.

1.10 Except for DAA system integrators for whom all the "shalls" in this specification apply, not all aspects of this specification are universally relevant. relevant to all actors/contributors. In some instances, the actor most likely to satisfy a requirement has been identified in brackets after the requirement; this is for informative purposes only and does not indicate that only that actor may fulfill that requirement. Where not specified, the system integrator/applicant is assumed to be the primary actor; in all cases, the system integrator/applicant is responsible for all requirements and may choose to delegate requirements as is suitable to the system design. Nonetheless, familiarity with the entire specification will inform all actors/contributors of how their contributions affect the overall DAA capability and is strongly recommended.

1.11 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system are not necessarily exact equivalents; therefore, to ensure conformance with the standard, each system shall be used independently of the other, and values from the two systems shall not be combined.

1.12 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.13 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 When external standards, documents, or studies are referenced by this specification, the latest revision applies unless otherwise stated herein. Standards referenced should not be considered normative unless explicitly stated.

2.2 *ASTM Standards:*[4]

F3060 Terminology for Aircraft

F3341/F3341M Terminology for Unmanned Aircraft Systems

[3] ACAS sXu is intended to serve as a reference architecture for this specification.

[4] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

ASTM TR1-EB Autonomy Design and Operations in Aviation: Terminology and Requirements Framework

2.3 *Other Documents:*

14 CFR § 1.1 General definitions[5]

14 CFR § 91.111 Operating near other aircraft[5]

14 CFR § 91.113 Right-of-way rules: Except water operations[5]

14 CFR § 91.119(c) Minimum safe altitudes. General.[5]

14 CFR § 91.215 ATC transponder and altitude reporting equipment and use[5]

14 CFR § 91.225 Automatic Dependent Surveillance-Broadcast (ADS-B) Out equipment and use[5]

14 CFR § 107.37 Operation near aircraft; right-of-way rules[5]

FAA AC (Advisory Circular) 23.1309-1E System Safety Analysis and Assessment for Part 23 Airplanes

FAA AC ~~(Advisory Circular)~~ 25.1322-1 Flightcrew Alerting ~~(Dec. 13, 2010)~~[6]

FAA Order 8260.3 United States Standard for Terminal Instrument Procedures (TERPS)[6]

JARUS Specific Operations Risk Assessment (SORA) (package) ~~V2.0, 30 January, 2019~~V2.0[7]

~~Public Law 112-95 § 331 FAA Modernization and Reform Act of 2012—Definitions~~[5]

RTCA ~~DO-365A~~DO-365C Minimum Operational Performance Standards (MOPS) for Detect and Avoid (DAA) ~~Systems, published May 2017~~Systems[8]

RTCA DO-381 MOPS for Ground-based Surveillance System (GBSS) for Traffic Surveillance[8]

SERA Standardised European Rules of the Air[9]

3. Terminology

3.1 *Unique and Common Terminology*—~~See Terminology~~ Terminology used in multiple standards is defined in Terminologies F3341/F3341M and F3060 and ~~ASTM TR1-EB for definitions and abbreviations.~~UAS Terminology Standard. Terminology that is unique to this specification is defined in this section.

3.2 *Use of Shall, Should, and May*—The use of *shall* indicates a requirement, *should* indicates a recommendation, and *may* is used to indicate that something is permitted.

3.3 *Definitions:*

3.3.1 *alert function, A1F, n*—~~the~~ function within the DAA system tasked with notifying the avoid function (whether human or automated system, or both) of the presence of an intruder.

3.3.2 *avoid function, A2F, n*—~~the~~ function within the DAA system tasked with providing the flight guidance necessary to maneuver away from the potential hazard posed by detected intruder(s). Avoidance may be executed automatically by a flight controller or manually by a pilot.

3.3.3 *beyond visual line of sight, BVLOS, n*—operation when the UA cannot be seen by the individuals responsible for see-and-avoid with unaided (other than corrective lenses or sunglasses, or both) vision, but where the location of the ~~sUA~~UA is known through technological means without exceeding the performance capabilities of the ~~C2 link.~~command and control (C2) link. See Terminology F3341/F3341M.

3.3.4 *collision avoidance, n*—avoidance maneuver with the objective of preventing the predicted penetration of the near-midair collision volume (NMAC).

3.3.5 *controlled airspace, n*—an airspace of defined dimensions within which air traffic control service is provided in accordance with the airspace classification.

3.3.5.1 *Discussion*—

For example, in the United States, Classes A, B, C, D, and E airspace.

3.3.5.2 *Discussion*—

Controlled airspace does not automatically imply separation services, or that the location of all traffic is known.

[5] Available from U.S. Government Publishing Office (GPO), 732 N. Capitol St., NW, Washington, DC 20401, http://www.govinfo.gov.

[6] Available from Federal Aviation Administration (FAA), 800 Independence Ave., SW, Washington, DC 20591, http://www.faa.gov.

[7] Available from Joint Authorities for Rulemaking on Unmanned Systems (JARUS), http://jarus-rpas.org/content/jar-doc-06-sora-package.

[8] ~~Available~~Available from RTCA, Inc., 1828 L St., NW, Suite 805, Washington, DC 20036. 6

[9] Available from European Union Aviation Safety Agency (EASA), Konrad-Adenauer-Ufer 3, D-50668 Cologne, Germany, https://www.easa.europa.eu.

3.3.6 *cooperative intruder, n*—those intruders using a Mode C/S transponder or ADS-B, or both, that operate with like equipment used on other aircraft or ground-based services to establish the intruder's position.

3.3.7 *detect and avoid, DAA, n*—~~a~~ subsystem within the UAS providing the ~~situational~~situation awareness, alerting, and avoidance necessary to maintain safe ~~BVLOS~~ operation of the ownship in the presence of intruders.

3.3.8 *DAA cycle, n*—~~the~~ maximum time from the ~~presence~~detection of the ~~intruder~~ intruder's presence to the ~~execution~~initiation of an avoidance ~~maneuver.~~maneuver

3.3.9 *DAA system integrator, n*—person/organization/entity who integrates the parts of a DAA system, and then shows that the risk ratios required by this standard are met.

3.3.10 *detect function, DF, n*—~~the~~ function within the DAA system tasked with maintaining temporal and spatial awareness of intruders.

3.3.11 *encounter, n*—~~the~~ event associated with the presence of an intruder.

3.3.12 *encounter rate, n*—~~the~~ number of encounters per unit of time.

3.3.13 *false alert, n*—an incorrect alert caused by a non-aircraft track or by a failure of the alerting system, including the sensor.

3.3.14 *intruder, n*—a ~~manned~~crewed aircraft external to ownship within or projected to be in the ownship's vicinity in the near future.

3.3.14.1 *Discussion*—
This definition is deliberately equivocal since the DAA system architecture and technologies employed, as well as ownship maneuvering capabilities, will shape the specific definitions of "vicinity" and "near future." The term "traffic" is often used synonymously with intruder.

3.3.15 *loss of well clear, loWC, n*—two aircraft coming within the well clear boundary of each other while in flight.

3.3.16 *loss of ~~well-clear~~ well clear risk ratio (LR) measurement, n*—~~the~~ LR is the quotient of the probability of a loss of ~~well-clear~~ well clear (LoWC) given an encounter with a DAA system, and the probability of loss of ~~well-clear~~ well clear given an encounter without a DAA system. The lower the LR, the better the DAA system is at preventing a loss of ~~well-clear.~~ well clear. The LR is

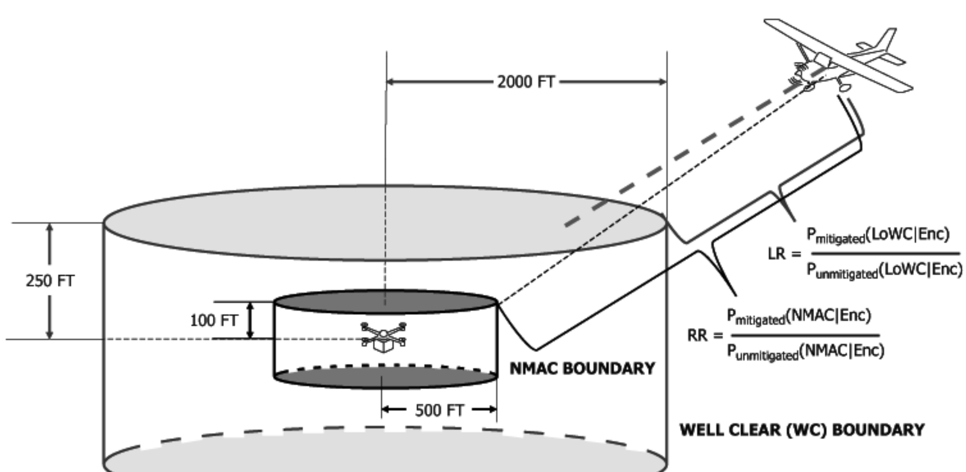

FIG. 1 RR and LR Illustration

a measurement to ensure that a portion of the mitigation happens before loss of ~~well-clear~~ well clear as opposed to ~~after loss of WC.~~ after. See Fig. 1~~.~~ for depictions and formulae. See also Ref (**1**).[10]

3.3.17 *mid-air collision, MAC, n*—two aircraft colliding with each other while in flight.

3.3.18 *maintain well clear, n*—the act of maneuvering an aircraft with the objective of preventing the predicted erosion of the well clear margin of safety.

3.3.19 *near mid-air collision, NMAC, n*—two aircraft coming within 100 ft vertically and 500 ft horizontally of each other while in flight.

3.3.20 *NMAC risk ratio (RR) measurement, n*—~~the~~ RR is the quotient of the probability of an NMAC given an encounter with the DAA system and the probability of an NMAC given an encounter without the DAA system. The lower the RR, the better the DAA system is at preventing an NMAC.

3.3.20.1 *Discussion*—

The RR used in this assessment is not a measurement of the ~~avoid function.~~ collision avoidance function alone. The RR is a measurement from an encounter to an NMAC, and it is a measurement of all UAS DAA systems components used in mitigating NMAC. See Fig. 1~~.~~ for depictions and formulae.

3.3.21 *non-cooperative intruder, n*—any aircraft not meeting the definition of cooperative in 3.3.6.

3.3.22 *nuisance alert, n*—alert generated by a system that is functioning as designed, but which is inappropriate or unnecessary for the particular condition.

3.3.23 *operational volume, n*—~~the~~ volume of airspace in which the ~~UAS~~UA operation intends, or is authorized, to take place.

3.3.23.1 *Discussion*—

The term *operational volume* in this specification is aligned with the JARUS use of the term in Annex C of the Specific Operations Risk Assessment (SORA) and is different from the UAS traffic management ~~(UTM)/U-Space~~(UTM)/U-space communities' use of the term. "Area of operation," or the intersection of acceptable air and ground risk in accordance with the concept of operations, is how this concept might be described in ~~UTM/U-Space.~~UTM/U-space.

3.3.24 *ownship, n*—~~the~~ UA controlled by the pilot flying and for which the pilot in command (PIC) is responsible.

3.3.25 *pilot flying, n*—~~an~~ individual or system that manipulates the flight controls of an aircraft during flight; may or may not be the pilot in command.

3.3.25.1 *Discussion*—

This is the same definition as in Terminology F3060, but we keep it here for the reader's benefit.

3.3.26 *regain well clear, n*—the act of maneuvering an aircraft with the objective of restoring the well clear margin of safety that has been degraded by preceding circumstances.

3.3.27 *remote pilot in command, ~~PIC,~~RPIC, n*—~~the person who has final authority and responsibility for the operation and safety of the ownship flight;~~ person who is directly responsible for and is the final authority as to the operation of the UAS; has been designated as ~~PIC~~ remote pilot in command before or during the ~~flight;~~ flight of a UAS; and holds the appropriate ~~category class and type-rating, if appropriate,~~ CAA certificate for the conduct of the flight. ~~**(14 CFR § 1.1)**~~

3.3.27.1 *Discussion*—

This is the same definition as in Terminology F3341/F3341M, but it is here for the reader's benefit.

~~3.3.19 *remain well-clear (RWC) function, n*—DAA system function where the UAS takes appropriate action to prevent an intruder from penetrating the WC boundary (and thus causing a loss of separation). The action is expected to be initiated within a sufficient timeframe to conform to accepted air traffic standards. Any UAS maneuvers will be in accordance with regulations and procedures.~~

3.3.28 *risk ratio measurement, n*—used to measure the performance of a DAA system(s); the probability of an outcome with the

[10] The boldface numbers in parentheses refer to the list of references at the end of this standard.

DAA system(s), divided by the probability of an outcome without the DAA ~~system(s),~~system(s); see Fig. 1~~.~~ for depictions and formulae. The lower the risk ratio, the better the DAA system is at mitigations.

3.3.29 *rural area, n*—~~all areas~~an area not defined as urban (see ~~3.3.26~~3.3.32).

3.3.30 *track, n*—~~the~~ specific collection of data that a particular DAA system accumulates and is used in determining whether an intruder aircraft is a collision risk or loss of ~~well-clear~~ well clear risk, or both.

3.3.31 *uncontrolled airspace, n*—an airspace that is not controlled (see ~~3.3.4~~3.3.5).

~~3.3.24 *unmanned aircraft, UA, n*—any aircraft that is operated without the possibility of direct human intervention from within or on the aircraft. **(Public Law 112-95 § 331)**~~

~~3.3.25 *unmanned aircraft system, UAS, n*—a system comprised of an unmanned aircraft and associated elements, including communication links, and the components that control the unmanned aircraft that are required for the pilot in command to operate safely and efficiently in the national airspace system. **(Public Law 112-95 § 331)**~~

3.3.32 *urban area, n*—~~a~~ town, outer suburban, suburban, residential area, urban, metro, city, or open-air assembly of people, or combinations thereof.

3.3.33 ~~*visual line of sight, VLOS,*~~ *well clear, n*—~~unaided (corrective lenses or sunglasses, or both, excepted) visual contact between a PIC and a UA sufficient to maintain safe operational control of the aircraft, know its location, and scan the airspace in which it is operating to see and avoid other air traffic or objects aloft or on the ground.~~state where there is a low residual midair collision risk informed by operational suitability.

3.3.34 ~~*well-clear*~~ *well clear (WC) boundary, n*—~~for UA in lower-risk airspace as defined above~~extent of the volume defined to calculate the operating performance of a DAA system. For UA in lower-rick airspace, this is defined as 2000 ft horizontally and ±250 ft ~~vertically~~ vertically; see Fig. 1 and Ref (**1**).

3.3.34.1 *Discussion*—

Remaining ~~well-clear~~ well clear is meant to support compliance with 14 CFR § 91.111 and § 91.113 or § 107.37 (or international equivalents) and reduce the chance of creating a collision hazard and therefore a collision.[11]

3.3.35 *yielded operating volume, n*—operating volume where the competent authority accepts that crewed aircraft normally will not fly because of regulatory limitations, or because crewed aircraft yield to a characteristic of the environment in the interest of safety.

3.3.35.1 *Discussion*—

Regulatory limitations, policy, and/or guidance, such as per operating rules, for example, Standardised European Rules of the Air (SERA), 14 CFR § 91.119(c), or restricted airspace. See 5.4.7 for operating environments with extremely low air risk airspace classification and Appendix X2 for examples and more detail

4. Significance and Use

4.1 This specification outlines the system objectives, activities, and evidence required to demonstrate adequate design and safe use of a detect and avoid (DAA) system. Such systems, in concert with other systems and equipment, enable ~~unmanned~~uncrewed aircraft systems (UAS) to operate beyond the visual line of sight (BVLOS) of the pilot in command (PIC). As the name suggests, these systems comprise a function for sensing potential flight hazards and assessing hazard severity ("detect") and a function for maneuvering the aircraft out of the way of the hazard ("avoid"). Such systems may also support operations within the PIC's visual line of sight (VLOS).

4.1.1 While there are many possible static and dynamic hazards to UA flight (for example, obstacles, birds, terrain, weather, other UAs), this specification addresses the safe operations of the UA in the presence of ~~manned~~crewed aircraft, which may or may not be cooperative with the UA, otherwise known as "intruders."

4.1.2 Despite the diversity in emerging DAA systems, these systems share the following attributes:

[11] Alternative ~~well-clear~~ well clear means may be appropriate in proximity to terrain or obstacles when justified.

4.1.2.1 *Intruder Level of Cooperation*[12]—Cooperative systems rely on information being supplied by the intruder (for example, intruder transponder, automatic dependent surveillance-broadcast (ADS-B) Out) whereas non-cooperative systems do not rely on the intruder supplying information. Many DAA systems use a combination of cooperative and non-cooperative sensors for obtaining information regarding an intruder.

NOTE 1—While some cooperative systems (for example, mode A transponder) provide very little information that is useful for the purposes of the DAA, they are still considered cooperative systems.

4.1.2.2 *DAA Level of Autonomy*—DAA systems may range from fully manual to fully automated functionality. In the fully manual construct, the PIC is presented with data, and it is up to them the PIC to decide and execute any needed maneuvers. In the fully automated construct, the system is responsible for determining and executingdetermines and executes any necessary maneuvers.[13] A spectrum of functional allocation is possible in between these two architectures.

4.1.2.3 *Location of DAA Systems and Functionality*—The architecture of a given DAA system may use any combination of airborne and ground components. The proximity of DAA functions to the UA versus the GCS Control Station each pose unique benefits and challenges regardless of system timing and latency, UA payload, sensor orientation, field of regard or surveillance coverage, range, track accuracy, etc.and so forth.

4.1.2.4 *Sensor Type*—The greatest differentiation between DAA systems is in sensors. Sensing technologies vary and include radio frequency (radar, passive radio frequency reception), light (camera, light detection and ranging (LiDAR)), and acoustic approaches. Each offers distinct advantages and disadvantages. Therefore, DAA systems may utilize multiple sensor categories to achieve comprehensive detection and appropriate levels of uncertainty and information quality.

4.1.2.5 *Equipage*—It is assumed that UA with a largest dimension of 25 ft or less are not equipped with either a transponder or ADS-B-out and thus are not cooperative with traditional crewed air traffic.

5. System Description

5.1 *Overview:*

5.1.1 This section identifies the set of objectives that the DAA system, including the pilots if they are human pilot if required to be "in the loop," must meetshall satisfy as a complete unit.

5.1.2 Two classes of DAA equipment are covered by this specification: specified: Class 1 for operations in low-risk airspaceairspace; and Class 2 for operating in low- or medium-risk airspace as defined by the CAA. See 5.3.1 for more information.description of airspace and 5.5.2 on Class 1 and 2.

5.1.3 This specification does not address integration of DAA equipment with other safety systems such as geographical containment systems (that is, geofencing) and terrain avoidance systems.

5.1.4 The communication link of DAA information (C2 and sensor) complies with regulatory policy in terms of spectrum use and frequency allocations.

5.2 *System Verification:*

5.2.1 If required to do so by the CAA, the applicant/proponent shall provide to the CAA or CAA-approved test organization, or both, evidence of physical verification demonstrating the DAA system meets all required performance criteria identified or generated in response to this specification.

5.2.2 Physical verification may take the form of field tests against actual targets and objectives or lab tests against representative targets, as long as data is supplied confirming equivalency to real targets. An approach to verifying these requirements will be defined in an ASTM test method currently under development.

[12] Intruder equipage entirely determines cooperative versus non-cooperative status.
[13] It is assumed the PIC is kept apprised of the action.

NOTE 2—An approach to verifying these requirements will be defined in an ASTM test method currently under development.

5.2.3 Analysis and simulation should be used as a form of performance verification when physical performance is impractical (for example, difficult corner cases, extensive time-based testing, or sheer volume of test case permutations). In these situations, the analysis or simulation shall still be substantiated using a sampling of physical test data to establish validity.

5.3 *Safety:*

5.3.1 *Air Collision Risk Classification of Operational Volume*—In order to assess risk, the airspace needs to be classified into categories based on airborne collision risk under which a UASUA would encounter a mannedcrewed aircraft. In a manner similar to the JARUS SORA, this specification assumes four unmitigated airborne collision risk classification levels: High, Medium, Low, and Extremely-Low Air Risk. However, only DAA system performance for DAA Class 1 and Class 2 systems (to be used in low- and medium-risk airspace, respectively), is in scope for this specification. As a DAA standard, this specification does not specify the method for determining the airspace risk classification level for a given operation, but general guidance is given to provide context for the system performance in low and medium air risk airspace.

5.3.1.1 *High Air Risk (Out of Scope for this Requirements Document)—(out of scope for this requirements document)—*This is airspace where mannedcrewed aircraft predominately fly, or the mannedcrewed aircraft encounter rate is frequent, or both. The competent authority is expected to require the operator to comply with recognized DAA system standards as available and appropriate to the application (for example,(that is, those developed by RTCA SC-228 (see RTCA DO-365A) DO-365C), SC-147, or EUROCAE WG-105, or both).WG-105).

5.3.1.2 *Medium Air Risk*—This is airspace where mannedcrewed aircraft predominately do not fly (excluding helicopters and crop dusters) or the mannedcrewed aircraft encounter rate is occasional, or both. This is generally uncontrolled airspace and/or airspace that goes from the ground to between 300300 ft to 1200 ft AGL (with 500 ft AGL used as a common default), above which most mannedcrewed aircraft operations are conducted. This includes airspace away from Class B, C, and D aerodromes, or near Class B, C, and D aerodromes with additional strategic mitigations.

5.3.1.3 *Low Air Risk*—This is airspace where manned aircraft predominatelycrewed aircraft generally do not fly (excluding helicopters and crop dusters) or the mannedcrewed aircraft encounter rate is remote or improbable in accordance with guidelines and regulations from the competent authority, or both. This is generally uncontrolled airspace and/or airspace that goes from the ground to between 300300 ft to 1200 ft AGL (with 500 ft AGL used as a common default), above which most mannedcrewed aircraft operations are conducted and away from urban population centers, towns, outer suburban, suburban, residential areas, metro, or cities, or combinations thereof, and outside all aerodromes. Helicopter and crop duster operations may occur in low-risk airspace and may require special consideration, as they may operate at low altitudes, in uncontrolled airspaces, or otherwise alter the expected crewed aircraft encounter rate.

5.3.1.4 *Extremely Low Air Risk (Out of Scope for this Requirements Document)—Airspace Classification—*This is airspace where mannedcrewed aircraft predominately do not fly or the manned aircraft encounter rate is extremely improbable, or both. It is generally defined as airspace where the risk of collision between a UAS and manned aircraft is acceptable without the addition of any tactical mitigation (for example, a DAA system). An example of this may be UAS flight operations in some parts of Alaska or northern Sweden where the manned aircraft density is so low that the airspace safety threshold could be met without any mitigation.fly, or the likelihood of an encounter with a crewed aircraft has been shown to be extremently improbably, or both. Examples of such a classification include the use of robust containment to remain within a yielded operating volume, or operations in remote, sparsely populated areas such as parts of northern Canada or northern Sweden.

5.3.2 *Local Air Risk Assessment of Operational Volume* (see 3.3.15)—If a local an airspace authority or air navigation service provider (ANSP), or both, has conducted an airspace characterization and classified the collision risk of the operational volume, that collision risk assessment will be used as the method for categorizing the airspace. Strategic mitigations and/or existence of yielded operating volumes may also be used in determiningwhen characterizing the operational volume airspace airspace.categorization.

5.3.3 *Generalized Collision Risk Assessment of Operational Volume*—If a local classification of the collision risk of the operational volume does not exist, the example a generalized air risk assessment inassessment, such 5.3.4 can be used. The JARUS SORAas the JARUS SORA or example in 5.3.4is a generalized air risk assessment., can be used.

5.3.4 *Generalized Air Risk Assessment DescriptionsDescriptions::*

TABLE 1 Example Generalized Collision Risk Airspace Classification Summary from JARUS SORA

Airspace	Airspace Description
Medium Air Risk	Uncontrolled Airspace Below 500 ft AGL in controlled airspace, at least 5 nm away from the center point of Class B, C, and D aerodromes Below 500 ft AGL over an urban area Below 500 ft AGL in/over/around Class E, F, or G aerodromes Near Class B, C, and D aerodromes with additional strategic mitigations, for example, remaining below facility map altitudes
Low Air Risk	Uncontrolled airspace, below 500 ft AGL, over a rural area, outside all aerodromes

TABLE 2 Summary of DAA Performance Guidance for UAS

Intruder Equipage	DAA Quantitative Performance Requirements	
	NMAC Risk Ratio (RR)	Loss of ~~Well-Clear~~ Risk Ratio (LR)
~~Transponder or ADS-B Out~~	~~≤0.18~~	~~≤0.40~~
Non-cooperative	≤0.30	≤0.50

TABLE 2 Summary of DAA Performance Guidance for UAS

Intruder Equipage	DAA Quantitative Performance Requirements	
	NMAC Risk Ratio (RR)	Loss of Well Clear Risk Ratio (LR)
ADS-B Out	≤0.18	≤0.40
Non-cooperative or transponder-only	≤0.30	≤0.50

5.3.4.1 These airborne collision risk classifications are generalized classifications. ~~As with any generalization,~~ Consequently, when the area becomes more refined, there ~~will~~may be specific areas where the generalized classification levels will be ~~true, and other specific areas where the generalized classification levels will not be true.~~ true and others where it will not. The operator will work with the local airspace authority to ensure that the appropriate air risk classification is assigned to the operational volume.

~~5.3.4.2 As with any classification scheme, it is always a balance between too few classifications and too many classifications.~~

5.3.4.2 *~~Example~~ Examples of a Generalized Airspace Air Risk Classification Summary*—See Table 1~~.~~ (taken from the JARUS SORA). The following are notional examples and not definitive classifications within this ASTM specification.

5.4 *UAS DAA Performance Requirements:*

5.4.1 The risk ratios in this specification are "logic" risk ratios as in ~~accordance with~~ the International Civil Aviation Organization (ICAO) definition. Included is nominal system ~~performance:~~ performance are: logic, specified surveillance performance, field of view limitations, expected human pilot performance, specified/nominal C2 link performance, expected latencies for all ~~components.~~ components, and ownship performance. Not included are ~~failures:~~ failures, for example, corrupted logic, sensor failures, C2 link failures, DAA equipment failures/faults, non-responsive pilot. Performance under failure conditions should be addressed through system safety assessments. Note that JARUS specifies total system risk ratios.

5.4.2 In this specification, the risk ratios discussed by the ICAO ~~remotely piloted aircraft systems~~Remotely Piloted Aircraft Systems (RPAS) panel[14] have been used but are applied to a smaller ~~well-clear~~ well clear boundary (for example, 2000 ft). This adjustment leads to a similar RR even with lower performing UAS DAA equipage. (See Ref (**2**).) The smaller ~~well-clear~~ well clear boundary is used due to the lower closure rates and smaller P(MAC|NMAC) due to the small size of the UAS.

5.4.3 The RR and LR performance requirements in this section shall be verified using a statistically significant ~~set(s)~~number of encounters that are representative of the operational environment airspace. Encounter sets are representative when they include

[14] See https://www.icao.int/safety/UA/Pages/Remotely-Piloted-Aircraft-Systems-Panel-(RPASP).aspx.

appropriate and realistic distributions of ownship and intruder flight dynamics, speeds, vertical rates, and encounter geomet-riesgeometries for the airspace class, altitude, and geographic region where the DAA equipment is expected to operate. For cooperative intruders, encounter sets and the mix of Mode C, Mode S, and ADS-B equipped intruders for verifying ratios are defined in DAA test methods. operate to the satisfaction of the CAA. When evaluating the DAA system against ADS-B Out intruders, the encounter set(s) should include behaviors representative of both 1200-code and discrete code operations. When evaluating the DAA system against non-cooperative and transponder-only intruders, the encounter set(s) should include behaviors representative of aircraft without a transponder and aircraft with a transponder but without ADS-B in both 1200-code and discrete code operations.[15] Limitations on the DAA equipment shall be identified based on limitations of the encounter setsset(s) used to verify the performance requirements.

5.4.4 In operational volumes with low and medium air risk, DAA performance for NMAC avoidance (RR) requirements are based on the ICAO work cited in 5.4.2 and are dependent on the equipage type of the intruder.

5.4.4.1 For encounters with intruders equipped with a transponder or ADS-B, ADS-B Out, the DAA system RR shall be ≤0.18.

5.4.4.2 For non-cooperative encounters with non-cooperative or transponder-only intruders, the DAA system RR shall be less than or equal to 0.30.≤0.30.

5.4.5 In operational volumes with low and medium air risk, DAA performance for remain well-clear loss of well clear (LR) requirements are based on the ICAO work cited in 5.4.2 and are dependent on the equipage type of the intruder.

5.4.5.1 For intruders equipped with a transponder or ADS-B Out, the DAA system LR shall be ≤0.40.

5.4.5.2 For non-cooperative or transponder-only intruders, the DAA system LR shall be ≤0.50.

5.4.6 *DAA Performance Summary*—See Table 2.

5.4.7 In operational volumes with extremely low air risk, RR and LR may not be appropriate DAA performance metrics. Here, the rate of unmitigated encounters with crewed aircraft is assumed to be extremely low. As such, the competent authority may not require a DAA system for operations within such airspace.

NOTE 3—While the risk ratio equation is unchanged, due to the low rate of unmitigated encounters, the risk ratio metric is uninformative because there may not be a DAA system in the traditional sense, or it is not possible to generate realistic unmitigated encounters because of the low rate of unmitigated encounters (the denominator would be near zero). Other performance metrics, such as navigation performance or robust containment, may be more useful to assess the DAA system.

5.4.8 In addition, it is expected that in certain operational volumes where the rate of non-cooperative or transponder-only equipped encounters can be demonstrated to be extremely low, the RR and LR for non-cooperative or transponder-only equipped encounters may not be appropriate performance metrics for a DAA system. As such, the competent authority may not require a non-cooperative DAA system for operations within operational volumes where the rate of non-cooperative or transponder-only equipped encounters can be demonstrated to be extremely low.

NOTE 4—While the non-cooperative or transponder-only equipped risk ratio equation is unchanged because of the low rate of unmitigated non-cooperative or transponder-only equipped encounters, the non-cooperative or transponder-only equipped risk ratio metric is uninformative because the denominator would be near zero.

5.5 *UAS DAA Robustness Requirements:*

5.5.1 The robustness of the DAA system shall be is characterized by the availability and assurance level of the system. This approach is similar to that adopted by JARUS.

5.5.2 *DAA System Availability:*

5.5.2.1 The approach to system availability here is derived from the JARUS process for UAS Special Operation Risk Assessment. SORA V2.0 Annex D, section 5.4 (TMPR (Tactical Mitigation Performance Requirement) Robustness (Integrity and Assurance)

[15] See Airspace Encounter Models on GitHub (https://github.com/airspace-encounter-models) for models of aircraft behavior in U.S. airspace.

Assignment). The level of system availability of the DAA system differentiates Class 1 and 2 systems. Loss of function includes failures such as sensor failures, C2 link failures, and DAA equipment failures, which are not captured in the RR and LR performance requirements.

5.5.2.2 For Class 1 equipment ~~(operational~~ (to be used in operational volumes with low air risk), the allowable loss of function and performance shall be less than 1 per 100 flight hours (1E-2 Loss/FH).

5.5.2.3 For Class 2 equipment ~~(operational~~ (to be used in operational volumes with medium air risk), the allowable loss of function and performance shall be less than 1 per 1000 flight hours (1E-3 Loss/FH).

5.5.2.4 The requirements on availability may be met by:

(1) Showing redundancy in the equipment providing that function. An analysis of a redundant system in the aircraft is usually complete if it shows isolation between redundant system channels and satisfactory reliability for each channel; or

(2) In the case where single failures can cause the failure condition, by showing the system is simple, uses conventional architecture, is appropriately qualified for the installed environment and the individual failure rates of its components are below the objective of 1E-2 for Class 1 Equipment or 1E-3 for Class 2 Equipment.

These are two ways, but not the only ways, of meeting 5.5.2.2 and 5.5.2.3.

5.5.3 *DAA System Assurance:*

5.5.3.1 The approach to system assurance here is derived from the JARUS process for ~~UAS Special Operation Risk Assessment.~~ SORA. The level of system assurance of the DAA system differentiates Class 1 and 2 systems. Hazardously misleading information is introduced by undetected software and hardware ~~faults which aren't~~ faults, which are not captured in the RR and LR performance requirements. Hazardously misleading information does not include information, such as false tracks, that does not result in a hazardous maneuver. Likewise, hazardously misleading information does not include faults that are detected and covered by the loss of function requirements in 5.5.2. Allowable failure rates are determined from the AC 23.1309-1E precedent that most misleading and/or malfunction without warning severity classifications (see Appendix 1 in the AC) are one category more severe than the regular loss of function and that, for Class I aircraft (see FIG. 2 in AC 23.1309-1E), a one category increase in severity is equivalent to a one order of magnitude decrease in the event rate per flight hour.

5.5.3.2 For Class 1 equipment ~~(operations in~~ (to be used in operations in low air risk airspace), the allowable introduction of hazardously misleading information shall be less than 1 per ~~10 000~~1000 flight hours ~~(1E-4~~(1E-3 Loss/FH).

5.5.3.3 For Class 2 equipment ~~(operations in low or~~(to be used in operations in medium air risk airspace), the allowable introduction of hazardously misleading information shall be less than 1 per ~~100 000~~10 000 flight hours ~~(1E-5~~(1E-4 Loss/FH).

5.5.4 *ADS-B Data Validation*—Independent validation of ADS-B is not expected to be a requirement in all smaller UAS DAA operational scenarios. There are some situations where other mitigations may be in place, or the operation is of such low risk that ADS-B validation is not necessary. Operators who want to use ADS-B in smaller UAS DAA applications without independent validation must demonstrate to the regulator that it is acceptable for their operation.

5.5.5 *Timestamping:*

5.5.5.1 The DAA system shall employ a consistent time basis across all functions for marking the time of applicability of measurements and calculated parameters (for example, GPS, UTC). Time of applicability is herein defined as the time at which a particular measurement or parameter was determined relative to some temporal origin point that is fixed for at least the duration of any one power cycle of the DAA system (though a universal time origin, like UTC, is strongly preferred). For parameters received from an outside source (for example, ADS-B In), time of applicability is to be taken from the corresponding field in the received data – reverting to the time of receipt if the time of applicability was not provided in the transmission.

5.5.5.2 The DAA system timing, if based on GPS, shall be resilient to GPS failures. GPS dropouts are common, so if GPS time is the time basis, a method of time-coasting is needed to ensure that timestamping can occur uninterrupted.

NOTE 5—As soon as a measurement or calculation is made, this information starts becoming stale (that is, increasingly irrelevant). As information flows through the system, it may accumulate non-uniform levels of staleness. Thus, it is important to be able to determine how stale each piece of information is. DAA integrators should work with individual function suppliers to ensure that a means of accurately timestamping information is available to all functions. Using a broadly accepted time basis (for example, GPS, UTC) is suggested to maximize compatibility between suppliers and integrators but is not mandated.

5.6 *Reliability and Maintenance:*

5.6.1 A methodology for anticipating and detecting failures and accomplishing appropriate maintenance actions should be identified and implemented for the major subsystems or components of the DAA system, as well as the system as a whole.

5.6.1.1 If required, the DAA system shall have a maintenance plan and maintenance schedule in accordance with the maintenance instructions provided by the manufacturer. The maintenance instructions shall provide direction as to verification of proper installation and calibration of the system to ensure continued performance is met in the field.

5.6.2 The DAA system shall have a test function for detecting ~~probable~~foreseeable "static" system failures. "Static" system failures are degradations in the condition of the system that would prevent correct operation (for example, memory faults, device failures, wear out). These are different than "dynamic" errors, which are due to unforeseen events during runtime. Test function requirements should be based on system safety principles considering rate, exposure, and criticality of latent failure.

5.6.3 The DAA system shall detect and notify the PIC of any degradation or loss of function that requires PIC action or take predefined automated contingency action to mitigate the risk if required by the operational safety case, within a timeframe appropriate for the alerting condition. A degradation of function includes *(1)* any partial loss of functionality or *(2)* any reduction of performance as required or advertised by the system. This does not prescribe specific mechanics of how a degradation or loss of function alert is to be communicated; depending on the safety assessment, it may be appropriate to have no in-flight indication or action. Failures without means of detection should be identified during system design, and the DAA system as a whole shall comply with the requirements for availability (5.5.2) and assurance (5.5.3). If notification is required, it may be a dedicated message, a special error code in an existing message, an invalid value in the field representing the loss of functionality, or a maintenance code. The DAA system shall persist the notification of degradation or loss of function until the functionality is fully restored. Human factors and training should be considered in the design of PIC notification.

5.7 *Security:*

5.7.1 The PIC shall be notified of any changes to DAA software, hardware, or configuration. This notification may take many forms, including technical or operational means, such as inspection or automatic reporting.

5.7.2 Making any changes to DAA software, hardware, or configuration shall be restricted to authorized and qualified personnel. This restriction may be implemented through various mechanisms, including technical or operational means.

5.7.3 Any changes to DAA software, hardware, or configuration shall require confirmation that the modified information is correct and uncorrupted. Confirmation may come in any combination of cyclic redundancy code (CRC)/checksums, digital signatures, embedded registers, pin-strapping, ~~or~~ manual checklists, or combinations thereof.

5.7.4 There shall be a means to prevent any changes to the DAA software, hardware, or configuration from inadvertently or maliciously occurring, or a suitable preflight check to detect such changes and prevent takeoff if ~~it~~ such changes were to occur. This requirement may be implemented through various mechanisms, including technical or operational means.

5.7.5 ~~Control of the~~ The DAA system ~~during flight shall only be accessible via authorized means.~~architecture shall prevent unauthorized access to the DAA system during operation.

5.8 *Environment:*

5.8.1 The DAA system shall satisfy performance requirements across the range of environmental conditions as defined by the manufacturer and communicated to the customer.

5.8.2 The DAA system integrator shall identify all environmental limitations of the system where it does not meet the performance requirements in 5.4 and document them in the operator's manual and technical specifications documents.

6. System Timing

6.1 ~~Fig. 2 outlines each segment of time from acquisition of an intruder by the detect function to the execution of the avoidance maneuver. Regardless of whether the system is airborne or ground-based, uses a pilot-in-the-loop or full-autonomy, the timing of~~

every DAA system can be described in terms of the model inThe DAA system integrator shall perform a timing analysis that identifies the timing elements Fig. 2. Depending on the system, it is permissiblefor the DAA system. Reference Appendix X2 that some of the terms be zero or combined to a measurable level.for a description of example timing elements for various architectures.

6.2 The maximum time from acquisition of an intruder by the detect function to confirmation of the maneuver beginning is described in terms of the model in Fig. 2.

6.3 *Detection Function (DF) Timing:*

6.3.1 t_{Scan} = The maximum time between sensor updates of the detected intruder, setting the minimum time precision of the DF.

6.3.2 t_{Relay} = The maximum latency from the sensor to its sensor processing/fusion, including any publishing rate of the sensor.

6.3.3 t_{Filter} = The maximum time required to pre-process the sensor data (for example, filtering, fusion, tracking) before passing along to the Alert function.

6.3.4 $t_{Publish}$ = The maximum latency from the filter processing to the presentation of the data to the Alert function, including any publishing rate of the filter processing.

6.3.5 The DF has flexibility in the time required to ascertain the presence of an intruder, as long as the safety performance (see 5.4) is met. The system trade-off is in the additional range at which intruders must be detected to satisfy alert times, which provide the appropriate safety performance and in the responsiveness of the system to a dynamically changing environment.

6.2 *Alert Function (A1F) Timing:* The timing elements shall be reflected in the test methods used to show that the DAA system supports the required risk ratios when operated in accordance with the DAA System CONOPS in the representative airspace defined in 5.3.4.

6.4.1 $t_{Classify}$ = The maximum time required in the determination and prioritization of the hazard level of each updated intruder.

6.4.2 t_{Notify} = The maximum time required to present the updated list of intruder hazards to the avoid function, including any publishing rate of the classifier.

6.5 *Avoid Function (A2F) Timing:*

6.5.1 t_{Plot} = The maximum time required for the avoid function to determine a satisfactory avoidance trajectory.

6.5.2 t_{Vector} = The maximum latency, including any publishing rate, of transferring the avoidance trajectory to the vehicle command.

6.5.3 $t_{Translate}$ = The maximum time needed to convert the trajectory to one or more vehicle command(s).

6.5.4 $t_{Command}$ = The maximum latency, including any publishing rate, of transferring the vehicle commands to the UA flight control.

NOTE 1—t_{Plot}, t_{Vector}, and $t_{Command}$ may be combined into a single human processing time if conducted manually by a human.

6.5.5 $t_{Control}$ = The maximum delay from receiving to initiating execution of the vehicle commands.

6.5.6 $t_{Maneuver}$ = The time allotted for executing the maneuver. This may be the maximum time required to execute a maneuver sufficient to generate full separation (horizontally or vertically) to maintain well-clear.

6.5.7 t_{Fix} = The maximum time required to determine the updated position and orientation of the ownship.

6.5.8 $t_{Telemetry}$ = The maximum latency, including publishing rate, of relaying the updated position and orientation of the UA to the alert function.