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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 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- and medium-risk airspace as described by Joint Authorities for Rulemaking on Unmanned Systems (JARUS)] airspace environment with assumed infrequent encounters with crewed aircraft; this is typically in classes G and E airspace [below about 1200 ft above ground level (AGL)], Class B, C, D (below approximately 400 ft to 500 ft AGL) below obstacle clearance surface (FAA Order 8260.3, as 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 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document system limitation (that is, due to operating environments and/or minimum altitudes at which the air picture is no longer valid).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 crewed aircraft by 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.

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, 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 system-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 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 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

[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.

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

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
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 25.1322-1 Flightcrew Alerting[6]
FAA Order 8260.3 United States Standard for Terminal Instrument Procedures (TERPS)[6]
JARUS Specific Operations Risk Assessment (SORA) (package) V2.0[7]
RTCA DO-365C Minimum Operational Performance Standards (MOPS) for Detect and Avoid (DAA) 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*—Terminology used in multiple standards is defined in Terminologies F3341/F3341M and F3060 and 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*—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*—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 UA is known through technological means without exceeding the performance capabilities of the 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.

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.

[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.

[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 from RTCA, Inc., 1828 L St., NW, Suite 805, Washington, DC 20036.
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[9] Available from European Union Aviation Safety Agency (EASA), Konrad-Adenauer-Ufer 3, D-50668 Cologne, Germany, https://www.easa.europa.eu.

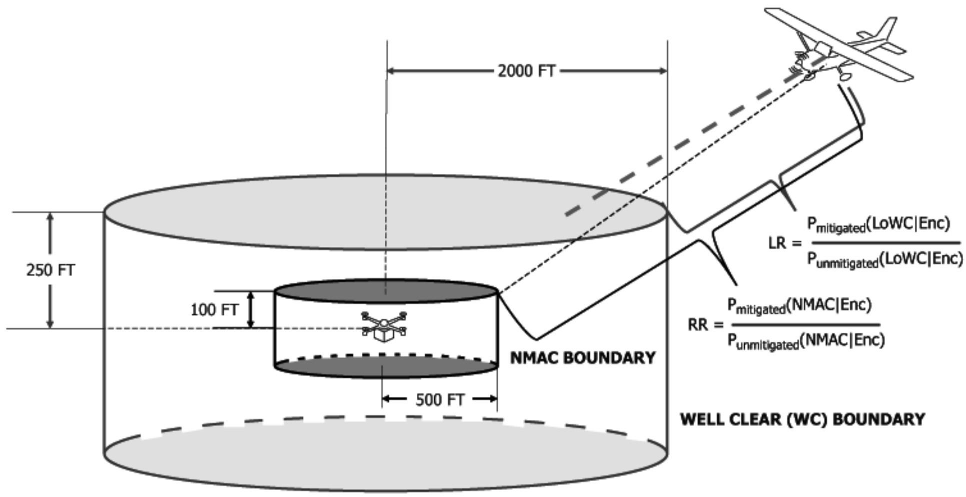

FIG. 1 RR and LR Illustration

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

3.3.8 *DAA cycle, n*—maximum time from the detection of the intruder's presence to the initiation of an avoidance 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*—function within the DAA system tasked with maintaining temporal and spatial awareness of intruders.

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

3.3.12 *encounter rate, n*—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 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 risk ratio (LR) measurement, n*—LR is the quotient of the probability of a loss of well clear (LoWC) given an encounter with a DAA system, and the probability of loss of 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. The LR is a measurement to ensure that a portion of the mitigation happens before loss of well clear as opposed to 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*—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 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*—volume of airspace in which the 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 communities' use of the term. "Area of operation," or the intersection of acceptable air and ground risk in accordance

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

with the concept of operations, is how this concept might be described in UTM/U-space.

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

3.3.25 *pilot flying, n*—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, RPIC, n*—person who is directly responsible for and is the final authority as to the operation of the UAS; has been designated as remote pilot in command before or during the flight of a UAS; and holds the appropriate CAA certificate for the conduct of the flight.

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

3.3.28 *risk ratio measurement, n*—used to measure the performance of a DAA system(s); the probability of an outcome with the DAA system(s), divided by the probability of an outcome without the DAA 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*—an area not defined as urban (see 3.3.32).

3.3.30 *track, n*—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 risk, or both.

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

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

3.3.33 *well clear, n*—state where there is a low residual midair collision risk informed by operational suitability.

3.3.34 *well clear (WC) boundary, n*—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; see Fig. 1 and Ref (**1**).

3.3.34.1 *Discussion*—Remaining 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 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 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:

4.1.2.1 *Intruder Level of Cooperation*[12]—Cooperative systems rely on information being supplied by the intruder 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 the PIC to decide and execute any needed maneuvers. In the fully automated construct, the system determines 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 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, 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

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

[12] Intruder equipage entirely determines cooperative versus non-cooperative status.

[13] It is assumed the PIC is kept apprised of the action.

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 human pilot if required to be "in the loop," shall satisfy as a complete unit.

5.1.2 Two classes of DAA equipment are specified: Class 1 for operations in low-risk airspace; and Class 2 for operating in medium-risk airspace as defined by the CAA. See 5.3.1 for 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 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.

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 based on airborne collision risk under which a UA would encounter a crewed 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)*—This is airspace where crewed aircraft predominately fly, or the crewed 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 (that is, those developed by RTCA SC-228 (see RTCA DO-365C), SC-147, or EUROCAE WG-105).

5.3.1.2 *Medium Air Risk*—This is airspace where crewed aircraft predominately do not fly (excluding helicopters and crop dusters) or the crewed aircraft encounter rate is occasional, or both. This is generally uncontrolled airspace and/or airspace that goes from the ground to between 300 ft to 1200 ft AGL (with 500 ft AGL used as a common default), above which most crewed 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 crewed aircraft generally do not fly or the crewed 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 300 ft to 1200 ft AGL (with 500 ft AGL used as a common default), above which most crewed 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 Airspace Classification*—This is airspace where crewed aircraft predominately do not 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 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 when characterizing the operational volume airspace.

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, a generalized air risk assessment, such as the JARUS SORA or example in 5.3.4, can be used.

5.3.4 *Generalized Air Risk Assessment Descriptions:*

5.3.4.1 These airborne collision risk classifications are generalized classifications. Consequently, when the area becomes

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)
ADS-B Out	≤0.18	≤0.40
Non-cooperative or transponder-only	≤0.30	≤0.50

more refined, there may be specific areas where the generalized classification levels will be 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 *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 the International Civil Aviation Organization (ICAO) definition. Included is nominal system performance are: logic, specified surveillance performance, field of view limitations, expected human pilot performance, specified/nominal C2 link performance, expected latencies for all components, and ownship performance. Not included are 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 (RPAS) panel[14] have been used but are applied to a smaller 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 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 number of encounters that are representative of the operational environment airspace. Encounter sets are representative when they include appropriate and realistic distributions of ownship and intruder flight dynamics, speeds, vertical rates, and encounter geometries for the airspace class, altitude, and geographic region where the DAA equipment is expected to 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 set(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 ADS-B Out, the DAA system RR shall be ≤0.18.

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

5.4.5 In operational volumes with low and medium air risk, DAA performance for 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 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.

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

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

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 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 SORA V2.0 Annex D, section 5.4 (TMPR (Tactical Mitigation Performance Requirement) Robustness (Integrity and Assurance) 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 (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 (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 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 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 (to be used in operations in low air risk airspace), the allowable introduction of hazardously misleading information shall be less than 1 per 1000 flight hours (1E-3 Loss/FH).

5.5.3.3 For Class 2 equipment (to be used in operations in medium air risk airspace), the allowable introduction of hazardously misleading information shall be less than 1 per 10 000 flight hours (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 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, 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 such changes were to occur. This requirement may be implemented through various mechanisms, including technical or operational means.

5.7.5 The DAA system 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 The DAA system integrator shall perform a timing analysis that identifies the timing elements for the DAA system. Reference Appendix X2 for a description of example timing elements for various architectures.

6.2 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.

7. Detection Function

7.1 *Overview*—This section defines the functionality, behavior, and performance required of the DF within an integrated DAA system. The role of the DF is to gather information regarding potential intruders that may pose a threat to the ownship and present the information in a form usable by follow-on functions (that is, adequately complete, timely, accurate, clean, and suited for the intended information consumer).

7.2 *Function:*

7.2.1 The DF surveils the airspace.

NOTE 6—The DF may work with sensors that provide raw surveillance measurements or surveillance tracks.

7.2.2 Upon detecting the presence of an intruder, the DF shall determine the track of the intruder as required by the alert function (A1F) to identify and prioritize hazards.

NOTE 7—A track may be based on information from a single sensor or the fusion of information from multiple sensors. Examples of parameters are: *(1)* lateral position, *(2)* velocity (speed and direction), *(3)* altitude, and *(4)* closure rate. These track parameters may be absolute to the surrounding environment (for example, latitude, longitude, altitude) or relative to the ownship (for example, range, bearing, angular elevation).

7.2.3 The DF shall output the track(s) of all detected intruders to the A1F.

7.2.4 *Track Coasting:*

7.2.4.1 When an intruder with an existing track is no longer detected, the DF should continue the track by extrapolating that intruder's trajectory to the current surveillance cycle, as discussed in the Timing Appendix, using its last known position and velocity and report it to the A1F as a coasted track. The DF may use intruder trend data, up to and including the last known position and velocity vector, for extrapolating the coasted track. However, the DF may not use an intruder's registered flight plan for extrapolation because the intruder may deviate from the flight plan at any time. (Refer also to A1F track coasting requirements in 8.2.9.)

7.2.4.2 If track coasting is implemented in the DF, the DF shall designate any track for which the intruder was not detected in the last surveillance cycle as a coasted track and report the time coasted (that is, the time since the last known detection). Else, the DF shall drop the track for any track that was not detected in the current surveillance cycle.

7.2.4.3 If track coasting is implemented in the DF, the DF shall drop tracks whose coasting time is longer than a configurable parameter set by the DAA integrator. This enables the DAA integrator to determine how much uncertainty in track inputs they wish to tolerate. It is incumbent on the DAA integrator to work with the DF vendor to understand the model assumptions in the DF implementation and how these contribute to uncertainty propagation in the integrated system. The DF may drop tracks before the configured parameter duration expires if the DF determines that to be appropriate.

7.2.5 *Track Uncertainty:*

7.2.5.1 The DF track output shall include the computed uncertainty parameters (often a covariance matrix) for each report of each track. This information enables the A1F to determine the confidence with which it predicts a conflict, the A1F to fuse the tracks from multiple DFs, and for a DF to fuse the tracks from multiple other DFs (that is, a nested DF architecture).

7.2.5.2 The DF uncertainty shall be computed as the accumulated uncertainty of the track estimation, the measurement uncertainty and, if implemented, track coasting.

7.3 *Performance*—An approach to verifying these requirements will be defined in an ASTM test method currently under development.

7.3.1 *Capacity*—The maximum number of targets that can be tracked simultaneously without violating the DF timing budget, as described in Timing Appendix, shall be identified. [DF vendor]

7.3.1.1 The maximum number of aircraft tracks passed on to the A1F so as not to violate assumptions concerning PIC workloads nor violate good human factors engineering considerations shall be identified. [System integrator]

7.3.1.2 This maximum number shall be demonstrated to be sufficient to meet LR and RR requirements given the air vehicle traffic rates in the operational environment, the rates for false tracks (for example, sensor noise and ground clutter), and the rates for tracks of non-interest (for example, real tracks on non-aircraft objects such as cars, birds, clouds). [System integrator]

NOTE 8—A false track is defined as a track that is established by the surveillance source for which there is no true target in the reported position.

7.3.2 *Field of View (FOV)/Field of Regard (FOR)*—The FOV/FOR of each sensor shall be identified in terms of azimuth and minimum/maximum angular elevation or coverage volume.

7.3.2.1 This coverage shall be demonstrated to meet the overall DAA system RR and LR performance requirements, and that the FOV/FOR meet any operational minimum coverage requirements. [System integrator]

NOTE 9—Regulatory requirements for UAS with a largest dimension of 25 ft or less may drive requirements for greater FOV/FOR (for example, 360 degree) even though a smaller FOV/FOR would meet LR and RR requirements.

7.3.3 *Range*—The detection and usable track range(s) needed from the DF for relevant intruders (as defined by the encounter models) to provide sufficient detection performance to meet overall system RR and LR requirements shall be identified. [System integrator]

7.3.3.1 The DF shall detect intruders out to the range(s) identified above for each sensor across its full FOV/FOR.

7.3.4 *Sensitivity*—The DF shall be demonstrated to acquire and maintain an intruder track of acceptable quality to meet LR and RR requirements for the relevant intruders (as defined by the encounter models) expected in the operational volume. [System integrator]

7.3.4.1 This detection sensitivity shall be demonstrated across the combined FOV/FOR and range(s) of the DF. Sensitivity may vary by sensor type and could include such considerations as the range of possible velocities, attitude, and angle of approach relative to the sensor, volume level, range of lighting conditions, etc. [DF vendor]

7.3.5 *Precision*—The precision of the track necessary to meet LR and RR requirements shall be identified and demonstrated. This precision shall be included in the determination of the maximum detection ranges required of each sensor, as defined in 7.3.3. [System integrator].

7.3.6 *Accuracy*—The aggregate accuracy of the sensor(s) shall be identified and demonstrated to be sufficient to ascertain the position and velocity of an intruder to the level necessary to meet the required LR and RR. System accuracy must consider the precision of the sensors, as defined in 7.3.5. [System integrator]

NOTE 10—Precision error will manifest itself as quantization error for accuracy and the effects of latency due to measurement delay.

7.3.7 *Interference, Ambient Noise, and Clutter*—The DF shall meet all the performance requirements of this specification in the presence of interference, noise, and clutter sources found within the operational environment as specified in 7.3.7.2 – 5.3.1.3.

7.3.7.1 Possible sources of interference, ambient noise, and clutter, based on the sensor modalities used, shall be identified and documented. [System integrator]

7.3.7.2 *Interference*—Interference is defined as any signal that diminishes the usable signal-to-noise ratio for a DAA system. Sources of interference will vary by sensor modality but may include such examples as other RF transmissions in the same band (radar), direct sunlight (camera), wave cancellation (acoustic), etc.

7.3.7.3 *Ambient Noise*—Ambient noise is defined as the detected ambient background signals measured under quiescent, operational conditions. The ambient noise level is the level where the signal from an aircraft can no longer be distinguished from ambient background measurements under quiescent operating conditions.

(1) For radar, the ambient noise level may be specified as the signal amplitude at which an aircraft return signal cannot be distinguished from the RF noise floor.

(2) For a camera, the ambient signal level may be that contrast ratio at which a relevant aircraft cannot be identified against operational background scenes.

(3) For acoustics, the ambient noise level may be specified as the signal amplitude at which an aircraft signature cannot be distinguished from flow and platform noise during operational conditions.

NOTE 11—This specification does not preclude the use of dynamic configuration, adaptive thresholding, or other forms of modifying the response of the system to variation of ambient noise due to changes in the environment.

7.3.7.4 *Clutter*—Clutter is defined as the measured signals generated by sources other than aircraft that may be present in addition to noise. Clutter is situational and episodic, whereas ambient noise is always present during operation.

(1) For radar, clutter may be echo returns from objects in the environment that are not aircraft, like automobiles.

(2) For cameras, clutter may be images of clouds, birds, or moving trees.

(3) For acoustics, clutter may be the sound of a train.

Hazardous objects including birds, ground obstacles, and possibly clouds (depending on the operational limitations) are not typically counted as clutter in the determination of DAA system performance.

7.3.8 *False Alarm*—False alarm is defined as the unique incident where something other than a crewed aircraft caused the system to alert the PIC to take action to avoid a loss of well clear.

7.3.8.1 The effects of the false alarms on the risk ratios RR and LR shall be included in the determination of the risk ratios LR and RR.

NOTE 12—The LR and RR are logic risk ratios and do not include the effect of human factors related failures. Examples of human factor failures include pilots who ignore alarms, override an avoidance maneuver, or deactivate the DAA system. Only false alarms that lead to a hazardous maneuver that results in a loss of well clear or near miss are included in the RR and LR calculation.

7.3.8.2 The manufacturer shall define all common sources of false alarms and should minimize the contribution of each alarm to overall performance.

7.3.8.3 The number of false alarms should be less than 10 % of the total encountered tracks (this value is best engineering judgment and may be used as a rough guide or rule of thumb).

7.4 *Built-in-Tests (BIT)*—BIT may be designed to be an automatic or manual system.

7.4.1 The DF shall provide an indication when BITs and configuration checks are complete, and detection/tracking of intruders is available or, conversely, when the system is not available.

7.4.2 In the event of a midflight restart, the A1F shall be continuously alerted to the loss of function until such time as the DF resumes detection of intruders.

8. Alert Function

8.1 *Overview:*

8.1.1 This section defines the functionality, behavior, and performance required of the alert function (A1F) within an integrated DAA system. The role of the A1F is the identification and prioritization of hazards from the intruder information received from the DF. These hazards, or "alerts," are then provided to the avoid function (A2F) for determining appropriate UA response.

8.1.2 For pilot-in-the-loop systems and for automated avoidance systems as appropriate, the A1F also provides alert information to a visual/aural component for apprising the PIC of hazards and the changing status of alerts.

8.1.3 This specification does not define the allocation of A1F between the UA and Control Station. It is conceivable, especially for airborne DAA, that parts of the alerting function could be onboard the UA while other parts could be part of the Control Station or a sensor console, or both, but many other architectures could be envisioned.

8.2 *Function:*

8.2.1 At a minimum, the A1F shall issue an alert for an intruder if it determines that the UA must maneuver to remain well clear from that intruder. This alert shall be declared early enough to permit resolution of the hazard (within the appropriate LoWC and NMAC risk ratio thresholds) and no later than the occurrence of loss of well clear. A system that alerts too early will likely alert unnecessarily frequently (that is, will have a high nuisance alert rate) and might be found unacceptable by operators. For a pilot-in-the-loop system, this alert shall be annunciated as a warning-level alert in accordance with AC 25.1322-1, Section 6(b), indicating that immediate pilot awareness is required, and immediate pilot action is required.

8.2.2 Additional levels of alerting may be employed for prioritization of alerts and as appropriate for the system concept of operations (CONOPS) (for example, additional alert levels might be desirable for a pilot-in-the-loop system).

8.2.2.1 The A1F may issue a lower-priority alert for an intruder if that aircraft does not or is not currently expected to lose well clear. These alerts are intended to highlight intruder aircraft (for example, for PIC awareness) that may abruptly become a LoWC or NMAC hazard if either the intruder or the ownship maneuvers. If implemented for a pilot-in-the-loop system, these alerts shall be annunciated as advisory or caution-level alerts in accordance with AC 25.1322-1.

8.2.2.2 The A1F may issue a high-priority alert for an intruder if it determines that the UA must maneuver to avoid NMAC with that intruder. If implemented, this alert shall be declared early enough to permit resolution of the hazard (within the appropriate NMAC risk ratio threshold) and no later than the occurrence of NMAC. If implemented for a pilot-in-the-loop system, this alert shall be annunciated as a warning-level alert in accordance with AC 25.1322-1, indicating that pilot action is required but distinguished in some manner from the alert of 8.2.1.

8.2.3 The A1F passes information regarding each intruder to the A2F. The same data should be passed to the display as is relevant for the system CONOPS. The accuracy and precision of this data is dependent on the underlying DF.

8.2.3.1 At a minimum, the A1F shall pass the alert status (on/off or alert level for systems implementing multiple alert levels) of each intruder to the A2F;

8.2.3.2 The A1F may pass other information about each intruder to the A2F as is relevant to the system CONOPS, to include any of the following:

(1) Bearing of the intruder relative to ownship trajectory or airframe;

(2) Velocity (speed and direction) of the intruder (including vertical velocity, if available);

(3) Range of the intruder from the ownship;

(4) Vertical separation of intruder from the ownship, if available.

8.2.4 For an ownship automatically flying a pre-determined flight plan, the A1F may calculate alerts along the planned horizontal or vertical flight path, or both, using the future positions and velocities along the flight path. For an ownship not flying according to a pre-determined flight plan or forced to temporarily deviate from its flight plan, the A1F shall calculate the alerts using the current position and velocity vector of the ownship.

8.2.5 The A1F shall calculate warning-level alerts using the stated estimates (for example, position and velocity) of the intruder derived solely on data received from the DF up to the current time. Expected future events as might be found in a registered flight plan must not be used for calculation of warning-level alerting for an intruder since the intruder may deviate from its flight plan at any time. Caution- or lower-level alerts, if implemented, may use intruder flight plan information.

8.2.6 The A1F shall update alerts and targets in the following prioritized order consistent with AC 25.1322-1 Flightcrew Alerting:

(1) Warning-level alerts;

(2) Caution-level alerts (if implemented);

(3) Advisory alerts (if implemented);

(4) Other detected traffic.

8.2.7 For alerts of the same priority level, the A1F shall further prioritize the alerts by a criterion associated with reduced collision risk, such as by increasing order of time to Closest Point of Approach (CPA).

8.2.8 For an intruder meeting the criteria of multiple alerts (for example, both caution and warning-level alert criteria), the A1F shall assign the highest priority alert to the intruder based on the priority rules in this section.

8.2.9 *Alerting on Coasted Tracks:*

8.2.9.1 The A1F may coast a non-current track by extrapolating the intruder's trajectory to the current time using its last known position and velocity.

8.2.9.2 If the A1F implements track coasting, it may use intruder trend data (for example, turn rate) up to and including the last known position and velocity vector for extrapolating the coasted track. However, the A1F shall not use an intruder's registered flight plan for extrapolation because the intruder could deviate from the flight plan at any time.

8.2.9.3 If the A1F implements track coasting, a maximum coasting time shall be identified such that the appropriate NMAC and LoWC risk ratios are still achieved.

8.2.9.4 The A1F shall provide alerts on any tracks that have been coasted for less than the identified maximum coast time in the same manner as current tracks (that is, in accordance with 8.2.5).

8.2.9.5 The A1F shall generate no alerts on coasted tracks exceeding the maximum coast time.

8.2.9.6 The A1F shall pass no information on coasted tracks exceeding the maximum coast time to the A2F.

8.3 *Timing*—The A1F shall output the updated alert status of an intruder no later than $t_{Classify} + t_{Notify}$ (as discussed in Appendix X2) after receiving new data on the intruder from the DF and subject to the timing analysis required in 6.1.

8.4 *Human Machine Interface:*

8.4.1 Even for systems with a high degree of autonomy, some level of human interaction or oversight will be needed. This section addresses those human machine interface (HMI) considerations. Unless otherwise specified, all requirements for display of information in this section can be satisfied either graphically or as part of a data label.

8.4.2 At a minimum, all traffic meeting the alerting conditions in 8.2.1 and, if implemented, 8.2.2 shall be displayed as appropriate for the mission CONOPS. For example, if human-in-the-loop is required for the A1F, then alerts are displayed in time for the human to react and meet the RR requirements.

8.4.3 The DAA traffic display shall provide traffic information appropriate to the DAA system CONOPS for each displayed traffic element. Traffic information should be displayed consistent with RTCA DO-365C. More/different information may be appropriate for a pilot-in-the-loop system than for a fully automatic one. Some examples of traffic information that may be displayed are as follows:

8.4.3.1 Horizontal position (range and azimuth of traffic symbol on display);

8.4.3.2 Traffic directionality (if applicable);

8.4.3.3 Traffic altitude;

8.4.3.4 Traffic vertical direction indicator (an indication of climb or descent) when vertical rate is available and is greater than or equal to a threshold established by the developer (nominally, 500 ft/min); and

8.4.3.5 Horizontal velocity trend (that is, predictor line or history trail).

8.4.4 The traffic display shall not display traffic coasted beyond the maximum coasting time in accordance with 8.2.9.3.

8.4.5 The traffic display shall use the following colors to present alert information (see AC 25.1322-1):

8.4.5.1 Warning-level alerts – Red;

8.4.5.2 Caution-level alerts (if implemented) – Amber or yellow;

8.4.5.3 Advisory-level alerts (if implemented) – Any color except red, green, or amber/yellow, consistent with control station philosophy;

8.4.5.4 Non-alert traffic (if implemented) – Any color except red, green, or amber/yellow, or the color used for Advisory-level alerts consistent with control station philosophy.

8.4.6 Iconography should provide more than one dimension of encoding. This may take many forms, including color and symbol shape.

8.4.7 The A1F should avoid information clutter on a display. Therefore, other intruder parameters beyond what are specified in 8.4.3 may be called up by the operator. Examples of methods by which this may be done include:

8.4.7.1 A separate window or table in alert priority order, and

8.4.7.2 Expanded parameter detail when the operator selects a specific alert icon (for example, data block).

8.4.8 Warning-level alerts shall include distinct aural indications (also known as "aural alert").

8.4.8.1 If implemented, caution-level alerts shall include an aural indication distinct from that for a warning-level alert.

8.4.9 The A1F may inhibit or suppress (as described by AC 25.1322-1) aural alerts when directed by the operator or as appropriate to the mission CONOPS. This is provided as an aid to minimize operator workload during critical phases of the