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Standard Specification for Design and Performance of an Airborne Sense-and-Avoid System[1]

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1. Scope

1.1 This specification covers requirements for the design and performance of airborne sense-and-avoid (S&A) systems. This specification includes requirements to support detection of, and safe separation from, airborne objects such as manned or unmanned aircraft and air vehicles.

1.2 This specification applies to the manufacturer of an appliance seeking civil aviation authority approval, in the form of flight certificates, flight permits, or other like documentation, as providing an equivalent level of safety to the see-and-avoid capability of a human pilot.

1.3 This specification is not intended to apply to the design and performance of cooperative S&A systems. Existing standards and guidance should be referenced for specifications describing these transponder or broadcast-based systems (examples of existing guidance and standards for cooperative S&A systems include FAA 20-131A, RTCA DO-289, and TSO-C119B).

1.4 This specification does not apply to appliances on-board one or more airborne objects flying in formation flight.

1.5 *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 and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *Code of Federal Regulations (CFR):*[2]

14 CFR 91.1 General Operating and Flight Rules–Applicability

14 CFR 91.113 General Operating and Flight Rules–Right-of-Way Rules: Except Water Operations

14 CFR 91.123 General Operating and Flight Rules–Compliance with ATC Clearances and Instructions

2.2 *Federal Aviation Administration (FAA) Publications:*[3]

FAA 8700.1 General Aviation Operations Inspector's Handbook

FAA P-8740-51 How to Avoid a Midair Collision

FAA 90.48C Advisory Circular–Pilots' Role in Collision Avoidance

FAA 20-131A Advisory Circular–Airworthiness Approval of Traffic Alert and Collision Avoidance Systems (TCAS II) and Mode S Transponders

TSO-C119B Traffic Alert and Collision Avoidance System (TCAS) Airborne Equipment

TSO-C153 Integrated Modular Avionics Hardware Elements

AC 21–33 Quality Assurance of Software used in Aircraft of Related Products

AC 20–145 Guidance for Integrated Modular Avionics (IMA) that Implement TSO-C153 Authorized Hardware Elements

2.3 *ICAO Publications:*[4]

ICAO Rules of the Air–Annex 2

2.4 *RTCA Publications:*[5]

DO-289 Minimum Aviation System Performance Standards (MASPS) for Aircraft Surveillance Applications (ASA)

3. Terminology

3.1 *Definitions:*

3.1.1 *airborne object*, *n*—any object that is operating in the airspace to include manned or unmanned aircraft or air vehicles.

3.1.2 *airspace of operations*, *n*—all classes of airspace in which a system is intended to operate.

3.1.3 *closing velocity*, *n*—rate of change of the decreasing distance between two objects.

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[2] Available from U.S. Government Printing Office Superintendent of Documents, 732 N. Capitol St., NW, Mail Stop: SDE, Washington, DC 20401, http://www.access.gpo.gov.

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

[4] Available from International Civil Aviation Organization (ICAO), 999 University St., Montreal, Quebec H3C 5H7, Canada.

[5] Available from RTCA, Inc., 1828 L Street, NW, Suite 805, Washington, DC 20036.

3.1.4 *collision threat*, *n*—hazard consisting of a manned or unmanned aircraft, air vehicle, or other airborne object.

3.1.5 *cooperative S&A system*, *n*—system capable of communicating with systems on-board other airborne objects in order to facilitate detection or coordinate resolution maneuvers, or both.

3.1.6 *detection distance*, *n*—distance at which an S&A system can perceive a potential collision threat.

3.1.7 *field of regard (FOR)*, *n*—area capable of being perceived or monitored by a sensor, or both, specified in terms of azimuth and elevation from the fixed body reference frame of the S&A platform.

3.1.8 *miss distance*, *n*—distance between two airborne objects at their closest point of approach.

3.1.9 *non-cooperative S&A system*, *n*—system capable of detecting other airborne objects that do not have a cooperative S&A system.

3.1.10 *platform*, *n*—manned or unmanned aircraft, air vehicle, or other airborne object on which the S&A system is intended to operate.

3.1.11 *resolution maneuver*, *n*—intentional change in an airborne object's flight path, velocity, or altitude, or a combination thereof, to avoid a collision threat.

3.1.12 *S&A system infrastructure*, *n*—system of systems consisting of the S&A system, pilot(s), or related systems, or a combination thereof, combined with the air traffic control infrastructure in place on the ground and in orbit, that is intended to provide safe separation of two or more airborne objects.

3.1.13 *scan rate*, *n*—time between successive surveys of the entire field of regard for potential collision threats.

3.1.14 *sense and avoid (S&A)*, *v*—process of determining the presence of potential collision threats, and maneuvering clear of them; the automated equivalent to the phrase "see and avoid" for the pilot of a manned aircraft.

3.1.15 *sense-and-avoid system*, *n*—appliance which fulfills the requirements of 14 CFR 91.113.

3.1.15.1 *Class 1*—Pilot-in-the-loop: Declares collision threat to the human pilot for action by that pilot.

3.1.15.2 *Class 2*—Automated Air: Initiates avoidance maneuver upon declaring a collision threat while in the air; interfaces with the autopilot.

3.1.15.3 *Class 3*—Automated Air and Surface: Initiates avoidance maneuver upon declaring a collision threat while operating in the air or on the ground; interfaces with the autopilot, throttles, and brakes.

4. Performance Requirements

4.1 *General Performance*—All performance requirements apply in and shall be corrected to International Civil Aviation Organization (ICAO) defined standard atmosphere. Speeds shall be given in true airspeed (TAS) in nautical miles per hour (knots).

4.2 *Sensing*:

4.2.1 *Detection Distance*—Detection of the collision threat shall be at a range to allow a resolution maneuver that results in a required miss distance of 500 ft or greater (see FAA 8700.1).

4.2.2 *Field of Regard*:

4.2.2.1 *Azimuth*—It shall be demonstrated that the S&A system can search from ±110° referenced from the S&A platform's body frame of reference.[6]

4.2.2.2 *Elevation*—It shall be demonstrated that the S&A system can search from ±15° referenced from the S&A platform's body frame of reference.[7]

4.2.3 *Latency*—It shall be demonstrated that the time between detection of a collision threat and initiation of a resolution maneuver does not compromise the required miss distance specification. This time latency may include, but is not limited to:

4.2.3.1 Communication delays,

4.2.3.2 Scan rates,

4.2.3.3 Pilot-in-the-loop reaction times,

4.2.3.4 Coordination with air traffic control authorities, and

4.2.3.5 On-board or ground-based processing time for collision avoidance or flight control algorithms.

4.3 *Avoidance*:

4.3.1 *Traffic*—Resolution maneuvers shall achieve the required miss distance from all aircraft, air vehicles, and other airborne objects that are:

4.3.1.1 Equipped with cooperative S&A systems (a cooperative flight environment), and

4.3.1.2 Not equipped with cooperative S&A systems (a non-cooperative flight environment).

4.3.2 Resolution maneuvers may include one or more of the following changes in flight profile:

4.3.2.1 Altitude,

4.3.2.2 Heading, and

4.3.2.3 Airspeed.

4.3.3 If any resolution maneuver deviates from an air traffic control clearance or instruction, air traffic control shall be notified of the deviation as soon as possible (see 14 CFR 91.123).

4.3.4 When the potential for multiple collision threats exists, the resolution maneuver to avoid one collision threat shall be planned and executed to reduce the occurrence of subsequent or more hazardous conditions, or both.

4.3.5 *Maneuvering*—For straight flight and turns in either direction during climb, cruise, and descent, it shall be shown that:

4.3.5.1 All resolution maneuvers are within the structural and aerodynamic performance limitations of the S&A system and platform at all flight conditions and profiles.

4.3.5.2 The S&A platform is safely controllable and maneuverable during all phases of the resolution maneuver from initiation to its return to an original or newly assigned flight path and altitude.

4.3.5.3 All maneuvers to return to an original or newly assigned flight path and altitude comply with current right-of-way rules for aircraft, air vehicles, and other airborne objects in accordance with 14 CFR 91.113. This applies to both autonomous and pilot-initiated maneuvers.

[6] FAA P-8740-51 suggests that azimuth FOR be ±60° off the aircraft nose; ICAO Annex 2 specifies ±110° off the aircraft nose.

[7] FAA P-8740-51 suggests that elevation FOR be ±10° from the aircraft's body frame of reference; Department of Defense and NASA studies indicate ±15° is an appropriate threshold.

4.3.5.4 Non-emergency maneuvers for course or altitude changes, or both, do not compromise the performance of the S&A system.

4.4 *Proof of Compliance*:

4.4.1 These requirements shall be met at the most critical (for example, highest) closing velocities and most unfavorable (for example, climbing, descending) flight profiles. To the extent that the S&A system may operate in all-weather conditions, it will be evaluated in the least favorable flight conditions to include minimum Visual Meteorological Conditions (VMC) and Instrument Meteorological Conditions (IMC), when weather conditions permit.

4.4.2 The characteristics outlined are meant to serve as a set of minimal performance requirements for S&A systems. Performance that exceeds these specifications are acceptable, but exceeding performance in one area shall not substitute for a lack of performance in another.

4.5 *Proof of Performance*:

4.5.1 Compliance of the S&A system shall be demonstrated through simulated collisions involving the S&A platform. The performance of any S&A system on which overall safe flight is dependent shall be proven by demonstration. Methods of demonstration may include:

4.5.1.1 Flight test,

4.5.1.2 Analytical modeling and simulation, and

4.5.1.3 Another method mutually agreed upon between the cognizant certification authorities and the manufacturer(s) of S&A system.

4.5.2 Detection and avoidance with the required miss distance shall be shown for combinations of the following flight profiles and collision geometries:

4.5.2.1 For co-altitude collision threats with a perceived position within the required FOR of 0°, ±10°, ±30°, ±50°, ±70°, ±90°, and ±110° azimuth.

4.5.2.2 For climbing/descending collision threats with a perceived position within the required FOR of ±5°, ±10°, and ±15° elevation.

4.5.2.3 For minimum, maximum, and typical cruise speeds of the S&A platform.

4.5.2.4 For collision threat speeds resulting in closing velocities that are representative of all those likely to be encountered in the S&A platform's airspace of operations.

4.5.2.5 For collision threat sizes that are representative of all those likely to be encountered in the S&A platform's airspace of operations.

4.6 The S&A system shall be designed to minimize conflicts with resolution advisories or avoidance maneuvers generated by cooperative S&A systems on-board other airborne objects.

5. Design and Construction

NOTE 1—The manufacturer should also refer to TSO-C153 and AC 21–33 during design and construction, and to AC 20–145 during installation.

5.1 *Power Supply*:

5.1.1 Power consumption of the S&A system shall be low enough to operate from primary platform power or auxiliary power during:

5.1.1.1 The entire mission (taxi, takeoff, in-flight, landing) without compromising the safe operation of other platform subsystems, and

5.1.1.2 Regular ground-based testing in support of verification, validation, and system diagnostics.

5.1.2 The power supply for in-flight operation of the S&A system can be from a source independent of the platform's primary power subsystem.

5.2 *Communication*:

5.2.1 It shall be demonstrated that in the event of a loss of direct command, control, or communication, or a combination thereof, with the S&A platform, a resolution maneuver in accordance with 4.3 will still be safely executed when required.

5.2.2 The bandwidth requirement for S&A systems that require downlink or uplink command and control data links, or both, shall not compromise safe operation of other platform subsystems.

5.3 *Loads*—The S&A system shall withstand the maximum load factor generated by the platform.

5.4 *Subsystem Integration*:

5.4.1 Although presented as individual subsystems in this specification, the detection and avoidance hardware and software can be integrated into a single subsystem for cost or performance enhancements, or both.

5.4.2 The S&A system shall not impede the operation of any platform subsystem critical to safe operation. The S&A system design should eliminate probable malfunctions or failures that could propagate into these systems.

5.4.3 The S&A system operation shall not be impeded by platform subsystems unrelated to sense and avoid.

5.4.4 S&A systems retroactively added to an airborne-capable object in order to conform to this specification shall not adversely affect the following properties:

5.4.4.1 Stability and control (for example, weight and balance), and

5.4.4.2 Overall platform reliability.

5.5 *Data Output*—All of the data elements necessary for the interoperability of the S&A system with the platform, pilot(s), or air traffic control, or a combination thereof, shall be identified and provided in a compatible form for the end-use or user.

5.6 *Human Systems Interface*:

5.6.1 Operation of an S&A system shall not increase pilot workload such that:

5.6.1.1 Additional flight crewmembers are required, and

5.6.1.2 Primary mission objectives are compromised during times of non-emergency.

5.6.2 An audible or visual alarm or other method of notification to the pilot(s) shall accompany any detection of a collision threat and subsequent initiation of a resolution maneuver.

5.6.3 The S&A system shall provide a clear method to alert its pilot(s) or ground crew, or both, regarding its operational status to indicate:

5.6.3.1 Fully functional status, and

5.6.3.2 Diagnostic information if the system is not fully functional.

5.7 *Sensor Configuration*:

5.7.1 The S&A sensor shall be located on-board the aircraft, air vehicle, or airborne object.

5.7.2 The required FOR may be scanned by single or multiple sensors.

5.8 *Proof of Compliance*—The manufacturer(s) of the S&A system shall coordinate with the cognizant certification authorities to obtain concurrence on an acceptable means of compliance with these specifications. Compliance may be proven by conservative analysis, test, or another mutually agreed upon method.

6. Reliability and Maintenance

6.1 *Accessibility*—The S&A system components shall be accessible for routine inspection, maintenance, repair, and replacement as needed.

6.2 *Environment*—The S&A system shall demonstrate the ability to operate in the same conditions as those intended for its platform to include:

6.2.1 Atmospheric conditions (for example, temperature, humidity, icing, turbulence, etc.),

6.2.2 Altitude,

6.2.3 Daytime/nighttime, and

6.2.4 Airspace of operations (for example, congestion, air traffic control requirements).

6.3 *Operating Limitations*—The operating limitations and related performance information of the S&A system shall be established and made available to the pilot(s) and air traffic control authorities as required to facilitate safe operation.

6.4 *Failure Rate*:

6.4.1 The manufacturer(s) of the S&A system shall be responsible for identifying and classifying the major failure modes that can compromise the performance of the S&A system or its platform.

6.4.2 The S&A system infrastructure shall have an overall critical failure rate of no more than 0.51 per million flight hours, which is equivalent to the level of safety of manned general aviation. Methods by which this failure rate can be achieved include, but are not limited to:

6.4.2.1 High component reliability or performance of the S&A system, or both, and

6.4.2.2 Risk-mitigating operating procedures or environments for the S&A platform, or both.

NOTE 2—The critical failure rate of the manned S&A system infrastructure for general aviation is known; it is the rate of mid-air collisions per year (0.51 per million flight hours). This value is based on the mid-air collision statistics for general aviation aircraft, which has the highest historical incidence of mid-air collisions (that is, highest failure rate of all manned S&A system infrastructures). Table 1 provides the 10-year statistics used to calculate this rate. The consequence of exceeding this rate is that the sense-and-avoid system would then be failing more frequently than the manned system, and would therefore not be equivalent to it. While it is likely that very few of these S&A system failures would result in mid-air collisions, neither do all failures of the manned S&A system infrastructure. In manned aviation, for example, there are both reported and unreported near mid-airs, as well as mid-airs that are never detected by either pilot. These occur not just from a failure of eyesight (that is, the human sensor), but also from inadequate scanning, inattentive piloting, obscuration of the FOR by the aircraft structure, and so forth. As a result, as long as the S&A system has a failure rate equal to or better than 0.51 per million flight hours (including reliability and performance of the system), it should be deemed equal to or better than a manned aircraft's level of safety with respect to mid-air collisions.

6.5 *Proof of Compliance*—The reliability and maintenance of any S&A system design on which overall platform safety is dependent shall be proven by conservative analysis, test, or a combination of both, and done in coordination with the cognizant certification authorities.

7. Keywords

7.1 active/passive sensing; airworthiness; avoid; collision avoidance; cooperative targets; detect; EO IR; helicopter; NAS; non-cooperative targets; RF; see; sense; sense and avoid; sensor; target avoidance; target identification; unmanned aerial vehicles; unmanned air vehicle; unmanned aircraft systems

TABLE 1 General Aviation Mid-Air Collision 10-year History[A]

Year	Mid-Air Collisions	Operating Hours (millions)	Rate per 10^6 Operating Hours
1991	18	27.2	0.66
1992	11	24.8	0.44
1993	13	22.8	0.57
1994	11	22.2	0.50
1995	14	24.9	0.56
1996	18	24.9	0.72
1997	13	25.5	0.51
1998	14	26.8	0.52
1999	15	29.5	0.51
2000	19	30.8	0.62
2001	5	25.9	0.19
2002	7	25.9	0.27
Average	13.17	25.93	0.51

[A] Available from Aircraft Owners and Pilots Association (AOPA) Air Safety Foundation, 421 Aviation Way, Frederick MD 21701.