RTCA, Inc.
1150 18th Street, NW, Suite 910
Washington, DC 20036
USA

Minimum Operational Performance Standards (MOPS) for Detect and Avoid (DAA) Systems

RTCA DO-365
May 31, 2017

Prepared by: SC-228

Copies of this document may be obtained from:

RTCA, Inc.
1150 18th Street, NW, Suite 910
Washington, DC 20036-4001, USA
Telephone: 202-833-9339
Facsimile: 202-833-9434
Internet: rtca.org

Please visit the RTCA online store for document pricing and ordering information.

FOREWORD

This document was prepared by Special Committee 228 (SC-228) and approved by the RTCA Program Management Committee (PMC) on May 31, 2017

RTCA, Incorporated is a not-for-profit corporation formed to advance the art and science of aviation and aviation electronic systems for the benefit of the public. The organization functions as a Federal Advisory Committee and develops consensus based recommendations on contemporary aviation issues. RTCA's objectives include but are not limited to:

- coalescing aviation system user and provider technical requirements in a manner that helps government and industry meet their mutual objectives and responsibilities;
- analyzing and recommending solutions to the system technical issues that aviation faces as it continues to pursue increased safety, system capacity, and efficiency;
- developing consensus on the application of pertinent technology to fulfill user and provider requirements, including development of minimum operational performance standards for electronic systems and equipment that support aviation; and
- assisting in developing the appropriate technical material upon which positions for the International Civil Aviation Organization and the International Telecommunication Union and other appropriate international organizations can be based.

The organization's recommendations are often used as the basis for government and private sector decisions as well as the foundation for many Federal Aviation Administration Technical Standard Orders.

Since RTCA is not an official agency of the United States Government, its recommendations may not be regarded as statements of official government policy unless so enunciated by the U.S. government organization or agency having statutory jurisdiction over any matters to which the recommendations relate.

This Page Intentionally Left Blank

Revision History

Rev Level	Description	Date	Effective Sections
-	Draft for RTCA/Program Management Committee Review	01/20/17	All

This Page Intentionally Left Blank

EXECUTIVE SUMMARY

RTCA has been developing the Minimum Operational Performance Standards (MOPS) needed to support Unmanned Aircraft (UA) flights within the National Airspace System (NAS) and beyond the operational limits placed on small Unmanned Aircraft Systems (UAS). In 2013, the RTCA initiated Special Committee 228 (SC-228) with a narrower scope; namely to develop MOPS needed for (a) a Detect and Avoid (DAA) system (the focus of Working Group (WG) 1) and (b) a Terrestrial Control and Non-Payload Communications (CNPC) Link System (focus of WG 2).

The DAA system was developed to assist the Pilot-in-Command (PIC) with his/her duties of operating an aircraft safely in the NAS. All aircraft flying in the NAS must comply with the operating rules of Title 14 of the Code of Federal Regulations (14 CFR). Specifically, Part 91, §§.3, .111, .113(b), .115, .123 and .181(b), which address see and avoid, collision avoidance, and right-of-way rules. These operating regulations assumed that a pilot would be onboard the aircraft, so he/she would be able to exercise his/her authority to fully comply with these rules.

This document contains Phase 1 MOPS for DAA systems used in aircraft transitioning to and from Class A or special use airspace (higher than 500' Above Ground Level (AGL)), traversing Class D, E, and G airspace in the NAS. It does not apply to small UAS operating in low-level environments (below 500') or other segmented areas. Likewise, it does not apply to operations in the Visual Flight Rules (VFR) traffic pattern of an airport. Future revisions of this document are expected to address other operational scenarios and sensors better suited to meet smaller aircraft needs, as well as other DAA architectures, including ground-based sensors.

This Page Intentionally Left Blank

TABLE OF CONTENTS

Table of Figures

Table of Tables

1 PURPOSE AND SCOPE

1.1 Introduction

This document contains Phase 1 Minimum Operational Performance Standards (MOPS) for Detect and Avoid (DAA) systems used in Unmanned Aircraft Systems (UAS) transitioning to and from Class A or special use airspace (higher than 500’ Above Ground Level (AGL)), traversing Class D, E, or G airspace in the National Airspace System (NAS). It does not apply to small UAS (sUAS) operating in low-level environments (below 500’) or other segmented areas. Likewise, it does not apply to operations in the Visual Flight Rules (VFR) traffic pattern of an airport. These standards specify DAA system characteristics that should be useful for designers, manufacturers, installers and users of the equipment.

These Phase 1 MOPS focus on Unmanned Aircraft (UA), in order to fly in airspace normally frequented by commercial transport and general aviation aircraft. Aircraft operating in all classes of airspace vary from operation under Instrument Flight Rules (IFR) in Reduced Vertical Separation Minimum (RVSM) airspace to VFR operations with minimal onboard equipage. The technology needed to detect this range of aircraft as defined in these Phase 1 MOPS at sufficient distance to prevent the risk of collision may limit the size of the UA in which this equipment can be integrated. The UAS will need to carry relatively large and high-power sensor systems, which could weigh 200 pounds or more. Therefore, these MOPS are unlikely to be applicable to smaller size UAS, but such aircraft are not prohibited from installing equipment that meet the standard and have a need to transit to Class A airspace. Future revisions of this document are expected to address other operational scenarios and sensors better suited to smaller UAS needs, as well as other DAA architectures, including ground-based sensors.

During development of this document, members of the committee expressed concern about Equipment Class 1 providing an appropriate level of safety for the in-scope operations. There were also concerns expressed regarding the safety of the system when compared to manned see-and-avoid capability, the usability of the well clear definition, the impacts of replacing “collision avoidance” with a "recover well clear" concept, concerns that a formal safety analysis was not available to guide MOPS development, and concerns that a top level performance requirement was not established to provide a means for requirement traceability to lower level requirements.

To this end, the Federal Aviation Administration (FAA) is conducting an internal Safety Risk Management Panel to establish the conditions under which Equipment Class 1 or Equipment Class 2 would be sufficient for the intended operations in the NAS. The outcome of this safety analysis will be used to determine required equipage and any necessary operational mitigations. The information will be shared with the committee and any necessary changes needed to the standard will be addressed during the Phase 2 effort.

Compliance with these standards is recommended as one means of assuring that the equipment will perform its intended function(s) satisfactorily under the conditions specified herein. Any regulatory application of this document is the sole responsibility of appropriate governmental agencies.

1.1.1 Document Hierarchy

Recommendations and standards in these MOPS are generally consistent with Subsection 4.1 of the FAA Roadmap for *Integration of Civil Unmanned Aircraft Systems (UAS) in the National Airspace System (NAS),*[1] given the system limitations identified in Paragraph 1.2.3.

Recommendations and standards in these MOPS have also generally been based on the assumptions and approach defined in RTCA Paper No. 074-14/Program Management Committee (PMC)-1200, that the collision avoidance function is optional in this phase of the DAA MOPS development.[2]

Interoperability requirements between a DAA system and existing collision avoidance systems such as TCAS II are defined in Appendix M. Theses MOPS provide a means of meeting the collision avoidance interoperability requirements listed in Appendix M.

Section 1 of this document provides information needed to understand the rationale for the equipment characteristics and requirements outlined in these MOPS. It describes typical equipment operations and operational goals as envisioned by the members of RTCA Inc. Special Committee (SC)-228, and establishes the basis for the standards stated herein. Recommendations for mitigating aircraft information security risks and assumptions essential to proper understanding of this document are also provided in this section.

Section 2 contains the MOPS for the equipment. These standards specify the required performance under standard environmental conditions. Also included are recommended bench test procedures necessary to demonstrate equipment compliance with the stated minimum requirements.

Section 3 describes the performance required of installed equipment. Tests for the installed equipment are included when performance cannot be adequately determined through bench testing.

Section 4 describes the operational performance characteristics for equipment installations and defines conditions that will assure the user that operations can be conducted safely and reliably in the expected operational environments.

Section 5 contains an informative listing of SC-228 committee members who contributed to these MOPS.

Appendix A contains an informative Operational Services and Environment Description (OSED) that provides a basis for assessing and establishing operational, safety, performance, and interoperability requirements for DAA systems.

Appendix B contains an informative listing of acronyms and definitions associated with the development and understanding of these MOPS.

---

[1] Federal Aviation Administration's (FAA) Roadmap for *Integration of Civil Unmanned Aircraft Systems (UAS) in the National Airspace System (NAS),* UAS Aviation Rulemaking Committee (ARC), November 7, 2013

[2] RTCA Paper No. 074-14/PMC-1200 Detect and Avoid (DAA) White Paper. Prepared by: SC-228, March 18, 2014

Appendix C contains an informative description of the development of the quantitative definition of DAA Well Clear (DWC) by the UAS Executive Committee Senior Steering Group established by the Office of Secretary of Defense.

Appendix D contains the minimum UAS maneuver performance requirements needed to install a DAA system described in these MOPS.

Appendix E contains an informative description of latency issues that need to be taken into account when integrating sensors into a DAA system.

Appendix F contains an informative description and analysis of the Example Functional Description for Airborne Surveillance Data Processor (ASDP) subsystem.

Appendix G contains an informative description of sample algorithms for the guidance-processing function.

Appendix H contains an information summary of the Right-of-Way (ROW) rules and associated algorithms for implementing these rules into a DAA system.

Appendix I contains an informative analysis of and guidance material on the effects of Traffic Alert and Collision Avoidance System Model 2 (TCAS II) Interference Limiting.

Appendix J contains an informative description and analysis of qualification conditions for alternative ground equipment.

Appendix K contains an informative description and analysis of the requirements levied on the Command and Non-Payload Communications (CNPC) link to support the requirements of a DAA system.

Appendix L contains an informative description of the Open and Closed Loop DAA Metrics

Appendix M contains an informative description and analysis of requirements for TCAS II interoperability.

Appendix N contains an informative description and analysis of Automatic Dependent Surveillance-Broadcast (ADS-B) validation.

Appendix O contains an informative matrix that traces requirements to equipment classes.

Appendix P contains an informative description of the test vectors used for verification and validation of requirements.

Appendix Q contains an informative description of modeling and simulation work used to validate the tracker performance, DAA alerting algorithms, and sensor performance assumptions.

This document sets performance standards for specific UAS DAA equipment, including all physical articles necessary for the DAA system to properly perform its intended function(s). Articles specified in this standard include an airborne traffic radar, an airborne active surveillance sensor, an ADS-B In system, a TCAS II system (Optional), DAA processors, a CNPC data link system, a control panel, and traffic displays.

1.2 System Overview

The DAA system was developed to assist the Pilot-in-Command (PIC) of his/her duties of operating an aircraft safely in the NAS. All aircraft flying in the NAS must comply with the operating rules of Title 14 of the Code of Federal Regulations (14 CFR). Specifically, Part 91, §§.3, .111, .113(b), .115, .123 and .181(b), address see and avoid, collision avoidance, and right-of-way rules. These operating regulations assumed that a pilot would be onboard the aircraft, so he/she would be able to exercise his/her authority to fully comply with these rules. These rules were not written for remotely piloted aircraft in the NAS. Using such terms as "well clear," "see and avoid" and "collision avoidance" are very subjective. One methodology adopted by the Special Committee SC-228 was to define these terms with respect to distance, time and velocity. SC-228 leveraged the UAS Executive Committee Science and Research Panel (SaRP) to quantify the "well clear" terminology. The list of organizations representing the panel is found in Appendix C.

The results of this study led to the development of a risk-based DAA Well Clear definition, which provided the basis of the alerts and guidance of the DAA system. A low level of risk was assumed and no direct comparison to human vision was made. The risk level chosen was largely driven by the time-based thresholds required to ensure interoperability with TCAS II and an airspace safety threshold appropriate to fly in all of Class D, E, and G airspace for transit operations. For aircraft operating solely in airspace where transponder equipage is not required and/or for aircraft that have lower operating speeds than those defined in the operating assumptions, this risk level may be conservative compared to the existing risk in that airspace. Details of the assumptions used in the study are documented in Appendix C.

Note: *RTCA SC-228 has adapted the term, "DAA Well Clear," abbreviated as DWC as a temporal and/or spatial boundary around the aircraft intended to be an electronic means of avoiding conflicting traffic. For a quantitative definition, please see equation in Appendix C of these MOPS. RTCA SC-228 has also adapted the International Civil Aviation Organization (ICAO) term of "Remain Well Clear" into two components: "maintain DWC" and "regain DWC."*

The DAA Phase 1 MOPS equipment is not considered a replacement of a pilot onboard the aircraft for "see and avoid" and collision threat operations. It does not attempt to achieve equivalent levels of performance of a manned pilot. Direct comparison with onboard pilot functional performance is very subjective; therefore these MOPS do not address pilot performance. Nor does it address collision risk from manned pilot operation to unmanned operation. Future work may consider risk ratios or other aspects of the system, such usage of the system for VFR only aircraft or in VFR traffic patterns.

Figure 1-1 provides an overview of the DAA system for the Phase 1 DAA MOPS. The DAA system consists of the DAA equipment, the UAS PIC, CNPC data link, and other UAS articles necessary to maintain DWC.

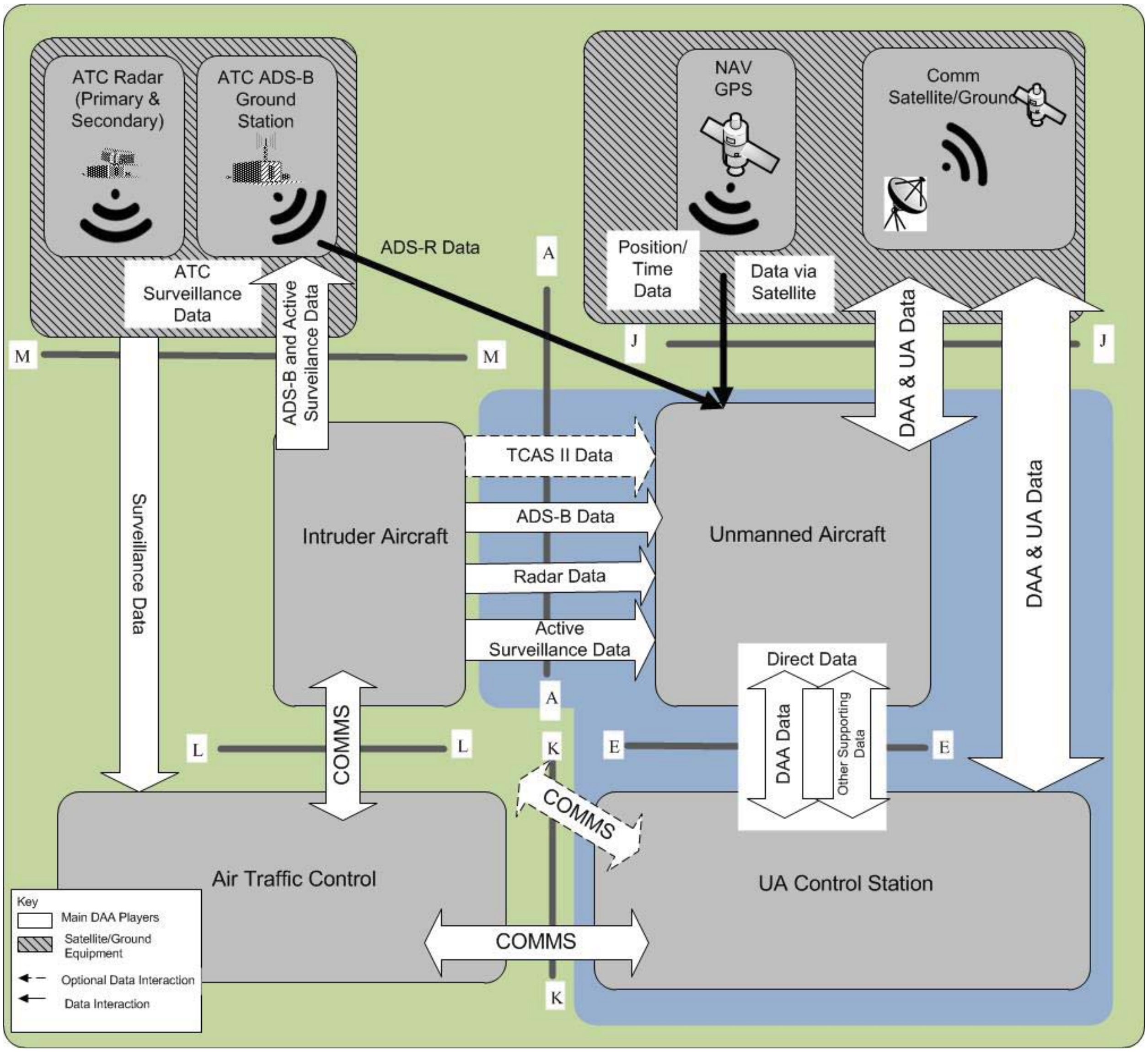


Figure 1-1 **Top Level DAA System Architecture**

As illustrated in Figure 1-1, the DAA system consists of a number of subsystems and articles that include the UA, its CS, intruders, ATC, supporting ground surveillance, navigation (NAV) systems, the Global Positioning System (GPS), as well as communication systems (COMMS). The interfaces A-M were chosen to provide information where latencies could occur outside each of the major systems. Traffic information starts with the intruder (Interface A) to the UA. This would have the shortest latency of sensor data to the UA. Then Interfaces B-D are found within the UA ad Interfaces F-I are found within the UA Control Station (CS). The UA receives intruder data such as state information and Resolution Advisories (RAs) via Interface A. The intruder (if cooperative) sends data to the ATC ground stations (Interface M), or directly to the UA (Interface A). The UA processes the intruder data along with its ownship information and data provided via Interface J. The UA sends the data to the CS directly or via satellite as defined by Interface E and the CS receives and processes this data and displays it to the pilot. Using this information, the PIC decides whether an action is necessary. If an action is required, the PIC will contact ATC via Interface K. ATC receives both UA and intruder surveillance information from ground-based radar and ADS-B ground stations, via Interface M, and may communicate with the intruder through Interface L.

The DAA equipment includes hardware, software, firmware, processors, displays, and controls, to perform the DAA intended functions (see Subsection 1.4). The DAA equipment is intended to provide the UAS PIC an electronic means of compliance with 14 CFR Part 91, §§.111a, .113, .115 and .181.

The DAA equipment has two distinct domains: the UA and the CS. The UA domain detects traffic using three types of sensors, including active airborne surveillance, ADS-B In and airborne radar. These surveillance types are necessary to detect most traffic types, including non-cooperative aircraft, Air Traffic Control Radar Beacon System (ATCRBS)-equipped aircraft, ADS-B equipped aircraft, Mode S equipped aircraft and TCAS II-equipped aircraft. The CS domain allows UA PICs to conduct safe and efficient transit operations through Class D, E and G airspace while not in an airport traffic pattern using displays, alerts, communication systems, and ATC. The DAA equipment allows both automatic and manual modes, but the minimum operational set considers a UAS PIC in the Loop (PITL); therefore, these MOPS will reference the UAS PIC as a minimum, and all other types of interactions with the equipment (automatic/Pilot on-the-Loop (POTL)) as optional.

The FAA's UAS Operational Concept document includes assumptions, constraints, requirements, and high-level operational considerations for UAS, and is intended to provide the foundation for these Phase 1 DAA MOPS. However, the limited scope and functionality of these Phase 1 MOPS may require specific restrictions, operating limitations and/or supplemental operational controls or provisions to achieve an acceptable level of airborne collision risk mitigation for use in the NAS. An initial set of system operating limitations and/or supplemental operational controls or provisions will be documented as part of these MOPS as found in Paragraph 1.2.3.

1.2.1 Detect and Avoid (DAA) System Description – Unmanned Aircraft

DAA equipment onboard the UA consists of four major groups, as shown in Figure 1-2: a set of surveillance sources, a DAA processor, the aircraft systems (which are not subjects of these MOPS), and CNPC equipment (which is also not a subject of these MOPS).

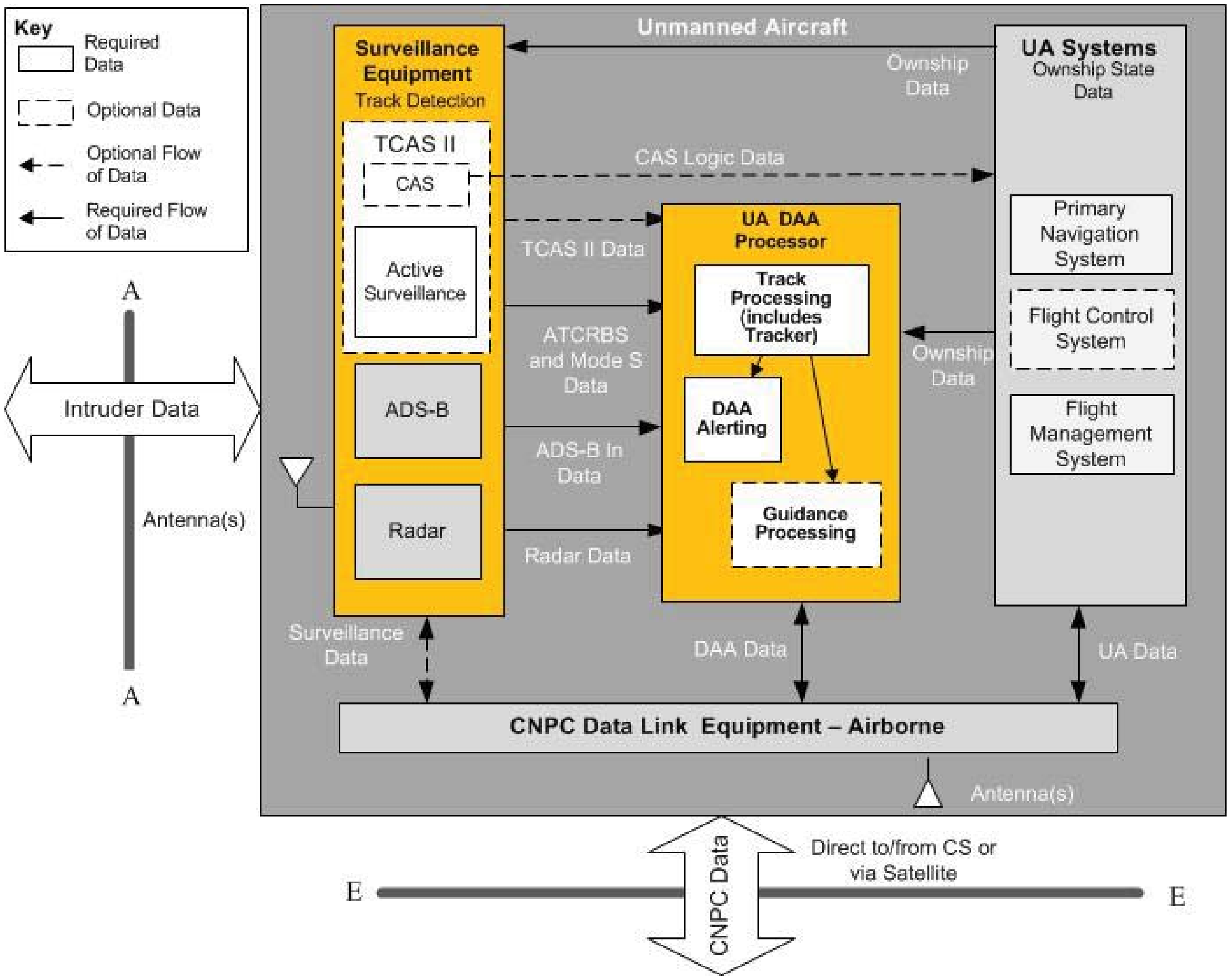


Figure 1-2 **Major Elements of the DAA System Onboard the Aircraft**

Note: *Figure 1-2 provides a functional view of the architecture. This is not intended to preclude a manufacturer or designer from either having onboard equipment that provides a federated approach (i.e., individual pieces of equipment providing the respective functionality) or taking an integrated approach to meet the requirements of these MOPS (i.e., individual pieces of equipment that combine functionalities, such as an article that provides both TCAS II and ADS-B In/Out).*

1. The surveillance sources minimally consist of the following:
   a. Active airborne surveillance, which provides surveillance of other Mode S and ATCRBS-equipped aircraft;
   b. An ADS-B In unit, which provides information on proximate traffic transmitting ADS-B data, and receipt of Automatic Dependent Surveillance-Rebroadcast (ADS-R) data if not equipped with dual-links;
   c. Radar for tracking of cooperative and non-cooperative traffic.
   d. Optional TCAS II equipment enables coordination with other TCAS II RA-enabled aircraft and has Collision Avoidance System (CAS) logic data that can be sent directly to the flight control system for automatic responses.

These sources all provide traffic detection data, surveillance reports and equipment/system status to the UA DAA processor.

2. The UA DAA processor receives data from surveillance sources and ownship data from the various UA systems. The UA DAA processor contains software that processes surveillance data to produce tracks. It is assumed the alerting algorithms are processed onboard the aircraft to help prioritize the track; however, some manufacturers may want to process the alerting through the CS DAA processor. The manufacturer needs to label the equipment appropriately so there is no mismatch of function between the equipment sets. With respect to the guidance processing function, this functionality may also be provided by the UA DAA processor, but is assumed in this architecture to reside in the CS DAA processor.
3. The UAS provides the UA DAA processor with the ownship state data, which may come from the primary navigation system and flight management system. It also sends mode control information to the UA DAA processor, which may come from the CS.
4. The CNPC airborne equipment sends packets of DAA data and other necessary information to the CS for UAS PIC operation. The airborne CNPC equipment also receives packets of data from the CS and will receive DAA mode inputs and maneuvers from the UA PIC.

Note: *The UA system architecture defined above may differ from that of an actual UA platform. Nonetheless, the manufacturer and designer need to ensure that the data from the UA provides the information necessary for the DAA system to meet the requirements defined herein.*

1.2.2 DAA System Description – Control Station

The DAA system in the CS consists of six major groups of entities as shown in Figure 1-3 and described below.

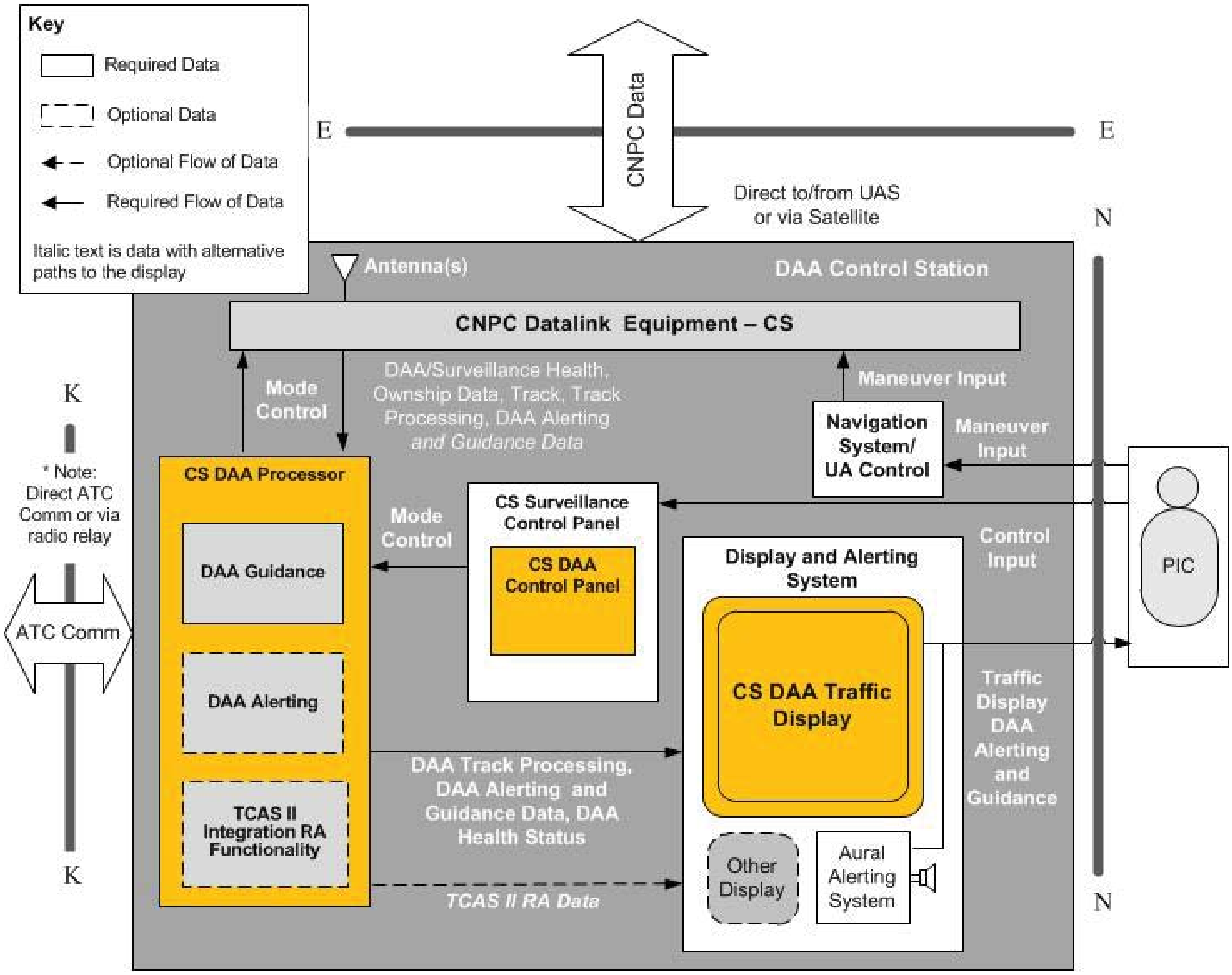


Figure 1-3 **Major Elements of the DAA System in the Control Station**

1. The CS CNPC equipment receives both UA DAA processor data and surveillance data from the UA. It may also receive guidance processing data, but it will depend on the system designer where these functions reside. The CS CNPC simultaneously sends packets of UA maneuver command data, mode control data and status data to the airborne CNPC equipment.
2. The CS DAA processor receives data from the CNPC equipment and processes the data, similar to the DAA processor onboard the UA. It sends DAA data to the necessary equipment to support DAA functionality and prioritization of alerting in the CS.
3. The DAA control panel provides the UAS PIC an interface to change the different modes/functionality of the DAA system. Paragraph 2.2.6 provides a detailed description of the mode controls.
4. The display system includes the DAA traffic display, other display(s) and aural alerting used by the UAS PIC to decide the actions necessary to maintain DWC.
5. The UAS PIC is the human controlling the UAS, acting on information provided by ATC, UA control equipment, and the DAA equipment.

6. The UA control/navigation system controls the aircraft operation. It allows the PIC to perform maneuvers, which may include changes in speed, bank, altitude and direction.

1.2.3 System Limitations

Operations of the DAA equipment complying to these MOPS specifically do not address:

1. Any visual separation clearance or flight under VFR.
2. Operations in the VFR traffic pattern of an airport.
3. Ground taxi operations.
4. Flights operating in Class A, B, or C airspace.
5. Detection of conditions such as terrain, ground obstructions, hazardous weather and wake turbulence.
6. Bird encounters. For certain operations, encounters with birds that could be detected by an airborne radar may be just as common as encounters with other aircraft. Estimated bird encounter rates are dynamic and depend on location, altitude, season, and time of day. In general terms, bird encounters may occur on the rough order of magnitude of once per hour or more.
7. All types of UAS.

1.3 Operational Application(s)

The DAA system will allow a UAS PIC to conduct IFR flight operations between an airport or launch/recovery zone, where another means of traffic separation is provided in Class A or Special Use Airspace (SUA). The Phase 1 MOPS of the DAA system will facilitate departures and arrivals in, and transition through Class D, E, or G airspace. This DAA system does not support operations on the airport surface, operations in the airport traffic pattern and operations in Class A, B or C airspace.[3]

These MOPS only address those UAS greater than 55 lbs, capable of carrying the required equipment, and meeting the aircraft performance maneuverability listed below and as detailed in Appendix D.

1. UA turn rate and airspeed comply with the following limits:
   a. For 1.5 degrees/second ≤ Turn Rate < 3.0 degrees/second:
      i. Below 10,000’ Mean Sea Level (MSL), 60 Knots True Air Speed (KTAS) ≤ airspeed ≤ 200 KTAS
      ii. Above 10,000’ MSL, 60 KTAS ≤ airspeed ≤ 600 KTAS
   b. For Turn Rate ≥ 3.0 degrees/second:
      i. Below 10,000’ MSL, 40 KTAS ≤ airspeed ≤ 200 KTAS
      ii. Above 10,000’ MSL, 40 KTAS ≤ airspeed ≤ 600 KTAS
2. UA capable of a roll rate of at least 5 degrees/second or greater.

[3] See FAA Aeronautical Information Manual (AIM) 4-3-3 or FAA Joint Order (JO) 7110.65W, §3-10-1; includes overhead maneuvers.

3. UA capable of a sustainable vertical rate of at least 500 feet per minute (fpm) for an altitude change of 500’ for vertical DAA maneuvers .
4. UA capable of making vertical accelerations of ±0.25 the acceleration of gravity (g) or greater.

Note:

1. *It is widely recognized that other systems may meet the functional and performance requirements contained in these MOPS, but it will be up to the system designer and regulator to determine the appropriateness of such systems.*
2. *The operational application of the DAA system defined by these Phase 1 MOPS was chosen to limit the scope of the committee’s initial work to a smaller subset of airspace in order to accommodate the resources available to the committee, and not to limit a user’s ability to access other airspace if that user can demonstrate compliance to the rules applicable to that other airspace.*

1.4 Intended Function

The intended functions of the DAA equipment built to the specifications in these MOPS are as follows:

1. Traffic Detection
2. Track Processing
3. DAA Alerting
4. Guidance to maintain DWC
5. Guidance to regain DWC when it has been lost
6. Display of Traffic
7. Integration of DAA alerting and guidance with TCAS II Resolution Advisories (Equipment Class 2 only)

1.5 Operational Goals

1.5.1 General

The DAA equipment functions are intended for UA operating above 400' AGL or outside the Part 107 rule. The UA should be capable of carrying all necessary equipment onboard, including sensors, processors, and support equipment, and capable of maneuvering as described in Subsection 1.3. The operational goals of the DAA equipment include:

1. Provide traffic information relative to the UA ownship position to the PIC. (an electronic means of compliance with 14 CFR Part 91 §§.111a, .113, .115, .123 and .181)
2. Provide timely alerts to the UAS PIC when traffic is approaching near or at the DWC boundary. See Appendix C for the DWC definition
3. Provide timely alerts to enable UAS PICs to coordinate with ATC when possible

4. Provide UAS PICs suggestive guidance for remaining DWC
5. When optionally equipped with a collision-avoidance system, be able to coordinate maneuvers with TCAS II-equipped aircraft.

1.5.2 Unmanned Aircraft (UA)

The UA is used or intended to be used for flight with no onboard pilot. The UA can be any type of airplane, helicopter, airship, glider (powered or unpowered), or powered-lift aircraft. Unmanned free balloons and unmanned rockets discussed in 14 CFR Part 101 are not considered UA. For the context of these MOPS, the UA should be able to carry the airborne portion of the DAA equipment, support the DAA intended function, and have the maneuver capability to act on DAA alerts and guidance information.

Note: *The surveillance equipment should also be able to identify false tracks or tracks of non-interest at a certain rate.*

1.5.3 UA DAA Surveillance Equipment

The UA DAA surveillance equipment includes the Air-to-Air Radar (ATAR) as defined in the MOPS for Air-to-Air Radar for Traffic Surveillance (RTCA Paper No. 170-16/ SC228 034), ADS-B In, and active airborne surveillance equipment. The operational goal of the UA DAA equipment is to detect surrounding airborne traffic relative to the ownship position. The equipment must be compliant with the performance requirements defined in their respective TSOs and in Subsection 2.2 of these MOPS.

1.5.4 DAA Alerting, Guidance Processing and DAA Traffic Display

The DAA Alerting and Guidance Processing functions reside in the UA DAA processor and CS DAA processor, respectively, and information is sent to the UA DAA Display. The operational goal is to provide information to the PIC so the PIC can make decisions that will influence the operation of the UA against traffic.

1.5.5 Control Station

The CS is a remote facility, which can be ground-based, ship-based, or air-based, that houses PIC controls for the UAS. The CS should be able to support the remote-based functions of the DAA system under all its intended operating conditions as defined in Subsection 2.3 of these MOPS.

1.5.6 Compatibility with Other Systems

A DAA system should not interfere with other system operations on the UA, in the CS or the NAS. This includes operation of the DAA system with and without an operable TCAS II system. The DAA should not degrade the performance of other aircraft equipped with TCAS II in applicable airspace classes. Degradation means increasing risk for the TCAS II aircraft or increasing undesirable alerting behavior (crossings and reversals). If the DAA system includes a collision avoidance function (Class 2), the DAA system will explicitly coordinate Collision Avoidance (CA) maneuvers with TCAS II-equipped intruders using standard messaging and coordination protocols. See Appendix M for TCAS interoperability requirements.

1.6 Assumptions

The design and operational performance requirements and guidelines presented in Section 2 of this document were developed based on the following assumptions. For any assumptions listed below that are not met as of the initial publishing date of these MOPS, the manufacturer will assure that the assumptions are valid through compliance to the applicable operating and airworthiness regulations.

1.6.1 Equipage and Airworthiness Assumptions.

1. The UA is equipped according to the applicable 14 CFR Part 91 rules for the airspace in which it is intended to operate, including, but not limited to §§.207, .215, .225, and .227. The UA will be equipped with communication, surveillance and navigation instruments and an anti-collision lighting system appropriate for IFR operation.
2. All equipment that supports or sends data to the DAA system is at a design assurance level appropriate for the intended function. This includes displays, power sources, circuit breakers, etc. For example, the UAS must be equipped with a CNPC data link that sufficiently supports all the necessary DAA functions. See Appendix A for lost link provisions.
3. The DAA Well Clear threshold was tuned to a level of risk (defined as the unmitigated probability of Near Mid-Air Collision (NMAC) given Loss of DAA Well Clear) to ensure interoperability with TCAS II alerting times and to support an airspace safety threshold appropriate for the operating assumptions specific to these MOPS.

1.6.2 Pilot-in-Command Assumptions

1. The UAS PIC is able to control the flight path of the UA under normal operating conditions.
2. The UAS PIC operates in compliance with Part 91 and/or FAA waivers/exemptions to make Part 91 applicable to UAS operations.
3. The UAS PIC is responsible for the safety of flight operations and is appropriately trained, rated and qualified with a pilot's certificate that allows this person to fly the UAS flight under IFR.
4. The UAS PIC is qualified to file an IFR flight plan and capable of accepting and complying with any instructions or clearances as directed by ATC, with the exception of visual clearances and delegated separation.
5. The UAS PIC has a means to communicate with ATC in the event of a CNPC failure.
6. The UAS PIC is rated or certified to operate the UAS with the DAA equipment.
7. The UAS PIC can command and/or reject DAA guidance/maneuvering under normal operating conditions. The UAS PIC is authorized operationally to use the DAA system to maintain DWC under the authority of 14 CFR Part 91, §§.111a, .3, .113, .115 and .181. Authorization to deviate from ATC control is the purview of ATC. The DAA system should provide the PIC with enough time for ATC coordination, but the PIC is the final authority (§91.3) in determining actions to avoid conflicting traffic and adhering to the right-of-way rules.
8. The UAS PIC minimizes deviation from a cleared flight plan to the extent possible to prevent encounters with other proximate traffic.
9. The UAS PIC will interact with control system equipment to observe DAA guidance and maneuver the UA remotely.

10. After the DAA alerting and guidance has stopped, thereby indicating that the ownship is DAA Well Clear of traffic, the UAS PIC will return the UA to its previously cleared flight plan as soon as practical. The PIC will coordinate with ATC when appropriate.

1.6.3 Operational Assumptions

1. Air Traffic Controllers are trained to manage UAS operations.
2. Supplemental procedures and controls will be developed by the operator for operations of the UAS when operating outside of the environment where DAA systems are approved for use, such as below the maneuvering floor of the system.
3. The DAA system operates in the environment defined in the Operational Services and Environment Description (OSED) in Appendix A and has the performance needed to meet the timeline assumptions defined in Appendix D. Use of DAA equipment meeting these MOPS for operations other than those defined in the OSED will require additional analysis, which, being out of scope, was not performed by RTCA SC-228.
4. All aircraft operating above 10,000' AGL are required to have some type of surveillance equipment.
5. The visual conspicuity of the UA will be similar to or larger than the visual conspicuity of a manned single-engine fixed wing aircraft.

1.6.4 Modeling and Simulation Assumptions.

Modeling and simulation was used to validate the performance required of the DAA system. The following list provides UA and traffic operating assumptions for the purposes of specifying tracking range requirements:

1. Above 10,000' AGL, the upper aircraft speed limit regardless of maneuverability is 600 KTAS.
2. Below 10,000' AGL, ownship UA aircraft fly at speeds up to 200 KTAS.
3. Below 10,000' AGL, cooperative intruder aircraft fly at speeds up to 291 KTAS.
4. Below 10,000' AGL, non-cooperative intruder aircraft fly at speeds up to 170 KTAS.

1.6.5 Control Station (CS) Assumptions

1. The CS will contain equipment for the PIC to observe traffic and control the UA to support DAA operation.
2. The PIC should be able to perform a DWC maneuver using the UA controls in the CS.
3. UA controls in the CS allow the PIC to enter and execute the DWC maneuver within 10 seconds (see note) of a DAA warning alert.
4. For Class 2 equipment installations, the PIC should be able to perform a vertical RA maneuver using the UA controls in the CS.
5. For Class 2 equipment installations, UA controls in the CS allow the PIC to enter and execute the maneuver within 5 seconds (see note) of a RA.

> ***Note:*** *This time does not include the time it takes the PIC to determine that a maneuver is necessary or how long the vehicle takes to complete the maneuver.*

1.6.6 Performance Assumptions for UA and Intruder Avionics

The following performance assumptions are based on the traffic demographics in the airspace that the UA is expected to encounter at the time these MOPS were published. It is expected that the UA and intruders are appropriately equipped for their intended operation. The operator is responsible for the integrity and performance of the DAA equipment as defined in this standard for continued safe operation in the NAS.

1.6.6.1 Performance Assumptions for UA Avionics

1. The UA pressure altimetry and reporting system will perform as well as or better than what was required per §91.217 at the time these MOPS were published.
2. The UA transponder system will perform as well as or better than what was required during per §91.215 at the time these MOPS were published.

   Note: *Acceptable performance of transponders and altitude systems for transponder-based surveillance is found in TSO-C10b, Altimeter, Pressure Actuated, Sensitive Type, and TSO C-88b, Automatic Pressure Altitude Reporting Code Generating Equipment, and TSO-C112e, ATCRBS/Mode S Airborne Equipment.*

3. The UA has an ADS-B Out System compliant with TSO-C166b.
4. The UA has a Global Positioning System (GPS) compliant with RTCA DO-229D,[4] MOPS for GPS/Satellite-Based Augmentation System Airborne Equipment.
5. The position source for the UA provides position updates at least once per second using World Geodetic System – 1984 (WGS-84) coordinates.
6. The availability, integrity and continuity of the CNPC data link are sufficient to support the allocation of the DAA control and command functionality to the UAS PIC. This assumption is met by installing a CNPC data link that complies with the performance defined in Appendix K:
   a. CNPC Link with 99.8% availability
   b. Required Link Performance (RLP) transaction expiration time: 2 seconds
   c. One-way RLP transaction time: 128 ms
   d. Two-way RLP transaction time: 256 ms.

1.6.6.2 Performance Assumptions for Cooperative Intruder Avionics

Cooperative aircraft carry and operate equipment for the purposes of surveillance. These aircraft transmit surveillance data directly from their onboard systems. The following are the performance assumptions for their onboard avionics:

[4] Change 1 to DO-229D, Minimum Operational Performance Standards for Global Positioning System/Satellite-Based Augmentation System Airborne Equipment, 01 February 2013

1. The pressure altimetry and reporting system of the cooperative aircraft will perform as well as or better than what is required per §91.217 at the time these MOPS were published.
2. The transponder system of the cooperative aircraft will perform as well as or better than what is required per §91.215 at the time these MOPS were published.
3. If equipped with ATCRBS, the cooperative aircraft meets the performance requirements of RTCA DO-144A, Minimum Operational Characteristics – Airborne ATC Transponder Systems [5]
4. If equipped with Mode S transponder, the cooperative aircraft meets the performance requirements of RTCA DO-181E.[6]
5. If equipped with ADS-B, the cooperative aircraft:
    a. Has a barometric altitude system that provides the same data to the transponder and ADS-B message reports, and
    b. Meets the performance requirements of RTCA DO-260B, Corrigendum 1, Minimum Operational Performance Standards for 1090 Megahertz (MHz) Extended Squitter (1090ES) Automatic Dependent Surveillance – Broadcast (ADS-B) and Traffic Information Services – Broadcast (TIS-B),[7] or
    c. Meets the performance requirements of DO-282B Corrigendum 1, Minimum Operational Performance Standards for Universal Access Transceiver (UAT) Automatic Dependent Surveillance – Broadcast.[8]
6. If equipped with TCAS II, the cooperative aircraft meets the performance requirements of Change 2 to RTCA DO-185B, MOPS for Traffic Alert and Collision Avoidance System II (TCAS II).[9]

Note: *Aircraft equipped with an ATCRBS transponder with a Mode A only reply are not considered cooperative and are detected by the ATAR.*

1.7 Test Procedures

The test procedures specified in this document are intended to be used as one means of demonstrating compliance with the performance requirements defined in Subsection 2.2. Although specific test procedures are cited, it is recognized that other methods may be preferred. These alternate procedures may be used if they provide at least equivalent information. In such cases, the procedures cited herein should be used as one criterion in evaluating the acceptability of the alternate procedures. Users of this document should not use the test procedures as a method of deriving the performance requirement.

---

[5] RTCA DO-144A, Minimum Operational Characteristics – Airborne ATC Transponder Systems, 02 October 2008
[6] RTCA DO-181E, MOPS for Air Traffic Control Radar Beacon System/Mode Select (ATCRBS/Mode S) Airborne Equipment, 17 March 2011
[7] RTCA DO-260B, Corrigendum 1, Minimum Operational Performance Standards for 1090 MHz Extended Squitter Automatic Dependent Surveillance – Broadcast (ADS-B) and Traffic Information Services – Broadcast (TIS-B), 13 December 2011
[8] DO-282B, Corrigendum 1, Minimum Operational Performance Standards for Universal Access Transceiver (UAT) Automatic Dependent Surveillance – Broadcast, 13 Dec 2011
[9] RTCA DO-185B Change 2, MOPS for Traffic Alert and Collision Avoidance System II (TCAS II), 20 March 2013

The order of tests specified suggests that the equipment be subjected to a succession of tests as it moves from design to design qualification to operational use. For example, compliance with the requirements of Section 2 need to have been demonstrated as a precondition to completion of the installed system tests of Section 3.

1. Environmental Tests

   a. Environmental test requirements are specified in Subsection 2.3 and Appendix J

   b. The procedures and their associated limits are intended to provide a laboratory means of determining the electrical and mechanical performance of the equipment under environmental conditions expected to be encountered in actual operations, including those environments that might affect optical or antenna performance.

   c. Unless otherwise specified, the environmental conditions and test procedures used to demonstrate equipment compliance for both the airborne and CS equipment are identified in Paragraph 2.3.2 and Paragraph 2.3.3, respectively.

2. Bench Tests

   Bench test procedures are specified in Subsection 2.4. These tests provide a laboratory means of demonstrating compliance with the requirements of Subsection 2.2. Test results may be used by equipment manufacturers as design guidance for monitoring compliance, and, in certain cases, for obtaining formal approval of equipment design.

3. Installed Equipment Considerations

   a. Tests for installed equipment are included when performance cannot be adequately determined through bench testing.

   b. Test procedures and associated limits for installed equipment are specified in Section 3. Although bench and environmental test procedures are not included in the installed equipment test, their successful completion is a precondition to completion of the installed test. In certain instances, however, an installed equipment test may be used in lieu of bench test simulation of such factors as power supply characteristics, interference from or with other equipment installed on the aircraft, etc. Installed tests are normally performed under two conditions:

      i. With the aircraft on the ground using simulated or operational system inputs
      ii. With the aircraft in flight using operational system inputs appropriate to the equipment under test.
      Test results may be used to demonstrate functional performance in the intended operational environment.

4. Operational Tests

   The operational tests are specified in Section 4. These test procedures and their associated limits are intended to be conducted by operating personnel as one means of ensuring that the equipment is functioning properly and can be reliably used for its intended function(s).

1.8 Definitions of Terms

A list of definitions, acronyms and abbreviations used in this document can be found in Appendix B.

1.9 References

The following documents contain information necessary for the complete definition and understanding of these MOPS. They are referenced by code-letter throughout this document.

A. L. Fern, R.C. Rorie, J.S. Pack, R.J. Shively, and M.H. Draper. "An evaluation of Detect and Avoid (DAA) displays for unmanned aircraft systems: The effect of information level and display location on pilot performance." In *Proceedings of the 15th American Institute of Aeronautics and Astronautics (AIAA) Aviation Technology, Integration, and Operations Conference*, 2015.

B. J.S. Pack, M.H. Draper, S.J. Darrah, M.P. Squire, and A. Cooks. "Exploring performance differences between UAS sense-and-avoid displays." In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, vol. 59, no. 1, pp. 45-49, 2015.

C. R.C. Rorie, and L. Fern. "The impact of integrated maneuver guidance information on UAS pilots performing the Detect and Avoid task." In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, vol. 59, no. 1, pp. 55-59, 2015.

D. Santiago, C., and E.R. Mueller. "Pilot Evaluation of a UAS Detect-and-Avoid System's Effectiveness in Remaining Well Clear," *Eleventh USA/Europe Air Traffic Management Research and Development Seminar (ATM2015)*, Lisbon, Portugal, 2015.

E. Mueller, C. Santiago and S. Watza. "Piloted 'Well Clear' Performance Evaluation of Detect-and-Avoid Systems with Suggestive Guidance," National Aeronautics and Space Administration (NASA) TM-2016-219396, 2016, in publication.

F. Mueller, D. Isaacson, and D. Stevens. "Air Traffic Controller Acceptability of Unmanned Aircraft System Detect and Avoid Thresholds," NASA TM-2015-219392, 2016, in publication.

G. R.C. Rorie, L. Fern, and R.J. Shively. "The impact of suggestive maneuver guidance on UAS pilots performing the detect and avoid function." *AIAA Infotech@ Aerospace*, 2016.

H. R.C. Rorie and L. Fern. "An interoperability concept for detect and avoid and collision avoidance systems: Results from a human-in-the-loop simulation." *19th Annual International Conference on Unmanned Aircraft Systems*, Amsterdam, The Netherlands, 2016, in publication.

I. R.C. Rorie, L. Fern, and R.J. Shively. "The impact of suggestive maneuver guidance on UAS pilots performing the detect and avoid function." *AIAA Infotech@ Aerospace*, 2016.

J. Edwards, M. An Analytic Approach to Deriving Surveillance Accuracy Requirements for UAS Detect and Avoid Systems (slides). Massachusetts Institute of Technology Lincoln Laboratory (MIT LL), 2015.

1.10 Aircraft Equipment Information Vulnerabilities

Aircraft equipment information vulnerabilities (such as cybersecurity risks) have been present for digital systems since the development of the Personal Computer (PC) in the late 70s and even longer for Radio Frequency (RF) systems, and the advent of internet connectivity has substantially increased those risks. Internet and Wireless Fidelity (Wi-Fi) connectivity have become popular as a means for aircraft or equipment manufacturers to update installed avionics software, to update databases, or provide an alternate means of communicating with the flight crew or cabin (e.g., in-flight entertainment, weather, etc.).

In most countries, the State provides oversight of safety-of-flight systems (sometimes referred to as “authorized services”), which provide information to aircraft, such as an Instrument Landing System (ILS), VHF Omnidirectional Range Radar (VOR), Global Navigation Satellite System (GNSS), and Distance Measuring Equipment (DME), to name a few. However, the State typically does not provide oversight on “non-trusted”[10] connectivity such as the internet, Wi-Fi, or manufacturer-supplied equipment interfaces that permit input of externally-supplied data into aircraft systems. A manufacturer may expose aircraft information vulnerability through equipment design, or introduce vulnerability as a result of being connected to a common interface. Therefore, it is important that manufacturers consider aircraft information security risk mitigation strategies in their equipment design, particularly when the equipment is responsible for an interface between the aircraft and aircraft-external systems.

Apart from any specific aircraft-information-security-related performance requirements contained in these MOPS, it is recommended that manufacturers look at a layered approach to aircraft information security risk mitigation that includes both technical (e.g., software, signal filtering) and physical strategies. From a technical perspective, for example, this could include signal spoofing detection capabilities or more stringent, multi-factored authentication techniques such as passwords, Personal Identification Numbers (PINs), and digital certificates. From a physical perspective, for example, such as in an in-flight entertainment system in the cabin, a manufacturer could consider connectors that require special tools to remove to prevent passenger tampering. And finally, but just as important, manufacturers should consider supply chain risk management; for example, if a manufacturer is outsourcing software code development, is the contractor and its staff properly vetted?

Civil aviation authorities have a regulatory interest when an applicant’s design makes use of a non-trusted connectivity where the installation can potentially introduce aircraft information security vulnerability. This requires the applicant to address not only the information security vulnerabilities and mitigation techniques for the new installation, but to also consider how vulnerability could propagate to existing downstream systems. Therefore, it is recommended that manufacturers reference their equipment aircraft information security review and mitigation strategies in the equipment’s installation manual so that the applicant can consider them in meeting the installation regulatory requirements.

[10] A “non-trusted” connectivity (sometimes referred to as third-party system) is any frequency or service where an Air Navigation Service Provider (ANSP) is not providing direct monitoring/protection.

This Page Intentionally Left Blank

2 Equipment Performance Requirements and Test Procedures

2.1 General Requirements

2.1.1 Airworthiness

In the design and manufacture of the equipment, the manufacturer **shall (002)** provide for installation so as not to impair the airworthiness of the aircraft.

2.1.2 Intended Function

The equipment **shall (003)** perform its intended function(s), as defined by the manufacturer, and its proper use **shall (004)** not create a hazard to other users of the National Airspace System.

2.1.3 Federal Communications Commission Rules

All equipment **shall (005)** comply with the applicable rules of the Federal Communication Commission (FCC).

2.1.4 Fire Protection

All materials used **shall (006)** be self-extinguishing except for small parts (such as knobs, fasteners, seals, grommets and small electrical parts) that would not contribute significantly to the propagation of a fire.

Note: *One means of showing compliance is contained in Federal Aviation Regulations (FAR), Part 23, Appendix F.*

2.1.5 Operation of CS Controls

The equipment **shall (007)** be designed so that CS controls intended for use during flight cannot be operated in any position, combination or sequence that would result in a condition detrimental to the reliability of the equipment or operation of the aircraft.

2.1.6 Accessibility of Controls

Controls that do not require adjustment during flight under any conditions (i.e., normal, abnormal, or emergency) **shall (008)** not be readily accessible to the flight crew.

2.1.7 Effects of Test

The equipment **shall (009)** be designed so that the application of specified test procedures is not detrimental to equipment performance following the application of the tests, except as specifically allowed.

2.1.8 Equipment Interfaces

DAA equipment **shall (010)** be designed such that, when properly installed, it will not adversely affect the operation of the other equipment.

2.1.9 Design Assurance

Design Assurance Levels (DAL) should be adequate to mitigate the failure classification appropriate to the contribution of the equipment to a UAS-level failure in the aircraft in which it is to be installed. The DAL appropriate for a given hazard classification is not the same for all aircraft types, and the contribution of the equipment to an UAS-level failure may vary depending on the UAS and other installed equipment.

2.1.10 DAA Equipment Classes and Articles

Table 2-1 defines the DAA equipment classes by functionality in context of the UAS DAA architecture found in Figure 1-2 and Figure 1-3.

It is subdivided further into DAA equipment articles. This allows modular integration of the DAA system and allows DAA equipment manufacturers to build and design separate articles based on specific paragraphs of this standard. However, equipment manufacturers are responsible for the detailed interfaces between articles (e.g., Aeronautical Radio Incorporated (ARINC) standards, Interface Control Documents (ICDs)) and must ensure separate articles designed to work together have compatible interfaces. Appendix O cross-references articles and compliance with the requirements in Subsection 2.2.

2.1.10.1 DAA Equipment Classes

The purpose of classifying the equipment is to enable differences in the standard to allow different configurations. There are two DAA equipment classes. Equipment Class 2 builds from Equipment Class 1 and provides additional capabilities. This is the case for this version of these MOPS, but may change in following revisions. The DAA equipment classes are as follows:

1. Equipment Class 1 contains the basic DAA equipment. It requires a minimum of three airborne surveillance technologies for detecting traffic: ADS-B In, active surveillance and an ATAR system. It also includes the UA DAA processor, CS DAA processor, CS DAA traffic display, and CS DAA mode control panel. Together they meet the intended functions defined in Subsection 1.4.
2. Equipment Class 2 is an Equipment Class 1 that integrates a TCAS II system. The active surveillance article is replaced by a TCAS II, Version 7.1 system with Hybrid Surveillance and modifications to accommodate DAA functionality; specifically, the DAA guidance alerts replace the TCAS traffic advisory functionality. This type of equipment requires the UAS to perform a coordinated RA with equally equipped TCAS II intruder aircraft.

2.1.10.2 DAA Equipment Articles

The DAA equipment has five key articles. They work together to enable the DAA equipment class functionality. The five DAA equipment articles are listed in Table 2-1.

Table 2-1 Equipment Classifications and Article Designations

<table>
<tr><th>Class (Note 1)</th><th>Equipment</th><th>DAA Article Designation</th><th>DAA Equipment Article Name</th><th>Function</th></tr>
<tr><td rowspan="4">1</td><td rowspan="4">DAA – Basic (Note 1, Note 2)</td><td>-</td><td>Air-to-Air Radar (ATAR)</td><td>Radar Track Detection</td></tr>
<tr><td>A</td><td>Active Surveillance</td><td>ATCRBS/Mode S Intruder Detection, TCAS II Mode Data, CA Coordination Data</td></tr>
<tr><td>-</td><td>ADS-B In</td><td>Reception of ADS-B Messages, TCAS Coordination Data via ADS-B</td></tr>
<tr><td>B</td><td>UA DAA Processor</td><td>Track Processing and Alerting</td></tr>
</table>

Class (Note 1)	Equipment	DAA Article Designation	DAA Equipment Article Name	Function
		C	CS DAA Processor	DAA Guidance, DAA Display Processing
		D	CS DAA Control Panel	DAA Mode Control
		E	CS DAA Traffic Display	Traffic, Alerting, and Guidance Band Display
2	DAA with TCAS II (Note 2, Note 3, Note 4)	-	ATAR	Radar Track Detection
		A	TCAS II, Version 7.1	ATCRBS/Mode S Intruder Detection, TCAS II RA Status and Coordination Data, CAS Logic, Hybrid Surveillance
		-	ADS-B In	Reception of ADS-B Messages,
		B	UA DAA Processor	Track Processing and Alerting
		C	CS DAA Processor	DAA Guidance, DAA/TCAS II Display Processing
		D	CS DAA Control Panel	DAA Mode Control with TCAS II Integration
		E	CS DAA Traffic Display	Traffic, Alerting, Guidance Band, and RA Display

Note:

1. *These classes do not address automation of DAA maneuvers. The DAA articles may need additional functions to accommodate automation. It is anticipated that there will be differences in DAA equipment hardware and software to accommodate automated features. Therefore, later versions of these MOPS may reflect automation with separate designations than those that rely solely on the PIC to maneuver the UAS.*

2. *These classes do not address implementations of Airborne Collision Avoidance System Model X (ACAS X) (and other future collision avoidance systems). They will be included in later revisions to this classification scheme, when available.*

3. *These MOPS do not specify MOPS for Air-to-Air Radar (ATAR) for Traffic Surveillance, Universal Access Transceiver (UAT) Automatic Dependent Surveillance - Broadcast, MOPS for 1090 MHz Automatic Dependent Surveillance – Broadcast, MOPS for Traffic Alert and Collision Avoidance System II (TCAS II), or MOPS for Traffic Alert and Collision Avoidance System II (TCAS II) Hybrid Surveillance. These standards are found in the MOPS for Air-to-Air Radar for Traffic Surveillance (RTCA DO-TBD, (RTCA Paper No. 170-16/SC228-034)), RTCA DO-282B, DO-260B, DO-185B Change 2 and RTCA DO-300A,[11] respectively.*

[11] DO-300A, Change 1 – Minimum Operational Performance Standards (MOPS) for Traffic Alert and Collision Avoidance System II (TCAS II) Hybrid Surveillance, 15 December 2015

4. *In order to install and operate TCAS II with RA functionality with DAA, the UAS installation must meet the TCAS II pilot response and aircraft performance assumptions. These MOPS do not address automation of TCAS RA maneuvers. A system using automated RA maneuvers may need additional functions, safety assessments and requirements, different hardware reliably requirements, and/or software DAL level setting, to accommodate automation. That type of analysis is beyond the scope of these MOPS.*

2.2 Equipment Performance Requirements – Standard Conditions

2.2.1 General Equipment Characteristics

2.2.1.1 Latency

Since latency is addressed in each of the functional performance sections of these MOPS. There are latency allowances for ADS-B, radar, active surveillance, DAA tracker, DAA alerting algorithm, CNPC data link, DAA guidance processing, DAA display and command-to-execute; the table below was extracted from Appendix E and summarizes the maximum allowable latencies, and where the requirements on latency performance can be found.

Table 2-2 **Allowable Latency Contributions for DAA Subsystems**

Subsystem	Total Latency (seconds)	Latency Compensation Error (ms)	Source of Requirement
ADS-B (1090ES/UAT)	2.5	-200/+400	DO-260B/282B
ADS-B (ADS-R)	3.5	-300/+500	DO-260B/282B
ATAR	0.5	30	MOPS for Air-to-Air Radar for Traffic Surveillance (RTCA DO-TBD, (RTCA Paper No. 170-16/SC228-034)).
Active Surveillance (Mode C/S)	1.0	500	DO-185B
DAA Tracker	1.0	100	§2.2.3.2.3
DAA Alerting Algorithm	0.1	0	§2.2.4.3.4.1
CNPC Data Link	Max: 2.0 Nominal: 0.2	0	Appendix K
DAA Guidance Processing	0.2	0	§2.2.4.4
DAA Display	0.5	0	§2.2.5.4.1
Command-To-Execute	Max: 2.0 Nominal: 0.2	0	Appendix K

2.2.1.2 UA DAA Surveillance Equipment

The onboard DAA surveillance equipment provides surveillance coverage for a mixture of aircraft equipage configurations at the maximum aircraft densities as described in the

OSED. Sensors are required to detect the traffic (Interface A in Figure 2-1) that surrounds the UA; depending on the equipage of the intruder aircraft, the sensors required to detect them vary. For these MOPS, three surveillance sources are required: ADS-B In, active surveillance, and ATAR. Optical and other advanced sensors may be developed and included in future revisions.

Intruders can either be categorized as cooperative or non-cooperative. Cooperative intruders carry equipment that allows the ownship to receive state information about the intruder, while non-cooperative intruders are “silent” and all state data must be determined by sensors onboard the ownship. Under these MOPS, sensors used to detect cooperative intruders are active surveillance and ADS-B receivers. Non-cooperative targets, i.e., those that have no transponder or ADS-B broadcast capability, are detected via an onboard radar sensor.

2.2.1.3 Air-to-Air Radar(ATAR)

The ATAR is an airborne sensor that **shall (014)** comply with the MOPS for Air-to-Air Radar for Traffic Surveillance (RTCA DO-TBD, (RTCA Paper No. 170-16/SC228-034)). ATAR is the main surveillance source for non-cooperative intruders in a DAA system. The intended function of the radar is to generate tracks for all intruders within the radar detection volume. The radar can operate in the C, X, or Ku frequency bands of the Aeronautical Radio Navigation Spectrum (ARNS). Usage of a particular frequency will depend on the type of operation and may require coordination with the FCC (at the time these MOPS were published, many of the frequencies overlapped currently used aviation frequencies, which could degrade performance). The onboard radar will be the sole surveillance sensor for all aircraft that do not carry transponders or ADS-B equipment. The DAA system also makes use of radar data to validate ADS-B data.

2.2.1.4 Airborne Active Surveillance

The airborne active surveillance **shall (015)** comply with Paragraph 2.2.3 of these MOPS. It uses a 1030 MHz transmitter to interrogate transponders within a defined range of the ownship, and a 1090 MHz receiver to process replies. This enables measurement of the relative aircraft position and reception of the intruder’s barometric pressure altitude via the reply. The active surveillance also receives coordination information to comply with TCAS interoperability requirements. Active surveillance uses different methods to track ATCRBS vs. Mode S targets. The surveillance performance varies between the two methods: Mode S aircraft can typically be tracked at longer ranges than ATCRBS targets and have slightly better range accuracy.

2.2.1.5 Automatic Dependent Surveillance-Broadcast (ADS-B) System

1. The ADS-B system **shall (016)** comply with RTCA DO-260B, 1090ES receiver, Equipage Class A1 or higher. The ADS-B system detects aircraft equipped with ADS-B Out. As a minimum, it detects intruder aircraft with TSO-C154, TSO-C199, Class A or B, TSO-C166 Class A or B equipage. The UAS ADS-B In system detects broadcasts directly from intruder aircraft or through ADS-R. The ADS-B In system also receives coordination information to comply with TCAS interoperability requirements.
2. Optionally, if the DAA system has a UAT receiver, it **shall (017)** comply with RTCA DO-282B.

Note: *In addition, the DAA system may use a TCAS II system that also supports 1090ES reception compliant with RTCA DO-260B since it has a 1090 MHz receiver. Requirements for ADS-B 1090ES receivers shared with a TCAS II receiver are contained in RTCA DO-260B, and with Hybrid surveillance in DO-300A.*

2.2.1.6 Traffic Alert and Collision Avoidance System Model 2 (TCAS II) (Class 2)

TCAS II system detects RA status and coordination data from TCAS II-equipped aircraft. If equipped, it **shall (018)** comply with Paragraph 2.2.3 of these MOPS. At a minimum it coordinates RAs with TCAS II equipped intruder aircraft. The UA acts as a peer to the intruder aircraft. The UA TCAS II operates in RA mode for Equipment Class 2 and conforms to all applicable interoperability requirements in Appendix M of these MOPS. See Subsection M.14 for a mapping of requirements.

2.2.2 DAA Input/Output (I/O) Requirements

This paragraph follows the format of listing requirements for certain data in the first interface that it occurs. The following subparagraphs in which that data item is required will refer back to the prior subparagraphs, so that only new requirements are listed in subsequent subparagraphs.

Figure 2-1 shows the data inputs and outputs (denoted by the directional arrows) to and from the DAA equipment.

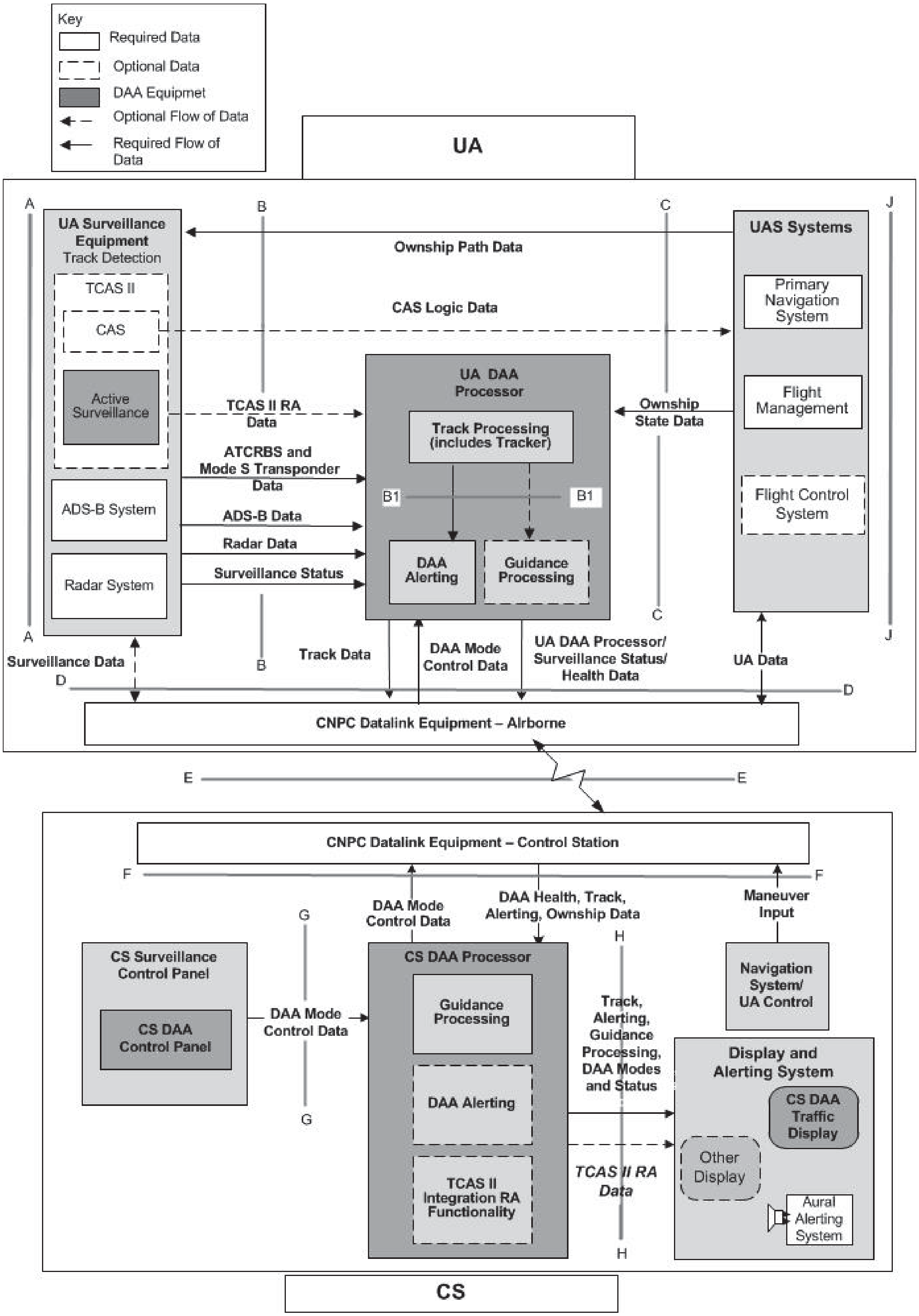


Figure 2-1 DAA Input/Output Data Diagram

There are five (5) main subsystems that comprise the DAA equipment. They include:

1. **UA Surveillance Equipment:** This includes ATAR, ADS-B In, and Airborne active surveillance (Equipment Class 1) or TCAS II, Version 7.1 (Equipment Class 2).
2. **UA DAA Processor**: This processor is installed onboard the UA. It receives (1) ownship data, (2) data from onboard surveillance equipment, and (3) CNPC data. It then processes the data and sends track and other DAA information to the CNPC for transmission to the CS. For Class 2 equipment, the UA DAA receives TCAS II data in addition to the other surveillance data. Additional data that can be passed to the UA DAA processor includes ownship flight path data, and flight control guidance data to the automatic Flight Control System (FCS).
3. **CS DAA Processor**: This processor is installed in the CS. It receives (1) prioritized track data and DAA status data from the UA DAA system via the CNPC system, and (2) DAA mode control commands from the CS DAA control panel. It then processes the data, forwards the information to the DAA display and aural annunciation system. Similarly, it forwards DAA mode control and command data to the CNPC system.
4. **CS DAA Mode Control Panel:** This is the interface between the PIC and the UA and CS DAA processors. It receives DAA status information from the CS DAA processor while sending command and control information to the CS DAA processor.
5. **CS DAA Traffic Display**: The display and aural alerts provide traffic information to the PIC. The display and aural speakers may be part of a dedicated DAA equipment kit or can be part of a pre-existing system. They receive data from the CS DAA processor.

2.2.2.1 UA DAA Processor Input Data Requirements

Table 2-3 DAA Ownship State Data Input

Ownship Data Element	Notes
Time of Applicability (ToA)	Note 1
Horizontal Position Latitude/Longitude	Notes 1, 2
Horizontal Position Uncertainty	Note 3
Horizontal Position Integrity	Note 3
Horizontal North/South (N/S) Velocity	
Horizontal East/West (E/W) Velocity	
Horizontal Velocity Uncertainty	Notes 3, 4
Geometric Altitude	
Geometric Altitude Uncertainty	Notes 1, 3
Vertical Rate	
Vertical Rate Uncertainty	
Barometric Pressure Altitude	
24-bit ICAO Address	
Airborne/Ground State	Note 5
True Heading	Note 6
Roll	
Pitch	
Roll Rate	

Ownship Data Element	Notes
Pitch Rate	
Heading Rate	
Validity Information	Note 9

The DAA processor receives data as defined in the following subparagraphs.

2.2.2.1.1 Ownship State Data

This subparagraph defines the ownship data (Interface C) supplied to the UA DAA processor from onboard equipment (see Notes 1, 6, and 7, below).

1. The UA DAA processor **shall (019)** receive the ownship state data in Table 2-3.

   Note:

   1. *ToA of the ownship state data is received from the ownship position sources and all sources should be synchronized within 30 milliseconds (ms). It does not have to be synchronized to UTC and can be independent of GPS failures. In an unsynchronized installation, time of receipt may be used to represent TOA.*
   2. *Horizontal position is based on reference to WGS-84 latitude/longitude from the ownship position sources.*
   3. *Ownship data quality is very similar to traffic data quality. However, the data that comes directly from the ownship position source is generally not yet categorized into Navigation Integrity Category (NIC), Navigation Accuracy Category (NAC) and Source Integrity Level (SIL) values.*
   4. *The horizontal velocity accuracy performance may be established by analysis of the installed equipment, and then will need to be evaluated during the certification/installation process.*
   5. *Airborne/Ground state determination on UAS may require algorithms based on inputs from multiple sensors to accurately detect the airborne/ground status. The A/G state should be the same state as determined by the onboard transponder to report airborne/on-the-ground state per RTCA DO-181E.*
   6. *True heading is required to satisfy the DAA display requirements, thus implies the UA system has a magnetic variation table for any necessary conversion.*
   7. *The term "position source" used in this document is a potential valid source of position and velocity information that may be used by DAA equipment. It is not meant to imply that the same source is used for navigating the aircraft.*
   8. *A DAA position source may have a position, velocity or vertical rate blended from multiple sensors (e.g., an Inertial Reference System (IRS) and the Global Navigation Satellite System (GNSS)).*
   9. *Indication of failure, degradation or validation of the sources will be sent to the DAA processor.*

2. The UA DAA processor **shall (020)** use the same position source for all of the following ownship parameters (see Notes 6 and 7, above):

a. Horizontal position

i. Latitude
ii. Longitude
iii. Horizontal position accuracy data (e.g., the 95% Accuracy Figure of Merit for Horizontal Position (HFOM) (see RTCA DO-260B))
iv. Horizontal position integrity data (e.g., the Horizontal Integrity Limit (HIL) (see RTCA DO-260B))

b. Horizontal velocity

i. North/South (N/S) Velocity
ii. East/West (E/W) Velocity
iii. Horizontal velocity accuracy data (e.g., the 95% Accuracy Figure of Merit for Horizontal Velocity (HFOMR) (see RTCA DO-260B))

c. Geometric vertical position

i. Height Above the Ellipsoid (HAE) (WGS-84)
ii. Vertical Figure of Merit (VFOM (see RTCA DO-260B)) (the 95% vertical accuracy)

d. Vertical Rate

e. Vertical Velocity Figure of Merit (VFOMR) (see RTCA DO-260B)

f. SIL, if dynamically sent

3. If the ownship position source has not provided updated position data for more than 2.6 seconds, the DAA **shall (021)** flag the data source as invalid for DAA functionality.

4. When the position source indicates that there is a non-isolated signal-in-space fault detected, no data from that source **shall (022)** be accepted.

5. If the horizontal position data from a position source is not valid (i.e., validation flag), then no data from that source **shall (023)** be accepted.

6. The horizontal ownship position **shall (024)** be considered invalid for the DAA functionality whenever:

   a. The 95% bound of horizontal position uncertainty exceeds 0.1 NM (NACp < 7), or

   b. The horizontal position integrity bound exceeds 0.3 NM, or

   c. The SIL is greater than $1E^{-7}$, or

   d. The ownship horizontal velocity uncertainty exceeds 10 meters per second (m/s) (see Note 4, above).

7. The ownship pressure altitude **shall (025)** be considered invalid for the DAA functionality whenever:

   a. The pressure altitude sensor has failed, or

   b. The system providing the pressure altitude information to the DAA system indicates the pressure altitude information is invalid.

2.2.2.1.1.1 Flight Intent Data

DAA flight intent data is an optional input for the UA DAA processor that contains data related to the UA path or intent (e.g., waypoints). This may include autopilot/autoflight information to indicate to the DAA system what data is in use, e.g., flight plan versus heading hold. Data may be used to aid the alerting logic within the track evaluation function.

2.2.2.1.2 ATAR Intruder Data

This subparagraph defines the data supplied to the UA DAA processor from an onboard ATAR capability (Interface B). The requirements specified in this subparagraph are meant to define the minimum required set of ATAR traffic data needed to support UA DAA processing. Requirements specific to the ATAR system and data link can be found in the MOPS for Air-to-Air Radar for Traffic Surveillance (RTCA DO-TBD, (RTCA Paper No. 170-16/SC228-034)).

The UA DAA processor **shall (027)** at a minimum receive the data listed in Table 2-4 from the ATAR.

Table 2-4 Radar Input Data

Radar Intruder Data	Notes
Time of Applicability	Note 1
Track Identifier (ID)	Note 2
Slant Range	Note 3
Slant Range Accuracy	
Range Rate	
Range rate Accuracy	
Elevation Angle	Note 4
Elevation Angle Accuracy	
Azimuth Angle	
Azimuth Angle Accuracy	
Track Priority Number	Note 5
Measured/Estimated Flag	
End of Track Coasting Flag	
Status Flag	

Note:

1. *TOA of the radar track should be synchronized within 30 ms with the ownship position sources. Timestamps should be based on time of measurement or time of estimate.*
2. *The radar track ID is a unique identifier that identifies the traffic for which data is being provided.*
3. *Radar range may be represented as slant range relative to the ownship's position.*
4. *The radar may provide relative altitude if it receives and processes ownship altitude.*

5. *Priority of the track based on the measurement per the MOPS for Air-to-Air Radar for Traffic Surveillance (RTCA DO-TBD, (RTCA Paper No. 170-16/SC228-034)).*

2.2.2.1.3 Active Surveillance Intruder Data

This subparagraph defines the data supplied to the UA DAA processor from an airborne active surveillance system (Interface B). The requirements specified in this subparagraph are meant to define the minimum required set of ADS-B traffic data needed to support UA DAA processing. Requirements specific to the airborne active surveillance system can be found in the MOPS for airborne active surveillance systems (RTCA DO-185B) and UAS (RTCA DO-300A)

subparagraph defines the data supplied to the UA DAA processor from an airborne active surveillance system (Interface B).

Note: *The requirements of this subparagraph are for DAA systems that receive active surveillance data from a fully compliant onboard TCAS II system designed to RTCA DO-185B (Equipment Class 2) and meet the interoperability requirements of Appendix M or from the active surveillance function of such equipment as contained in Subparagraph 2.2.3.1.1 (Equipment Class 1).*

The UA DAA processor **shall (519)** receive the data defined in Subparagraph 2.2.4.8.1a of RTCA DO-185B, as modified by Paragraph 2.2.11 of RTCA DO-300A. Data for both active and passively tracked aircraft **shall (520)**be received with an indication of whether the update is from active or passive measurement per Paragraph 2.2.11 of RTCA DO-300A. In addition, the complete surveillance report **shall (521)**be provided per Subparagraph 2.2.4.8.1b of RTCA DO-185B to indicate that all surveillance reports for the current surveillance update interval have been delivered.

Note:

1. *Per RTCA DO-185B requirements, the nominal surveillance update interval is one second. Traffic above the 60-second tau (tau as defined in RTCA DO-185B, §2.2.4.6.2.2.3) are updated once every 5 seconds or less when passively updated via hybrid surveillance.*
2. *Tracks from TCAS II with hybrid surveillance that are validated with an active surveillance measurement are considered validated for DAA purposes per Subparagraph 2.2.3.2.1.3.4.1. However, when an aircraft is below the 60-second tau, no validation is performed by TCAS and only active measurements are provided. In this case, DAA must use the active measurements to validate the ADS-B data.*

The UA DAA processor **shall (028)** at a minimum receive the data listed in Table 2-5 from an onboard active surveillance system for ATCRBS and Mode S targets.

Note: *A TCAS system certified to RTCA DO-185B MOPS provides an active surveillance capability, but is not required to provide the track data necessary for purposes of DAA. The minimum required track data output by TCAS systems is sufficient for use on TCAS displays only, and not sufficient for DAA. However, manufacturers have introduced the ability to output additional and/or different* *track data for use in various ADS-B applications. Data provided for the purposes of DAA can be provided over such an interface as well, if consistent with this subparagraph and Subparagraph 2.2.3.1.1.*

Table 2-5 **Traffic Data Input from Onboard Active Surveillance**

Active Surveillance Track Data	Notes
Track ID	Note 1
24-bit Mode S Address	Note 2
Slant Range	
Relative Bearing	Note 4
Barometric Pressure Altitude	
Altitude Quantization	Note 5
Time of Applicability	
Range Valid Flag	Note 6
Altitude Valid Flag	Note 6
Bearing Valid Flag	Note 6
TCAS Equipage	Note 7
Active/Passive Flag	Note 8
TCAS Coordination Data	Note 9

Note:

1. *The active surveillance track ID is a unique identifier that identifies the traffic for which data is being provided.*
2. *The 24-bit Mode S address is not provided for traffic equipped only with ATCRBS transponders. ATCRBS traffic is denoted by the address field set to 0.*
3. *N/A, note removed*
4. *Bearing measurements may not be available for every active surveillance track.*
5. *Altitude quantization is reported as either 25' or 100'.*
6. *Validity flags indicate if the data in the applicable field is available for the current surveillance update interval.*
7. *Equipage is detected by the active surveillance function, including TCAS equipage:*
    - *Transponder equipage: Mode C or Mode S, 2)*
    - *TCAS equipage: No TCAS, TCAS in Traffic Advisory (TA) Only Mode, or TCAS in TA/RA Mode.*
8. *Per Subparagraph 2.2.3.1.1, the active surveillance function indicates whether the measurement is from active or passive surveillance.*
9. *See Subparagraph 2.2.2.1.5 for TCAS RA and coordination data input requirements from active surveillance*

2.2.2.1.4 ADS-B In Intruder Data

This subparagraph defines the data supplied to the UA DAA processor from an onboard ADS-B In capability (Interface B). The requirements specified in this subparagraph are meant to define the minimum required set of ADS-B traffic data needed to support UA DAA processing. Requirements specific to the ADS-B system and data link can be found in the MOPS for 1090ES (RTCA DO-260B) and UAT (RTCA DO-282B).

1. The UA DAA processor **shall (029)** at a minimum receive ADS-B 1090ES data. The UA DAA processor may optionally receive 978 MHz UAT data from the onboard ADS-B system.
2. ADS-B reports received by the UA DAA processor **shall (030)** contain a field identifying its source (i.e., 1090ES Direct Receive, UAT Direct Receive, or UAT via ADS-R).
3. If there is no UAT system onboard, the UA DAA processor **shall (031)** receive ADS-R.
4. Traffic Information Services-Broadcast (TIS-B) reports **shall (032)** not be used for DAA functionality.

Note:

1. *The 978 MHz data link cannot be used in lieu of the 1090 MHz frequency, but may be used in addition to the 1090 MHz frequency.*
2. *The 978 MHz frequency is close to the CNPC link frequency band selected for RTCA DO-362 for the UAS.[12] If 978 MHz is used, the CNPC must be shown to not interference with UAT performance. See the RTCA DO-362 MOPS for interoperability requirements for the UAT and CNPC link.*

2.2.2.1.4.1 Intruder ADS-B Traffic State Vector Report Input Requirements

ADS-B traffic vector state data provides constantly changing intruder aircraft position information independent of the UA ownship position.

1. The intruder traffic data **shall (033)** be considered invalid for DAA functionality whenever:
   a. The 95% bound of horizontal position uncertainty exceeds 0.1 NM (NACp < 7), or
   b. The horizontal position integrity bound exceeds 0.3 NM, or
   c. The source integrity level is greater than 1E-07, or
   d. The intruder horizontal velocity uncertainty exceeds 10 m/s (NACv < 1), or
   e. The system design assurance is greater than 1E-05 (System Design Assurance (SDA) < 2).
2. The UA DAA processor **shall (034)** receive the ADS-B traffic data found in Table 2-6.

[12] RTCA DO-362, Minimum Operational Performance Standards for Command and Control (C2) – Terrestrial, 22 September 2016

<u>Table 2-6</u>   DAA Traffic State Data Input from ADS-B

ADS-B Intruder Reports	Notes
Time of Applicability	Note 1
Horizontal Position – Latitude/Longitude	Note 2
Horizontal – N/S Velocity, E/W Velocity	
Barometric Pressure Altitude	
Geometric Altitude	Note 2
Geometric Vertical Accuracy	
Geometric Vertical Rate	Note 3
Navigation Integrity Category (NIC)	

<u>Note:</u>

1. *Each of the ADS-B reports is triggered by either a position message reception or a velocity message reception. The report includes both position and velocity and the TOA for position and the TOA for velocity. Of these two, the more recent TOA indicates which type was just received.*
2. *Position is based on latitude/longitude/altitude from the ADS-B receiver with reference to the WGS-84.*
3. *DAA system designers may consider in their implementation to filter vertical rate based on the reception of vertical rate type (i.e., geometric or barometric) from the ADS-B receiver when available.*

The UA DAA processor will process:

- Version 2 messages formatted per the requirements of RTCA DO-260B,
- Version 1 messages formatted per the requirements of RTCA DO-260A, and
- Version 0 messages formatted per the requirements of RTCA DO-260.

These MOPS assumes that reports sent to the UA DAA processor will be labeled as to whether they are from Version 0, 1, or 2 transmitting systems.

Version 0 reports will have their Navigation Uncertainty Category (NUC) converted to the NIC. NACp and SIL parameters per Appendix N of RTCA DO-260B. Version 1 reports, where they differ from Version 2, will also be addressed per Appendix N of RTCA DO-260B.

2.2.2.1.4.2 ADS-B Intruder Mode Status Data Input Requirements

ADS-B intruder mode status data is information about the intruder that generally changes less frequently than the traffic state data (e.g., flight ID and 24-bit address).

The UA DAA processor **shall (035)** receive the ADS-B mode status data found in <u>Table 2-7</u>.

Table 2-7 DAA Intruder Mode Status Data Input from ADS-B

ADS-B Intruder Mode Status	Notes
Time of Applicability	
Flight Identification	
24-bit Address	Note 1
Address Qualifier	Note 2
NAC_P	
NAC_V	
SIL	
SDA	
Emergency/Priority Status	
TCAS Operational	Note 3
TCAS RA Active	

Note:

1. *The 24-bit address can be either an ICAO 24-bit address or a non-ICAO address.*
2. *The address qualifier indicates whether the 24-bit address is a 24-bit ICAO address or another kind of address.*
3. *TCAS Operational is used as one means of identifying intruders equipped with a TCAS II operating in TA/RA mode to meet the vertical guidance requirement in Subparagraph 2.2.4.5.2 for Class 1 equipment systems or Class 2 equipment systems with the TCAS II not operating in TA/RA mode.*

2.2.2.1.4.3 TIS-B/ADS-R Service Status Data – Optional

Optionally, the UA DAA processor may receive information regarding the ADS-R/TIS-B coverage area (i.e., service status message) to notify the PIC of ADS-R service status.

2.2.2.1.4.4 TCAS II Resolution Advisory (RA) Report

If another aircraft triggers an RA onboard an intruder equipped with TCAS II as well as ADS-B, the intruder's TCAS II will transmit an RA report via ADS-B (Interface B). The RA information from the intruder's onboard TCAS includes its RA data, RA status and RA complement data if it is coordinating an RA with another TCAS equipped aircraft. For example, if TCAS selects a climb advisory, it sends a message containing a "Do not climb" Vertical RA Complement (VRC). The VRC is used by the coordinating aircraft to select a compatible advisory. In ADS-B, the complement information is reflected in the Resolution Advisory Complements (RAC) record subfield as depicted in Table 2-8. The RA report also identifies the aircraft that the RA is against. In the case of an RA against a Mode C-tracked aircraft, no identification information is available, i.e., no 24-bit ICAO address; so range, bearing and altitude information is included to provide the position of the Mode C intruder. In the case of a Mode S intruder, the 24-bit ICAO address is provided.

The UA DAA processor **shall (036)** receive ADS-B TCAS RA broadcast data listed in Table 2-8 .

Table 2-8 TCAS II RA Report Data Input from ADS-B

ADS-B TCAS RA Report Data
Active Resolution Advisories (ARA)
Resolution Advisory Complements Record (RAC)
RA Terminated (RAT)
Multiple Threat Encounter (MTE)
Threat Type Indicator (TTI)
Threat Identity Data (TID)

Note: *See RTCA DO-185B §2.2.3.9.3.2.3.1.1 for a complete description of these fields.*

The TCAS II RA data listed in Table 2-8 provides information necessary to provide suitable guidance to a UA PIC in case an RA is triggered on a TCAS-equipped intruder aircraft with ADS-B. In Equipment Class 1 or Equipment Class 2 systems, this information is used by the DAA guidance function to ensure that the UA ownship does not initiate or continue a maneuver that may impact the intruder's RA path (see Subparagraph 2.2.4.5). Appendix M provides more information on TCAS interoperability.

2.2.2.1.4.5 Operational Coordination Message

Intruders equipped with collision avoidance systems developed later than TCAS II, e.g., ACAS X variants, may transmit an ADS-B Operational Coordination Message (OCM) via ADS-B to provide RA and RA complement information to DAA systems. The OCM provides the DAA alerting system knowledge of an RA against it as well as RA complement information. The intruder with such capability provides complement information in this manner even though the aircraft that the RA is against may not have a collision avoidance system, or alternatively, does not support the primary coordination method via 1030 MHz TCAS Resolution Message interrogation/reply. With Version 3 ADS-B Out/In equipage onboard, the DAA system may receive OCM data. The UA DAA processor **shall (037)** receive the OCM data elements contained in Table 2-9 if available. See Subparagraph 2.2.4.5 for DAA processing of OCM data.

Table 2-9 Operational Coordination Message Data Content

OCM Bits	Field Name	Value
1-5	Type Code (28)	11100
6-8	Subtype Code (3)	011
9	Reserved	0
10	Multiple Threat Bit (MTB)	As defined in International Civil Aviation Organization (ICAO) Annex 10, Volume (Vol.) IV, §4.3.8.4.2.3.2.1
11-12	Cancel VRC (CVC)	As defined in ICAO Annex 10, Vol. IV, §4.3.8.4.2.3.2.3
13-14	Vertical RA Complement (VRC)	As defined in ICAO Annex 10, Vol. IV, §4.3.8.4.2.3.2.2
15-17	Cancel HRC (CHC)	As defined in ICAO Annex 10, Vol. IV, §4.3.8.4.2.3.2.5

OCM Bits	Field Name	Value
18-20	Horizontal RA Complement (HRC)	As defined in ICAO Annex 10, Vol. IV, §4.3.8.4.2.3.2.4
21-25	Horizontal Sense Bits (HSB)	As defined in ICAO Annex 10, Vol. IV, §4.3.8.4.2.3.2.7
26-29	Vertical Sense Bits (VSB)	As defined in ICAO Annex 10, Vol. IV, §4.3.8.4.2.3.2.6
30-32	Reserved	000
33-56	Mode S Address	24-bit address of aircraft the RA is against

Note:

1. *The 1090ES OCM is not supported in 1090ES Version 2 or earlier. The 1090ES OCM format is provided herein so that DAA system implementers can make provisions for the OCM message data elements prior to publication of RTCA DO-260C MOPS (Version 3).*
2. *Bit numbers represent the 56-bit "ME" field of an Extended Squitter Message. See Appendix I for more information.*

2.2.2.1.5 TCAS II RA and Coordination Data

In addition to the surveillance data from transponder equipped intruders, DAA Equipment Class 1 and Class 2 equipment receives additional TCAS related data from active surveillance. DAA Class 2 systems integrated with an onboard TCAS II that operate with full collision avoidance functionality, i.e., in TA/RA mode, require additional data from TCAS II. In addition to the active surveillance data per Subparagraph 2.2.2.1.3 provided by the onboard TCAS II in Class 2 equipment, ownship RA information, when applicable, is required. In this configuration, the DAA system must be aware of RAs that the ownship TCAS II generates.

DAA Equipment Class 2 **shall (522)** receive active surveillance data per Subparagraph 2.2.2.1.3. In addition, TCAS RA data as defined in Table 2-10 **shall (523)** be received when an ownship TCAS RA is initiated, in process and terminated.

Table 2-10 Ownship TCAS II Data if RA is Issued against Intruder Aircraft

TCAS RA Data
Active Resolution Advisories (ARA)
Resolution Advisory Complements Record (RAC)
RA Terminated (RAT)
Multiple Threat Encounter (MTE)
Threat Type Indicator (TTI)
Threat Identity Data (TID)

TCAS RA information per Table 2-11 **shall (524)**be received when an RA is issued against the ownship from an intruder equipped with a collision avoidance system.

DAA Equipment Classes 1 and 2 **shall (532)** receive TCAS coordination data per Table 2-11 from Uplink Format 16 (UF16) TCAS Resolution Messages received as a result of RAs issued against the ownship by an intruder equipped with a collision avoidance system.

Note: *When an RA against the ownship occurs on an intruder aircraft equipped with TCAS II, only a DAA Equipment Class 2 operating in TA/RA mode receives coordination data via UF16 TCAS Resolution Messages. Since UF16s are the preferred method for DAA systems to receive indication of RAs against it, intruders with future CA systems (e.g., ACAS X) will be capable of sending UF16 coordination data as shown in Table 2-11 to both Class 1 DAA systems and Class 2 DAA systems whenever an RA occurs against the DAA aircraft. This capability requires DAA systems to be installed with a DO-260C 1090ES system, which will inform future CA equipped aircraft to send coordination data to such DAA systems. This capability is enabled by broadcast of DAA capability bits in DO-260C 1090ES messages.*

Table 2-11 TCAS Coordination Data if RA is Issued against Ownship

TCAS Coordination Data
Vertical Resolution Advisory Complement (VRC)
Cancel Vertical Resolution Advisory Complement (CVC)

2.2.2.1.6 Surveillance Equipment Operating Status and Health Data

1. The UA DAA processor **shall (041)** receive the surveillance equipment status (Interface B or D). Operating status modes are listed in Table 2-26 in Paragraph 2.2.8.
2. The UA DAA processor **shall (042)** receive the surveillance equipment response to a Built-In Test (BIT) check for each surveillance article. Refer to Table 2-26 for possible responses to the BIT check.
3. The UA DAA processor **shall (043)** receive health data from the surveillance equipment as described in Table 2-12.

Table 2-12 Surveillance Equipment Health Data

Surveillance Data	Notes
ATAR Health	Note 1
Active Surveillance Health	Note 2
ADS-B Health	Note 3
TCAS II Health	Note 4

Note:

1. *These MOPS assume that the ATAR includes health and integrity monitoring functionality and will be provided as part of the interface.*
2. *For Class 1 Equipment, these MOPS assume that the health and integrity monitoring functionality portion of RTCA DO-185B is implemented.*

3. *These MOPS assume that ADS-B receiver health monitoring is implemented according to RTCA DO-260B and RTCA DO-282B.*
4. *For Class 2 Equipment, these MOPS assume that the active surveillance health and integrity monitoring functionality portion of RTCA DO-185B is implemented.*

2.2.2.1.7 Flight Control System (FCS)

1. For Equipment Class 2 systems with automatic collision avoidance maneuver execution, if the FCS is following an RA, the UA DAA processor may receive positive confirmation of FCS execution (Interface C).

Note: *The TCAS II system will notify the UA DAA processor that an RA has been issued for the ownship. Even if the DAA system is in "RA – Auto" mode, additional information may be necessary to ensure that the UA is in fact following the RA.*

2. The UA DAA processor may receive a notification if the FCS is unable to follow an RA at the time the condition arises.

Note: *If the UA is unable to follow a TCAS II RA (e.g., due to reduced climb ability at high altitudes, failures, etc.), the operational mode of the DAA system may need to be changed to "RA Off" since TCAS II behavior onboard an intruder may change based on whether or not the UA is identified as TCAS II-equipped.*

2.2.2.1.8 Control and Non-Payload Communication(s) (CNPC) Data Link

The UA DAA processor receives CNPC data from the CNPC data link.

1. The UA DAA processor **shall (525)** receive CNPC transaction expiration status from the CNPC link to ensure timeliness of the UA DAA processor (see Subparagraph 2.2.8 and Appendix K).
2. The UA DAA processor **shall (047)** receive CS DAA Control Panel data from the CS DAA processor via the CNPC data link. Information on the CS DAA control panel data is found in Subparagraphs 2.2.2.6 and 2.2.2.7.

2.2.2.2 UA DAA Processor Output Data Requirements

The UA DAA processor has two main functions: to process track data from the various surveillance sources and provide DAA alerting (Interface D). The UA DAA processor sends the following data defined in the following subparagraphs.

2.2.2.2.1 Prioritized Track Data

A traffic report contains all the intruder data necessary for the CS DAA traffic display and DAA alerting and guidance functions. The UA DAA processor combines the position and state data received from the surveillance equipment into a single integrated track for each detected intruder aircraft. Since traffic data from the UA processor is passed to the CS DAA traffic display via the CNPC data link, this subparagraph assumes traffic data is minimized for maintaining continuity and availability of the data link as specified in RTCA DO-362. Additionally, the DAA system is expected to function under loss of Global Navigation Satellite System (GNSS) data, hence the prioritized track state data is specified relative to the ownship. However, designers may elect to send more traffic data if the bandwidth of the data link is sufficient.

1. Traffic not meeting the DAA data quality thresholds of Subparagraph 2.2.3.2.1.3.2 **shall (048)** not be forwarded to the CS DAA traffic display from the UA DAA processor.
2. The UA DAA processor **shall (049)** output prioritized track reports for available intruder aircraft in accordance with Subparagraph 2.2.4.3.4.1. Elements of the traffic report are summarized in Table 2-13 and described in the subparagraphs below.

Table 2-13 UA DAA Prioritized Track State Output Data

Intruder Traffic Report	Notes
Unique Track ID	
Flight ID	e.g., the aircraft flight number or the tail number
Time of Applicability	
Intruder Alert/Priority	
Source Data Type	
Validated ADS-B	Validated, Unvalidated, or Previously Validated See Subparagraph 2.2.3.2.1.3.4.
Air/Ground Status	
Relative Horizontal Position	See Subparagraph 2.2.3.2.3 for performance requirements. May be Relative Range/Bearing or Relative Lat/long.
Relative Horizontal Position Accuracy	See Subparagraph 2.2.3.2.3 for performance requirements.
Bearing Invalid	Set to TRUE per 2.2.3.2.1.1 only when horizontal position does not meet accuracy requirements.
Relative Horizontal Velocity	See Subparagraph 2.2.3.2.3 for performance requirements.
Relative Horizontal Velocity Accuracy	
Relative Altitude	See Subparagraph 2.2.3.2.3 for performance requirements.
Relative Altitude Accuracy	
Altitude Invalid	Set to TRUE per 2.2.3.2.1.1.
Relative Vertical Velocity	See Subparagraph 2.2.3.2.3 for performance requirements.
Relative Vertical Velocity Accuracy	

2.2.2.2.1.1 Unique Track ID (Track Number)

The Unique Track ID assigns a number to each track so that tracks can be time-correlated. Each traffic report **shall (050)** have a unique identification number that stays with it as long as the UA DAA processor is tracking it.

2.2.2.2.1.2 Flight ID

The Flight ID may also be referred to as Traffic Identification (e.g., the aircraft flight number or the tail number). This information may be conveyed in a data tag or data block or by other means, and does not have to be continuously displayed.

Each traffic report **shall (135)** contain a Flight ID, if available, from the source sensor data.

2.2.2.2.1.3 Time of Applicability (TOA)

A TOA on each intruder track will facilitate the synchronization of each traffic report to ownship data within each one-second epoch. Optimally, all DAA subsystems will be synchronized in time to the same reference (e.g., UTC).

Each traffic report **shall (051)** have a reference TOA. This does not mean each intruder; they could be grouped. However, each intruder track must satisfy the latency requirements of Subparagraph 2.2.3.2.3.1.

2.2.2.2.1.4 Intruder Alert/Priority

Each traffic report **shall (052)** contain an intruder alert status or priority. See the list in Subparagraph 2.2.4.3.4.1 or Subparagraph 2.2.3.2.3 for cases when alerting data is not available.

Note: *The alert status may be determined by the track processing/alerting function within the UA DAA processor. Priority may be conveyed through transmission order.*

2.2.2.2.1.5 Source Data Type

The source data type contains information on the sensor(s) providing data on the intruder track; for example:

1. Air-to-Air Radar
2. Active Surveillance
3. ADS-B 1090ES In (Air-Air)
4. ADS-B UAT In (Air-Air)
5. ADS-R

Each traffic report **shall (053)** contain information on the source of the data. Multiple source data types or enumerations should be used to indicate fused or hybrid sensor tracks.

2.2.2.2.1.6 Validated ADS-B

An indication of whether an intruder's ADS-B reports have been validated with another surveillance sensor per Subparagraph 2.2.3.2.1.3.4 2.2.3.2.1.3.4.

This information is used for alerting logic per Subparagraph 2.2.4.3.4.4.

2.2.2.2.1.7 Air/Ground Status

An indication of whether an intruder is on the ground or in the air helps to differentiate and de-clutter the traffic display. Only ADS-B will have a direct indication of whether the traffic is on the ground or in the air; otherwise the aircraft is assumed to be in airborne mode.

Each traffic report **shall (054)** contain an air/ground status.

2.2.2.2.1.8 Relative Horizontal Position

A track can either be referenced in terms of absolute position (e.g., latitude and longitude) or relative to the ownship using relative position or relative range and bearing. Experience with ADS-B In applications has shown that whenever possible, it is a best practice to maintain the absolute position of an ADS-B report. Therefore, both an absolute and relative position reference frame may be considered in anticipation of both being used for different targets.

1. Each traffic report **shall (055)** contain a horizontal position for the intruder.
2. Each traffic report **shall (056)** include horizontal position accuracy information.
3. The range resolution of the horizontal position **shall (057)** be 50’ or better.

2.2.2.2.1.9 Relative Horizontal Position Accuracy

The Relative Horizontal Position Accuracy is the estimate of the total expected error of the Relative Horizontal Position error. These total error estimates are meant to capture both the bias and variance of the error and should be representative of an R95 error.

2.2.2.2.1.10 Bearing Invalid

Because some surveillance measurements may not contain relative bearing information or very poor relative bearing information, the DAA system needs to account for this type of intruder. If the track information can be estimated with the required accuracy except for the horizontal position, then the track will be marked appropriately per Subparagraphs 2.2.3.2.1.1 and 2.2.3.2.1.4.

2.2.2.2.1.11 Relative Horizontal Velocity

Horizontal Velocity can either be referenced in terms of intruder East/North velocity, track angle and ground speed, or relative to the ownship using relative East/North velocity.

1. Each traffic report **shall (061)** contain a horizontal velocity for the intruder.
2. Each traffic report **shall (062)** include horizontal velocity accuracy information.

2.2.2.2.1.12 Relative Horizontal Velocity Accuracy

The Relative Horizontal Velocity Accuracy is the estimate of the total expected error of the Relative Horizontal Velocity error. These total error estimates are meant to capture both the bias and variance of the error and should be representative of an R95 error.

2.2.2.2.1.13 Relative Altitude

The relative altitude of each intruder should include a range of at least ±10,000’ since the highest vertical rate covered by the DAA OSED is ±5,000 fpm, giving the intruder at least one minute of time until co-altitude. Additionally, intruder geometric altitude may be provided in addition to the relative altitude information.

1. Each traffic report **shall (058)** contain the relative altitude of the intruder.
2. Each traffic report **shall (059)** contain the relative altitude accuracy.
3. Each traffic report **shall (060)** contain the relative altitude status information.

2.2.2.2.1.14 Relative Altitude Accuracy

The Relative Altitude Accuracy is the estimate of the total expected error of the Relative Altitude error. These total error estimates are meant to capture both the bias and variance of the error and should be representative of an R95 error.

2.2.2.2.1.15 Altitude Invalid

Because some surveillance measurements may not contain altitude information or very poor relative elevation information, the DAA system needs to account for this type of intruder. If the track information can be estimated with the required accuracy except for the relative altitude, then the track will be marked appropriately per Subparagraphs 2.2.3.2.1.1 and 2.2.3.2.1.4.

2.2.2.2.1.16 Relative Vertical Velocity

The reported relative vertical velocity of each intruder should be capable of a range of at least ±5,000 fpm per the DAA OSED and RTCA DO-185B.

1. Each traffic report **shall (063)** contain the relative vertical velocity of the intruder.
2. Each traffic report **shall (064)** contain the relative vertical velocity accuracy.
3. Each traffic report **shall (065)** contain the status information.

2.2.2.2.1.17 Relative Vertical Velocity Accuracy

The Relative Vertical Velocity Accuracy is the estimate of the total expected error of the Relative Vertical Velocity error. These total error estimates are meant to capture both the bias and variance of the error and should be representative of an R95 error.

DAA Alerting Data

The UA DAA processor **shall (066)** output DAA alerts based on the alert types in Subparagraph 2.2.4.3.4.

Note: *The alerting function can optionally be hosted on the CS DAA processor.*

2.2.2.2.2 DAA System Modes of Operation and Health Status

The UA DAA processor **shall (067)** output its mode of operation and health status. See Subparagraph 2.2.6.1 for a list of operating modes and health information.

2.2.2.2.3 TCAS II RA – Equipment Class 2

In order to perform manual (PIC-initiated) collision avoidance maneuvers and to determine when an automatic collision avoidance maneuver is taking place, the PIC will need to receive ownship TCAS RAs.

For Equipment Class 2 systems, the UA DAA processor **shall (068)** send the TCAS II RA to the CS DAA processor.

Note: *For a given system architecture, this requirement may be fulfilled if a TCAS II RA is received by the CS through an alternative data path and not from the UA DAA processor.*

2.2.2.2.3.1 Flight Control System Commands from the UA DAA Processor

An alternative architecture to the one depicted in Figure 2-1 may send RA commands (Interface B) from the UA DAA processor to the FCS instead of the FCS receiving such commands directly from the TCAS II system. If a DAA system interfaces with the UA flight control system, the implementation should follow the guidelines of Appendix C of RTCA DO-325, *MOPS for Automatic Flight Guidance and Control Systems and Equipment*.[13]

2.2.2.2.4 Onboard Data Recording Capability

The UA DAA processor **shall (069)** contain non-volatile memory for storing Flight History data associated with DAA encounters. For each encounter that triggers Guidance Maneuver Bands or results in a DAA Corrective Alert, a DAA Warning Alert, or a Resolution Advisory:

1. The UA DAA processor **shall (070)** record the traffic state and status data, and the ownship state and status data for the duration of the encounter into a flight history record in non-volatile memory.
2. The UA DAA processor **shall (071)** store a minimum of 100 encounter records, which spans a minimum of 15 seconds prior and 15 seconds after an indicated DAA alert before overwriting the oldest record.

2.2.2.3 CS DAA Processor Input Requirements

The CS DAA processor **shall (072)** receive the data listed in Table 2-14.

Table 2-14 Data Received by the CS DAA Processor

CS DAA Input Data	Reference Subparagraph
UA DAA Processor Output Data	2.2.2.2 (Interface D)
CS DAA Control Panel Data	2.2.2.6 (Interface G)
UA Ownship State Data	2.2.2.1.1 (Interface D)
CPNC Data	2.2.2.1.8 (Interfaces E/F)

2.2.2.4 CS DAA Processor Output Data Requirements

The CS DAA processor **shall (073)** output the data listed in Table 2-15.

[13] RTCA DO-325, Minimum Operational Performance Standards (MOPS) for Automatic Flight Guidance and Control Systems and Equipment, 08 December 2010

Table 2-15 **CS DAA Processor Output Data**

CS DAA Processor Output Data	Reference Subparagraph
UA DAA Processor Output Data	2.2.2.2 (Interface D)
DAA Control Panel Data	2.2.2.6 (Interface G)
CNPC Data	2.2.2.1.8 (Interfaces E/F)
Surveillance Equipment Operating Status and Health Data	2.2.2.1.6 (Interface B or D)
Track Processing Data	2.2.3.2 (Interface B1)
Alerting Data	2.2.4.3.4 (Interface D)
Maneuver Guidance Band Information	2.2.4.4
CS DAA Processor Health Status	2.2.2.4.1 2.2.2.4.1

2.2.2.4.1 CS DAA Processor Health Status Data

The CS DAA processor **shall (074)** output its mode of operation. See Subparagraph 2.2.6.1 for a list of operating modes and health information.

2.2.2.5 DAA Control Panel Input Requirements

The CS DAA control panel **shall (075)** receive pilot-selected modes (Interface N) as specified in Paragraph 2.2.6.

2.2.2.6 DAA Control Panel Output Requirements

The CS DAA control panel **shall (076)** send pilot-selected modes (Interface N) per Paragraph 2.2.6 to the CS DAA processor (Interface G).

2.2.2.7 CS DAA Traffic Display Input Data Requirements

The DAA traffic display **shall (077)** receive the following data from the CS DAA processor unless otherwise noted:

Table 2-16 **DAA Traffic Display Input**

DAA Display Data	Reference Subparagraph	Notes
Ownship Track Angle	2.2.2.1.1	Note 1
Ownship Heading	2.2.2.1.1	Note 1
Ownship Pressure Altitude	2.2.2.1.1	
Traffic Relative Position	2.2.2.1.2, 2.2.2.1.3, 2.2.2.1.4	
Traffic Relative Altitude	2.2.2.1.2, 2.2.2.1.3, 2.2.2.1.4	
Traffic Geometric Altitude (Optional)	2.2.2.1.2, 2.2.2.1.3, 2.2.2.1.4	
Traffic DAA Alert/Priority Status	2.2.2.1.2, 2.2.2.1.3, 2.2.2.1.4	
Traffic DAA Guidance Data	2.2.2.1.2, 2.2.2.1.3, 2.2.2.1.4	
DAA System Status and Health	2.2.2.2.2	Note 3
Surveillance Equipment Status and Health	2.2.2.1.6	Note 3
System Failures	2.2.2.2.2	Notes 2, 3
Ownship TCAS II RA Data	2.2.2.2.3	Note 4

Note:

1. *Ownship track angle/heading may be converted to both true and magnetic references.*
2. *System failures include any equipment failures on the UAS or in the CS that would affect any of the DAA functions.*
3. *This data can be sent to other displays in the CS that support the DAA functionality.*
4. *This data is only required for DAA Class 2 systems.*

2.2.2.7.1 Ownship Pressure Altitude

1. When ownship pressure altitude is used by the DAA traffic display to determine traffic actual altitude (optional), the DAA traffic display function **shall (078)** receive ownship pressure altitude from ownship position sources.
2. When used to display traffic actual altitude (optional), the DAA traffic display function **shall (079)** receive ownship barometric correction or corrected altitude from ownship position sources.

2.2.2.7.2 Ownship Length and Width Code

When used to display the physical extent of the aircraft (optional), the DAA traffic display function **shall (080)** receive the aircraft length and width codes from the UAS.

2.2.3 Active Surveillance, Equipment Class 2 RA Function and Tracker Performance Requirements

2.2.3.1 DAA Active Surveillance and DAA Equipment Class 2 RA Function Requirements

This subparagraph addresses the performance requirements for the active surveillance equipment and Equipment Class 2 collision avoidance capability.

Active surveillance requirements are contained in Subparagraph 2.2.3.1.1. The DAA active surveillance system provides surveillance for ATCRBS and Mode S transponder equipped targets. Active surveillance for DAA may be provided by an onboard TCAS II system designed to RTCA DO-185B and RTCA DO-300A. This equipment satisfies Subparagraph 2.2.3.1.1 and must also be capable of providing data to the UA DAA processor per Subparagraph 2.2.2.1.3 and Subparagraph 2.2.2.1.5. Alternatively, implementers of DAA Equipment Class 1 may integrate their own active surveillance capability as part of the DAA system per Subparagraph 2.2.3.1.1. DAA Equipment Class 2 provides the active surveillance function as part of the onboard TCAS II system. In addition to active surveillance, Equipment Class 2 has additional functional and data requirements to support collision avoidance as described in Subparagraph 2.2.3.1.2, below. To reduce the adverse impacts of active surveillance systems on the 1030 and 1090 MHz RF environment, the DAA active surveillance system is required to use Interference Limiting (IL). IL as described in RTCA DO-185B optimizes surveillance requirements to provide acceptable performance within the TCAS II service volume. This volume may be smaller than DAA service volumes. An analysis of how this design limitation can affect DAA performance is contained in Appendix I.

DAA active surveillance systems are required to use hybrid surveillance. Hybrid surveillance is used to decrease Mode S interrogations to qualified ADS-B targets that do not pose a near-term collision threat. The use of hybrid surveillance with RTCA DO-185B compliant TCAS II systems is described in RTCA DO-300A, "Minimum Operational Performance Standards (MOPS) for Traffic Alert and Collision Avoidance System II (TCAS II) Hybrid Surveillance."

Note: *Active surveillance and DAA Equipment Class 2 collision avoidance as defined herein conform to the interoperability requirements between a DAA system and existing collision avoidance systems such as TCAS II. Table M-5 in Appendix M depicts the interoperability requirements satisfied by these MOPS.*

2.2.3.1.1 DAA Active Surveillance

This subparagraph describes the active surveillance capability for a DAA system. If the active surveillance function is provided by onboard equipment external to the DAA system (i.e., onboard TCAS II equipment), the DAA system receives the input data as defined in Subparagraphs 2.2.2.1.3 and 2.2.2.1.5. The DAA active surveillance equipment **shall (085)** meet the requirements of Table 2-17.

Note: *Table 2-17 identifies the relevant sections of RTCA DO-185B needed to perform the active surveillance function for DAA. Except as noted, all RTCA DO-185B section references include the corresponding subsections.*

Table 2-17 RTCA DO-185B Requirements to Support DAA Active Surveillance

TCAS II MOPS Subdivision Number	TCAS II MOPS Subdivision Title	Notes
2.2.3.1	Radiated Output Power	
2.2.3.2	Unwanted Output Power	
2.2.3.3	Interrogation Spectrum	
2.2.3.4	Interrogation Jitter	
2.2.3.5	Transmit Frequency and Tolerance	
2.2.3.6.1	Interference Limiting Formulas	1
2.2.3.6.2	Interference Limiting Procedures	1
2.2.3.6.3	Interrogations from TCAS II on the Ground	1
2.2.3.6.4	Interrogations from TCAS II above 18,000' Barometric Altitude	1
2.2.3.8	Transmit Pulse Characteristics	
2.2.3.10	TCAS II Signal Protocol	
2.2.3.10.1	Mode C Surveillance	
2.2.3.10.2	Mode S Surveillance Signals	
2.2.3.11	Compatibility with the Ownship Mode S Transponder	
2.2.3.12	Aircraft Suppression Bus	

TCAS II MOPS Subdivision Number	TCAS II MOPS Subdivision Title	Notes
2.2.3.13.2.3.1	Data Received in Long Special Surveillance Interrogations (UF=16) from other TCAS Aircraft via the Ownship Mode S Transponder	2
2.2.4	Surveillance Requirements	3, 7
2.2.6.5.1 a., d.	TCAS II/Mode S Controls	4
2.2.7.1.1	Failure Response	5
2.2.7.1.2	Noninterference with Normal Operation	6
2.2.7.1.3	Self-Test	5

Note:

1. *See Appendix I for an analysis of impact of Interference Limiting on DAA surveillance performance.*
2. *TCAS Resolution Message data is provided to the DAA system per Subparagraph 2.2.2.1.5. Subparagraph 2.2.3.2.1.2 applies for priority handling and Subparagraph 2.2.3.2.1.3 as appropriate for meeting the overall DAA system integrity.*
3. *For DAA Equipment Class 1, RTCA DO-185B, §2.2.4.2, System Delay, does not apply.*
4. *See Paragraph 2.2.6 for mode control provisions.*
5. *See Paragraph 2.2.8 for self-test provisions.*
6. *See Paragraph 2.2.9 for monitoring provisions.*
7. *Requirements in RTCA DO-185B, §2.2.4.8.1 for data provided by TCAS to the CAS logic apply to data sent to the UA DAA processor per Subparagraph 2.2.2.1.3.*
8. *Manufacturers of DAA equipment and those seeking to install it on an aircraft need to consider the TCAS antenna installation requirements in RTCA DO-185B, §3.4.3. Since TCAS was designed for large air transport category aircraft, additional analysis and testing may be needed to justify the antenna installation on smaller aircraft. See Appendix I for additional guidance on antenna installation.*

In addition, the DAA active surveillance function **shall (086)** include the hybrid surveillance requirements in RTCA DO-300A.

Note: *Spectrum limitations require passive acquisition of 1090ES-equipped aircraft per RTCA DO-300A.*

2.2.3.1.2 DAA with TCAS II Resolution Advisory Functionality (Equipment Class 2)

In addition to the active surveillance requirements of Subparagraph 2.2.3.1.1, DAA Equipment Class 2 systems **shall (087)** include the full provisions of RTCA DO-185B that includes the collision avoidance function, providing RA detection and RA coordination with other TCAS equipped aircraft and meeting the interoperability provisions of Appendix M.

Note:

1. *In order to install and operate TCAS II in this configuration, the UAS installation must meet the TCAS II pilot response and aircraft performance assumptions.*
2. *When an RA exists between TCAS II equipped aircraft, coordination occurs between the aircraft to ensure that compatible maneuvers take place to prevent the aircraft from making similar vertical maneuvers. When an RA is received, this information may be used by the DAA system to control its navigation to comply with the RA guidance provided to the PIC. Refer to Subparagraph 2.2.2.1.5 for ownship RA data requirements for TCAS II systems used with DAA Equipment Class 2 systems.*

2.2.3.2 DAA Track Processing – Surveillance Data Processing and Tracking Requirements

Surveillance data processing and tracking requirements describe a continuous function that processes ownship state data and surveillance data from the DAA surveillance sensors for generating and maintaining intruder aircraft tracks to support the DAA alerting and guidance functions. The figure below depicts this continuous process.

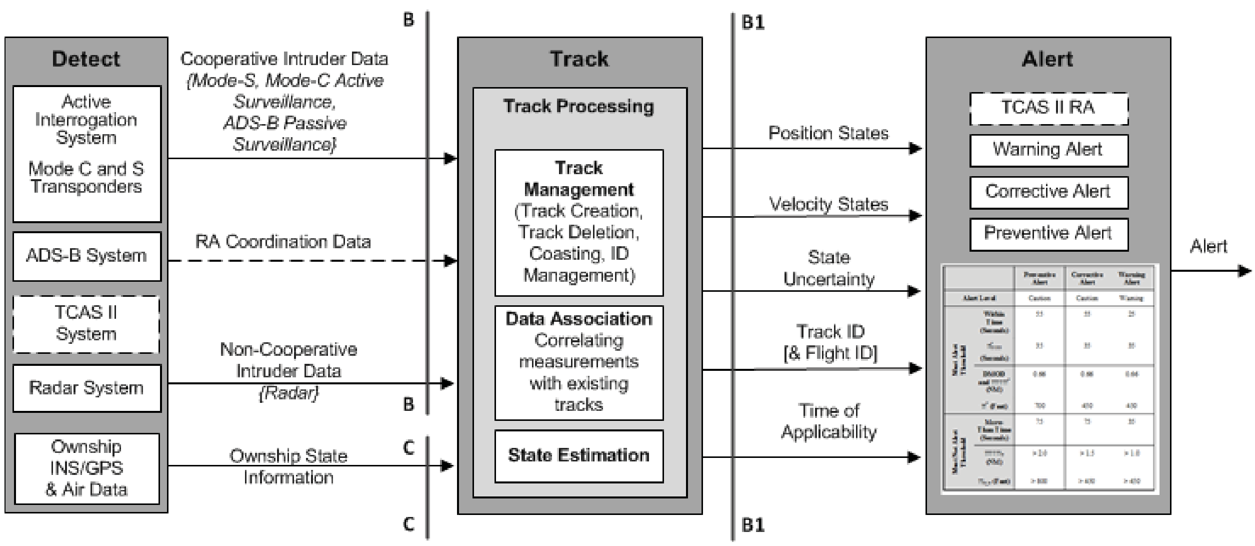


Figure 2-2 DAA Track Processing Objectives

Track Processing consists of three subfunctions: Track Management, and State Estimation. The Track Management subfunction operates together with the Data Association subfunction to initiate intruder aircraft trajectories, to maintain actively tracked intruder aircraft trajectories, and to delete actively tracked intruder aircraft trajectories while minimizing false track generation. The Data Association subfunction correlates measurements to an actively tracked intruder aircraft trajectory. State Estimation uses the sensor measurements to estimate the trajectory of the intruder aircraft. All three subfunctions operate together for processing alerting and guidance.

Note:

1. *Depending on the implementation or configuration (1090ES, UAT or radar specific formats), DAA surveillance data processing and tracking will receive varying report formats: split state vector and state uncertainty separately, full state vector and state uncertainty, or full state vector and state uncertainty separately. The Track Processing function should also be able to handle asynchronous or incomplete data.*
2. *Necessary state information required for alerting may not be available from all sensors, so some amount of intruder state estimation may be required.*
3. *State Estimation functionality is also used to extrapolate the state data to the current TOA.*

These MOPS define performance requirements for DAA track information, but do not specify a single method to attain that performance.

2.2.3.2.1 Track Management

Reports from each available source (i.e., ADS-B, active surveillance and onboard radar) are provided separately from the respective surveillance source per Subparagraph 2.2.2.1. Based on NAS assumptions, the DAA system **shall (088)** track cooperative traffic with closing speeds up to at least 1200 KTAS and relative altitude rates up to at least 10,000 fpm. The DAA system **shall (089)** track non-cooperative traffic with closing speeds up to at least 500 KTAS and relative altitude rates up to at least 5000 fpm (per discussion in Appendix D).

2.2.3.2.1.1 Track Initiation

Where there is no correlating track, the DAA system **shall (090)** begin the track initiation process for the following reports, sources and target identification types (e.g., ICAO vs. non-ICAO):

1. All ADS-B and ADS-R reports (if no UAT receiver is present)
2. All cooperative active interrogations (Mode S and Mode C) reports
3. All non-cooperative reports (e.g., onboard radar reports).

The DAA track **shall (091)** begin when the track accuracy is within 125% of the required track performance.

- If only the track accuracy of vertical position exceeds 125% of the required track accuracies, the track may still be initiated, but **shall (092)** be treated as a non-altitude reporting target (Subparagraph 2.2.4.3.5.3) and set the Altitude Invalid flag to TRUE.
- If only the track accuracy of horizontal position exceeds 125% of the required track accuracies, the track may still be initiated, but **shall (093)** be treated as a non-bearing reporting target (Subparagraph 2.2.4.3.5.2) and set the Bearing Invalid flag to TRUE.

Note: *The implementation of this accuracy requirement is left to the manufacturer and can be mechanized in several ways, such as using the estimated track accuracy (i.e., covariance output) to determine when the accuracy is within the threshold.*

2.2.3.2.1.2 Track Capacity

The DAA system **shall (094)** be capable of maintaining at least 36 tracks.

__*Note:*__ *This track capacity requirement was developed by examining the minimum execution ranges needed for cooperative and non-cooperative aircraft at high altitude (> 10,000') and low-altitude (< 10,000') airspace as described in Appendix D, taking the most conservative range (7.5 NM – low altitude) and an airspace density requirement of 0.3 aircraft/NM^2 (RTCA DO-185B). This yields 36 aircraft, and is the most expected aircraft in low or high altitude airspace for the execution ranges for head-on scenarios.*

Track processing **shall (095)** output prioritized track reports for available intruder aircraft in accordance with Subparagraph 2.2.4.3.4.1, if alerting information is available. If alert level information is not available, track processing **shall (096)** output prioritized track reports for available intruder aircraft in the following order:

1. Airborne intruders within 3 NM horizontally and 700' vertically via increasing horizontal range,
2. Converging airborne intruders greater than 3 NM horizontally and/or 700' vertically via increasing modified Tau with a 4000' Distance Modification of Modified Tau, (DMOD) (per the equation in Subparagraph C.5),
3. Diverging airborne intruders greater than 3 NM horizontally and/or 700' vertically via increasing range,
4. Ground intruders via increasing horizontal range.

__*Note:*__

1. *Slant range may be used if horizontal range is not available for an intruder. Likewise, if altitude information is not available, just the horizontal criteria may be used.*
2. *Alert information may not be known because the alerting processing may be done in a different location than the track processing per the optional architectures.*

2.2.3.2.1.3 ADS-B Report Processing and Track Maintenance

For each new ADS-B report containing an updated position and/or velocity surveillance measurement (Interface B), the DAA system **shall (097)** update a track report with the ADS-B report only when it passes all of the following ADS-B report validity checks and quality requirements.

2.2.3.2.1.3.1 ADS-B and ADS-R Report Validity Checks

The DAA system **shall (098)** reject horizontal velocity magnitude changes that exceed 1.5 g between velocity reports.

The DAA system **shall (099)** reject horizontal position changes that would require the aircraft horizontal acceleration in any direction to exceed 1.5 g between horizontal position reports.

The DAA system **shall (100)** reject vertical position changes that would require the vertical rate to exceed 10,000 fpm between vertical position reports.

An acceptable implementation of the validation criteria is found in Appendix D of RTCA DO-317B.[14]

Note:

1. *The traffic horizontal acceleration performance criterion is intended to cover the validity of updated horizontal position and velocity values.*
2. *The value of 1.5 g (14.7 meters/second squared (m/s^2)) was derived by investigating the horizontal acceleration of high performance business jets during surface takeoff and landings in conjunction with an Original Equipment Manufacturer (OEM).*
3. *The validation constant of 10,000 is based on TCAS II vertical tracker performance.*

2.2.3.2.1.3.2 ADS-B Velocity Quality Monitoring

Many ADS-B Out Link Version 2 installations provide acceptable velocity accuracy reporting. However, a considerable number of legacy installations are already fielded that either use earlier standards or do not adequately address velocity accuracy. While the majority of legacy ADS-B Out installations are expected to provide adequate data quality to support the applications in these MOPS, the transmitted velocity accuracy may not accurately reflect the actual quality. This could disqualify them from participating in some implementations when the actual reported velocity is sufficiently accurate.

The DAA MOPS group recognized the limited ability of today's avionic configurations to qualify velocity data to a 10 m/s accuracy (CFR 91.227 – rule compliant ADS-B), despite that GPS receivers report very good velocity accuracy (in the order of 1 – 2 m/s). The DAA MOPS therefore provides alternative means to qualify traffic velocity accuracy based on the knowledge that the transmitted velocity comes from a GPS receiver.

In order to ensure adequate velocity quality of legacy aircraft for DAA these MOPS have identified acceptable qualification means as described in Subparagraph 2.2.2.1.4 and summarized in Table 2-18,below.

Table 2-18 Summary of Acceptable Means for Velocity Qualification

Requirement Link Version (V)	DAA 10 m/s
V2	Valid Velocity and $NAC_V \geq 1$ OR Valid Velocity and Velocity Validation
V1	Valid Velocity and Velocity Validation
V0	Valid Velocity and Velocity Validation

[14] DO-317B, Minimum Operational Performance Standards (MOPS) for Aircraft Surveillance Applications (ASA) System, 17 June 2014

Note:

1. *Velocity validation refers to a receiving aircraft implementing a function to confirm that available velocity data is of sufficient quality for the application. An example algorithm for validating velocity quality from position reports is given in RTCA DO-317B, Appendix E.*
2. *SC-228 deemed identification of GPS source data using NAC_V and NACp for V 0 and V 1 acceptable for DAA.*
3. *For V1, the NAC_V of 1 or better identifies a GPS source since it can be associated with a GPS' $HFOM_R$ or inferred with HFOM.*
4. *For V0, the NAC_P of 4 or better (with a high likelihood) identifies a GPS source.*

More generally, a velocity/heading monitoring function should also be used to protect against sustained rogue velocity or heading information, such as could occur from a fault in the input from a heading sensor or some other systematic processing fault. A receiving aircraft should check that heading and speed are reasonable. In this case it is important to be aware that speed and heading data may originate from different sources and hence have independent failure modes (one example that has been observed from legacy installations is correct speed information reported together with an incorrect, frozen, heading value). Validation of heading may be done using position reports when the traffic is moving sufficiently. If the velocity quality checks fail, then the velocity should be considered invalid for the application.

2.2.3.2.1.3.3 Duplicate Address Processing

Note: *The duplicate address processing text is leveraged from RTCA DO-317B for DAA.*

2.2.3.2.1.3.3.1 Duplicate Address Processing for 1090 Megahertz (MHz) Systems

DAA **shall (101)** detect airborne ADS-B traffic with duplicate addresses. Duplicate address traffic is not required to be displayed. Since horizontal velocity and track angle are considered invalid, these tracks may be processed without track estimation and displayed as non-directional symbols.

ADS-B reports from RTCA DO-260B-compliant receivers will be marked with a duplicate address flag under certain criteria. The criteria are less stringent than the report validity checks given in Subparagraph 2.2.3.2.1.3.1. In cases where the DAA function is integrated with an RTCA DO-260B-compliant receiver, there is no need to implement the duplicate address processing by the receiver. The single criterion below using the report validity checks will meet the minimum requirements of both specifications.

ADS-B reports from 1090 MHz equipped targets that do not pass the report validity checks given in Subparagraph 2.2.3.2.1.3.1 or are marked as duplicates by an RTCA DO-260B-compliant receiver are subject to further processing to support tracking duplicate addresses as specified below.

1. Upon receipt of a report that does not meet the report validity criteria in Subparagraph 2.2.3.2.1.3.1 and there is not an existing duplicate address track for this participant address, the DAA system **shall (102)** create a candidate duplicate address track.

2. Candidate duplicate address tracks that are updated with position reports passing the Report Validity criteria three times within 25 seconds **shall (103)** transition to a duplicate address track.
3. The existing track and the newly created track are duplicate address tracks. A track **shall (104)** be flagged with a duplicate address condition by any of the following events:
   a. A candidate duplicate address track transitions to a duplicate address track per Item 2, above
   b. An existing track has an identical address as a new duplicate address track per Item 2, above.
   c. An existing track is updated by a 1090 MHz report with the duplicate address flag set
4. Upon transitioning to a duplicate address track, data for these tracks **shall (105)** be invalidated except for data from Type Codes 5 – 18 or 20 – 22 (see RTCA DO-260B) and all reports processed as Version 0 participants.

Note: *Additional data from other Type Codes could be used if additional processing is provided to correlate the data to the proper track.*

5. When initiating or updating a duplicate address track with a report, all data from the following 1090 MHz message Type Codes (see RTCA DO-260B) **shall (106)** be invalidated: Type Codes 1-4, 19, and 23-31, unless additional processing is provided to correlate the data to the proper track.
6. A duplicate address track, once initiated for a participant address, **shall (107)** exist until all tracks with this participant address are terminated per Subparagraph 2.2.3.2.1.4.

2.2.3.2.1.3.3.2 Duplicate Address Processing for Optional UAT Systems

When a UAT receiver is integrated with a DAA system, the DAA system **shall (108)** detect and track airborne ADS-B traffic from UAT sources with duplicate addresses.

ADS-B reports from UAT-equipped traffic that do not pass the report validity checks given in Subparagraph 2.2.3.2.1.3.1 are subject to further processing on UAT systems to determine if they are the result of a duplicate address as specified below:

1. For reports that do not correlate with an existing duplicate address track with a matching participant address, the DAA system **shall (508)** begin the track initiation process. Track initiation should mitigate for outliers and should not display a duplicate track at the first track update.
2. For each report containing an updated position and/or velocity, and where there is an existing track created as a result of duplicate address processing with the same participant address, the DAA system **shall (509)** update that track with the report only when it passes the report validity tests given in Subparagraph 2.2.3.2.1.3.1.

2.2.3.2.1.3.4 Additional Validation of ADS-B Traffic Position with Active Surveillance or Radar

A considerable number of legacy ADS-B Out installations are already fielded that do not adequately address position accuracy. Additionally, ADS-B data can potentially be spoofed causing false and misleading tracking information being sent to the DAA alerting and guidance functions. Therefore, DAA will require additional validation of ADS-B traffic position with active surveillance data or radar data if the data is to be used to provide warning alerts. Corrective and preventive DAA alerts can be issued using unvalidated ADS-B tracks. Unvalidated ADS-B tracks have modified alert symbology on the DAA traffic display.

The DAA system **shall (109)** perform ADS-B position data validation for DAA traffic if an active surveillance track or radar track is available.

If the validation passes, the DAA system **shall (110)** mark the track as validated.

If the validation fails or no active surveillance or radar track is available, the DAA system **shall (526)** mark the track as unvalidated.

Note: *Failing validation will likely lead to an unvalidated ADS-B track and an active surveillance and/or radar track without inter-source correlation.*

If the validation has passed for a track previously and the active surveillance track or radar track becomes unavailable, the DAA system **shall (527)** mark the track as previously validated.

2.2.3.2.1.3.4.1 Validation of Traffic Position with Active Surveillance

ADS-B data from traffic meeting the hybrid surveillance criteria in RTCA DO-300 or RTCA DO-300A **shall (111)** pass the validation test. For all other ADS-B traffic, the DAA system **shall (112)** pass the validation test with active surveillance data if:

|slant range difference| < 0.25 NM; and

|bearing difference| ≤ 45 degrees and range > 1 NM; and

|altitude difference| < 200’.

Note:

1. *If the ADS-B report contains an ICAO address and the validating TCAS II aircraft is a Mode S track, its 24-bit address must match the ADS-B ICAO address. TCAS II, Mode C and radar validation are based solely on the above spatial criteria.*
2. *If active surveillance bearing is not available, then the bearing comparison is not required to meet the validation requirements. One reason that bearing may not be available is the case of an aircraft tracked only with an omni-directional lower antenna.*
3. *An implementation should use filter criteria to prevent single validation failures from erroneously disqualifying traffic.*
4. *Appendix N outlines the analysis used to derive the validation thresholds.*
5. *Hybrid surveillance, per RTCA DO-300A, validates ADS-B position data in a manner acceptable for use by DAA alerting and guidance functions.*
6. *Extended hybrid tracks do not meet the validation criteria.*

7. *The bearing difference is not checked for ranges within 1 NM due to the error in the bearing calculated from ADS-B position at small ranges.*

For systems performing validation based on active surveillance output data, the DAA system **shall (113)** revalidate the ADS-B position data of traffic at least once every 10 seconds.

Note: *For a system integrated with hybrid surveillance based on RTCA DO-300 or RTCA DO-300A, it is not the intent to perform any additional interrogations beyond RTCA DO-300 or RTCA DO-300A. In RTCA DO-300, the interval between revalidation is either 10 or 60 seconds. In RTCA DO-300A, the interval between revalidation varies from 10 up to a maximum of 60 seconds based on range and range rate.*

The absolute difference in Time of Applicability between the ADS-B position data with the active surveillance data, when used for validation, **shall (114)** be no more than 250 ms.

2.2.3.2.1.3.4.2 Validation of Traffic Position with Radar Data

The DAA system **shall (115)** pass the validation test with radar data if:

|slant range difference| < 0.25 NM; and

|bearing difference| ≤ 15 degrees and range > 1 NM; and

|altitude difference| < sqrt (32000 + 70300 R^2)', where sqrt is the square root and R is the slant range in units of NM.

For systems performing validation based on radar data, the DAA system **shall (116)** revalidate the ADS-B position data of traffic at least once every 10 seconds.

The absolute difference in Time of Applicability between the ADS-B position data with the radar data, when used for validation, **shall (117)** be no more than 250 ms.

2.2.3.2.1.4 Track Termination

The DAA system **shall (118)** terminate a track when the track accuracy is greater than 125% of the required track accuracies for a duration of 8 seconds.

The track may still be output when certain parameters do not meet the required performance.

- If only the estimated track uncertainty of vertical position is greater than 125% of the required track accuracies for a duration of 8 seconds, the track should still be output, but **shall (119)** be treated as a non-altitude reporting target.
- If only the estimated track uncertainty of horizontal positions are greater than 125% of the required track accuracies for a duration of 8 seconds, the track should still be output, but **shall (120)** be treated as a non-bearing reporting target.

Note: *This requirement is related to bearing uncertainty and non-bearing reporting intruders. If the outputs are range/bearing or polar not Cartesian, equivalent performance metrics in those coordinates should be used.*

2.2.3.2.2 Data Association

The purpose of data association, or inter-source correlation, is to ensure that an aircraft detected by different surveillance sources produces a single track.

Individual ADS-B/ADS-R reports **shall (121)** be used for data association only after they have passed the report validation checks given in Subparagraph 2.2.3.2.1.3.1. Data association obtained with an address match **shall (122)** take precedence over correlation obtained with another method.

The inter-source correlation requirements presented in this subparagraph are defined for the following conditions:

1. Maximum aircraft horizontal acceleration of 1.5 g (14.7 m/s^2)
2. Maximum aircraft ground speed of 600 knots
3. Maximum time between received ADS-B and ADS-R reports (airborne traffic) of 6 seconds
4. Maximum time between received radar reports of 3 seconds
5. Minimum NACp of 7 (< 0.1 NM) for all ADS-B and ADS-R report updates.

Decorrelation refers to the removal of the established correlation between tracks from different sources on the same aircraft. Miscorrelation is defined as the match of different sources that are not from the same aircraft. Spatial correlation refers to any correlation not using an ICAO address match.

Note:

1. *Miscorrelation should not affect the decorrelation rate, as any subsequent decorrelation that may occur for incorrectly matched tracks is appropriate. However, a miscorrelation may affect the correlation rate if the subsequent correct decorrelation and correlation of sources requires more updates than given below.*
2. *ADS-B reports have either ICAO or non-ICAO addresses to uniquely identify the aircraft. Mode S reports typically have an ICAO address to identify them but the output surveillance information provided from a TCAS II bus may not include the ICAO address. Detected aircraft received from Mode C and the onboard radar contain a source-defined identifier, which cannot be used to match data between disparate sources. Therefore, at times, spatial correlation will be necessary to integrate data from the various sensors.*

Two methods of inter-source correlation of tracks are possible. One method is used if the track has been assigned an ICAO address. Since these addresses are unique for a given aircraft, inter-source correlation is accomplished if an address match track is found, and a reasonableness check is passed.

The second case is where the track address has been assigned by the source surveillance sensor, and thus an address match with the track is not possible. A correlation technique can be applied that uses other track characteristics such as position and position history; such a technique is termed a “spatial” correlation method, but non-positional track information such as velocity or Flight ID (if provided) may be used as well.

If tracks on the same aircraft have matching ICAO addresses, then the DAA system **shall (123)** correlate these tracks with the following performance:

1. At least a 99% correlation rate for the first report and subsequent track updates.
2. Less than the maximum permitted decorrelation rate of 0.2% after correct correlation has been achieved.
3. Less than a 0.2% miscorrelation rate.

If the spatial correlation of tracks is implemented, then the DAA system **shall (124)** correlate these tracks for the same aircraft with the following performance:

1. At least a 95% correlation rate the first report and subsequent track updates
2. Less than the maximum permitted decorrelation rate of 1% after correct correlation has been achieved
3. Less than a 1% miscorrelation rate.

For these MOPS, it is assumed that the radar is providing unique tracks. Therefore, DAA **shall (125)** not associate multiple radar tracks with different IDs.

2.2.3.2.3 Intruder State Estimation

Intruder state estimation has multiple meanings. For DAA tracking, it means the estimation of intruder positions, velocities, and associated uncertainties at the current epoch. This is done by using current or past surveillance data as defined in Subparagraph 2.2.2.1. These surveillance sources may provide a full set of data (such as ADS-B, which may provide at the same epoch both position and velocity data) but still need to be estimated at the current Time of Applicability (TOA), or a subset of data such that relative positions and velocities need to be estimated at the current TOA (e.g., estimated relative intruder velocities based on current and past position information). This process may also involve several reference frame transformations of not just the mean (sensor measurements), but also transformations of the variances.

The state estimation requirements below describe the required performance of the tracker outputs, or estimated intruder states, based on the source surveillance sources described in Subparagraph 2.2.1.2. Because source performance varies by sensor, track output performance requirements will also be based on source (e.g., tracker performance based on active surveillance only).

Track state data **shall (126)** be estimated to provide the information necessary to support alerting and guidance computations as outlined in Paragraph 2.2.4.

All elements of the traffic report are summarized in Table 2-13, which is repeated here for clarity.

Table 2-19 UA DAA Prioritized Track State Output Data

Intruder Traffic Report	Notes
Unique Track ID	
Flight ID	e.g., the aircraft flight number or the tail number
Time of Applicability	
Intruder Alert/Priority	
Source Data Type	
Validated ADS-B	Validated, Unvalidated, or Previously Validated. See Subparagraph 2.2.3.2.1.3.4 2.2.3.2.1.3.4
Air/Ground Status	
Relative Horizontal Position	See Subparagraph 2.2.3.2.3 for performance requirements. May be Relative Range/Bearing or Relative Lat/long.
Relative Horizontal Position Accuracy	See Subparagraph 2.2.3.2.3 or performance requirements.
Bearing Invalid	Set to TRUE per 2.2.3.2.1.1 only when horizontal position does not meet accuracy requirements.
Relative Horizontal Velocity	See Subparagraph 2.2.3.2.3 for performance requirements.
Relative Horizontal Velocity Accuracy	
Relative Altitude	See Subparagraph 2.2.3.2.3 for performance requirements.
Relative Altitude Accuracy	
Altitude Invalid	Set to TRUE per 2.2.3.2.1.1
Relative Vertical Velocity	See Subparagraph 2.2.3.2.3 for performance requirements.
Relative Vertical Velocity Accuracy	

The tracker **shall (127)** provide the estimated relative barometric altitude unless not available. If not available, the tracker **shall (128)** provide relative geometric altitude.

Because surveillance performance changes by source, the track state **shall (129)** have the minimum performance listed in Table 2-20 when the track is solely determined from a given source. If multiple surveillance sources are used to estimate intruder states, the track state **shall (130)** at least meet the minimum performance as defined in Table 2-20 for the single sources used to estimate the track states.

Note that while the track report may contain both relative and absolute values, the performance requirements identified in Table 2-20 are defined as relative state (intruder state – ownship state) performance.

Table 2-20 Single-Source Integrated Track Performance

Surveillance Sensor	Performance Metric	Metric Threshold (95%)
ADS-B	Horizontal Position	900’
	Vertical Position	300’
	Horizontal Velocity	30 kts
	Vertical Velocity	400 fpm
Radar	Horizontal Position	125*(x – 1 NM) + 250’ (1 NM, 6.7 NM)
	Vertical Position	100*(x – 1 NM) + 150’ (1 NM, 6.7 NM)
	Horizontal Velocity	10*(x – 1 NM) + 50 kts (1 NM, 6.7 NM)
	Vertical Velocity	380*(x – 1 NM) + 800 fpm (1 NM, 6.7 NM)
Active Surveillance	Horizontal Position	1000*(x – 0.5 NM) + 1250’ (0.5 NM, 14 NM)
	Vertical Position	300’
	Horizontal Velocity	33*(x – 0.5 NM) + 85 kts (0.5 NM, 14 NM)
	Vertical Velocity	400 fpm

Note:

1. *Some sensors are in polar coordination or change performance as a function of range, so the Cartesian performance metrics are written as a function of range.*

2. *Modeling assumptions and M&S results are presented in Appendix Q for the derivation of these requirements. This process used minimum performance for the respective sensors based on their respective MOPS.*

3. *Due to sensor performance and short ranges and because of the relative accelerations that occur at close ranges, these performance requirements cannot be guaranteed at short ranges. An effort to meet these requirements should be made if possible.*

4. *Ownship states were used as is – no ownship filtering was used as shown in Appendix Q. Ownship filtering may provide some system level performance improvements (such as smoother states, etc.) at the expense of filtering (such as lag, etc.). These MOPS did not use ownship filtering due to the expected accuracies of the Inertial Navigation Systems (INS) and/or GNSS systems likely to be used on these larger UAS platforms.*

5. *Radar performance is only guaranteed within the Radar Declaration Range (RDR) (within 6.7 NM), so the radar requirements are only defined to 6.7 NM. (see the MOPS for Air-to-Air Radar for Traffic Surveillance (RTCA Paper No. 170-16/SC228 034)). Nominally, this requirement would extend to larger ranges if the source radar performance meets the minimum performance requirements at those ranges.*

The track report estimates **shall (131)** be generated and output at a minimum rate of 1 Hertz (Hz).

2.2.3.2.3.1 Individual Time of Track Extrapolation and Traffic State File Generation

Data processing and update intervals result in increased data age, which reduces the usability of dynamic data. To improve the usability of traffic and ownship state data, it has been deemed necessary to require a maximum difference between the TOA of the track data and the time at which the data is being used. For requirements relating to alerting and guidance, the time at which the data is being used has been defined to be the time the data first is available for alerting (Interface B1).

The latency compensation error introduced by the DAA tracker between Interface B and Interface B1 (see Figure 2-2) **shall (132)** be no more than 100 ms.

2.2.4 DAA Alerting and Guidance Processing Requirements

This paragraph contains requirements related to DAA alerting and guidance processing. Subparagraph 2.2.4.1 and Subparagraph 2.2.4.2 apply to both alerting and guidance. Subparagraph 2.2.4.3 contains the DAA alerting requirements, Subparagraph 2.2.4.4 contains maintain DAA Well Clear (DWC) and regain DWC guidance requirements, and Subparagraph 2.2.4.5 contains collision avoidance interoperability requirements for DAA guidance.

2.2.4.1 DAA Alert and Guidance Suppression Requirements

Since DAA systems using these MOPS are not designed for the airport or recovery zone/launch environments, a mechanism is needed to prevent flight crew distraction from nuisance alerts. This is accomplished by inhibiting alerts and guidance for all intruders during the takeoff, landing, and possibly airport VFR pattern phases of flight or phases when other means of separation are being provided. This inhibit/uninhibit mechanism must be automatic for takeoff and landing phases to prevent an increase in workload during critical phases of flight and to prevent the system from accidently being left inhibited when needed. Additionally, a manual mechanism is necessary for operationally-defined situations when other means of separation are being provided.

The design of this mechanism is left to the manufacturer due to the variety of UAS launch and recovery methods. One example of an automatic inhibit mechanism could be one in which the DAA system alerts are suppressed below a certain altitude AGL as sensed by a radio altimeter, with the altitude set by the UAS PIC based on system limitations or operational procedures. Another example is an inhibit mechanism where DAA system alerts are suppressed when the gear or flaps are extended. Additional manual inhibit mechanisms may also be used.

The DAA system **shall (178)** have an automatic inhibit mechanism to inhibit DAA alerts during takeoff and landing.

The DAA system **shall (179)** have an automatic inhibit mechanism to inhibit DAA guidance during takeoff and landing.

Regardless of how the automatic inhibit mechanism is designed, there **shall (180)** be a function available to the PIC to manually enable and disable DAA alerts and guidance. This manual function may be used by the PIC for the purposes of troubleshooting or when directed by operational procedures.

Note:

1. *Sensor feeds may be removed from the source track correlation function independently when they are no longer valid, e.g., ADS-B only tracks when the ADS-B receiver has failed, but this should not inhibit all DAA alerts and guidance. There is an expectation of graceful system degradation, so no sensor validity triggers are included for inhibiting alerts and guidance.*

2. *The inhibit mechanism should be configurable to allow the threshold for inhibiting alerts to be set based on operational needs.*
3. *FAA Advisory Circular (AC) 25.1322-1 provides additional guidance on inhibiting alerts.*

The DAA system **shall (181)** inhibit DAA alerts when the ownship's Airborne/On-ground status is "On-ground."

The DAA system **shall (182)** inhibit DAA guidance when the ownship's Airborne/On-ground status is On-ground.

The DAA system **shall (183)** provide an indication to the display processor when alerts and/or guidance are inhibited. It is expected that alert and guidance inhibitions are coupled, but if they are independent, then two separate indications would be needed. See Subparagraph 2.2.5.7 for the related display requirements.

2.2.4.1.1 Intruder-Specific Alerting and Guidance Suppression

The DAA system **shall (184)** inhibit DAA alerts for an intruder that has an Airborne/On-ground status indicated as On-ground.

The DAA system **shall (185)** inhibit DAA guidance for an intruder that has an Airborne/On-ground status indicated as On-ground.

2.2.4.2 Ownship Intent Information Requirements

If ownship intent information is used, alert and guidance determinations occur along the flight plan and/or autopilot setting track prediction rather than extrapolating along the ownship's best state estimate. Intent information is knowledge of the future state of an aircraft not based on current trajectory information, but on information within the Flight Management System (FMS), autopilot, or autoflight system. Only information about what the ownship will automatically execute can be used. For example, flight plan information cannot be used while the ownship is in a heading autopilot mode.

To improve DAA guidance and alerting and to reduce PIC nuisance alerts, the DAA system may use automatically executed intent information (e.g., flight plan, altitude level-offs) instead of ownship future state extrapolation. This intent information has limited benefits due to the linearly projected nature of the Well Clear definition.

If ownship intent information is used to aid ownship track prediction, the ownship track prediction **shall (186)** use future horizontal, vertical, and speed changes that the ownship will automatically execute.

Note: *The corollary of this requirement is that if ownship intent information is not available or won't be automatically executed, then normal alerting per Subparagraph 2.2.4.3.4 will be used.*

If ownship intent information is used, alerting and guidance test pass/fail criteria may need to be modified to account for future ownship path knowledge. Otherwise alerts may be expected that are not generated due to intent information and likewise alerts may be generated when using intent information that were unnecessary when using linear projection.

2.2.4.3 DAA Alerting Requirements

Alerts can be a combination of aural and visual information given to the PIC and should comply with appropriate alerting regulations (e.g., 14 CFR 23.1322, 25.1322, 27.1322, and 29.1322). This subparagraph contains the requirements for triggering the alerts. Requirements for the visual display of the alerts are in Subparagraph 2.2.5.6.2.3, and requirements for the aural alert information are in Subparagraph 2.2.5.11.1.1.

The requirements for alerting are irrespective limitations due to sensor range or field of regard. The sensor range and field of regard requirements are defined in the applicable sensor requirements. In some encounters, intruders may be detected by the sensor within the alerting thresholds, in which case the intruder will initially be displayed in an alerted state.

2.2.4.3.1 DAA Well Clear (DWC) Definition

The qualitative definition of DWC is "a temporal and/or spatial boundary around the aircraft intended to be an electronic means of avoiding conflicting traffic." Please see Subsection C.5 for the quantitative definition.

2.2.4.3.2 Hazard Zone Definition

Each DAA alert type in the following alerting sections involves a specified hazard and non-hazard zone. The definition of the formulation of these zones is common and stated in this subparagraph while the variable parameters (τ^*_{mod}, HMD^*, h^*, and DMOD) are specified in Table 2-21 and referenced by the applicable requirements. The hazard zones are based on the Well Clear definition in Appendix C, which also contains details about the analysis behind the definition.

These hazard and non-hazard zones are used to define the trade space for when alerts must and must not be generated, but are not meant to imply a specific alerting algorithm. They are based on the DWC definition, but do not otherwise account for avoiding ownship RAs in Class 2 equipment. A manufacturer will develop an alerting algorithm that determines when to issue alerts; these alerts will then be evaluated against the hazard/non-hazard zones to determine the system's alerting performance. Using the hazard zone/non-hazard zone definitions as alerting thresholds will result in undesirable alerting behaviors and is discouraged; rather, manufacturers may use additional parameters, filters, buffers, or functions to achieve acceptable performance. For Class 2 equipment, different logic may be necessary for intruders that can cause RAs to reduce undesirable RAs when following DAA guidance. A possible implementation could be an alert triggering threshold between the Hazard and Non-Hazard zones with additional hysteresis and filtering as described in the reference implementation described in Appendix G.

Alerting requirements are based on the structure of the hazard/non-hazard zones, which are used to simplify compliance determinations without extensive analyses of alerting system performance.

An intruder is within a hazard zone when:

$$[r \leq S^*] \text{ AND } \left[HMD_p \leq HMD^*\right] \text{ AND } [d_h \leq h^*] == TRUE$$

where:

r is the current horizontal range between aircraft,

S^* is the horizontal size of the hazard zone for the alert type (the well clear τ^*_{mod} equation solved for range),

HMD_p is predicted Horizontal Miss distance at the Closest Point of Approach (CPA),

HMD^* is the Horizontal Miss distance threshold for the alert type,

d_h is the current vertical separation, and

h^* is the vertical separation threshold for the alert type.

The hazard zone is violated for a given point in time when all three conditions are true.

Horizontal range (r) is defined as:

$$r = \sqrt{{d_x}^2 + {d_y}^2}$$

where:

$d_x = x_2 - x_1$ is the current horizontal separation in the x dimension, and

$d_y = y_2 - y_1$ is the current horizontal separation in the y dimension.

The horizontal size of the hazard zone for a given alert type (S^*) is the value against which the horizontal range is compared, and is defined as:

$$S^* = \max\left(DMOD, \frac{1}{2}\left(\sqrt{(\dot{r}\,\tau^*_{mod})^2 + 4DMOD^2} - \dot{r}\,\tau^*_{mod}\right)\right)$$

where:

DMOD is the Distance Modification of Modified Tau,

$\dot{r} = \frac{d_x \cdot v_{rx} + d_y \cdot v_{ry}}{r}$ is the horizontal range rate between the aircraft (negative for closing geometries),

$v_{rx} = \dot{x}_2 - \dot{x}_1$ is the relative horizontal velocity in the x dimension,

$v_{ry} = \dot{y}_2 - \dot{y}_1$ is the relative horizontal velocity in the y dimension, and

τ^*_{mod} is the Modified Tau Threshold for the alert.

In all cases:

$$Horizontal\ Miss\ Distance\ (HMD^*) = DMOD$$

Note:

1. *If $HMD^* \neq DMOD$, then alerts may oscillate on and off with an un-accelerating ownship and intruder, which is an undesired behavior. For more information, see César Muñoz and Anthony Narkawicz, Formal analysis of extended well-clear boundaries for unmanned aircraft, Proceedings of the 8th NASA Formal Methods Symposium (NFM 2016), Lecture Notes in Computer Science, Vol. 9690, 2016.*
2. *All ranges and range rates are in the horizontal dimension and are not slant ranges.*
3. *These equations just define the values, but do not imply that the values must be calculated in this manner.*

Predicted Horizontal Miss Distance (HMD_p) is defined as:

$$HMD_p = \sqrt[2]{(d_x + v_{rx}t_{CPA})^2 + (d_y + v_{ry}t_{CPA})^2}$$

where:

$$t_{CPA} = max(0, -\frac{d_x v_{rx} + d_y v_{ry}}{v_{rx}^2 + v_{ry}^2})$$

Note: *$\boldsymbol{t_{CPA}}$ is the time to closest point of approach; positive for closing geometries and 0 for all others.*

The Horizontal Miss Distance threshold (HMD^*) is the value against which the HMD_p is compared for a given alert type.

Current vertical separation (d_h) is defined as:

$$d_h = abs(h_1 - h_2)$$

Vertical separation for alerting performance requirements is based on relative altitudes, so they can be calculated either by comparing reported barometric altitudes (for cooperative aircraft) or comparing true geometric altitudes (HAE, for non-cooperative aircraft), but not using one of each altitude type.

The vertical separation threshold (h*) is the value against which the current vertical separation is compared for a given alert type.

2.2.4.3.3 Non-Hazard Zone Definition

An intruder is within the non-hazard zone for a particular alert type when:

$$[r > S^*]\ OR\left[HMD_p > HMD^*\right]\ OR\,[d_h > V]\ == TRUE$$

where all the parameters are defined in the same manner as the hazard zone in Subparagraph 2.2.4.3.2, but with different values, with the addition of V.

The Vertical Proximity (V) is defined as:

$$V = max(VMOD, VMOD - \dot{h}_r \tau^*_{mod})$$

where:

VMOD is the Vertical Modification for the alert type, and

$\dot{h}_r$ is the vertical closure rate between the two aircraft.

The vertical closure rate ($\dot{h}_r$) is defined as:

$$\dot{h}_r = \dot{z}_2 - \dot{z}_1$$

where $\dot{h}_r$ is negative for closing geometries. Vertical position matters to ensure the correct sign. The vertical size of the non-hazard zone scales with vertical closure rate in order to ensure alerts can occur as early as the early alerting threshold during high vertical closure rate encounters.

2.2.4.3.4 Alert Types and Prioritization

This subparagraph contains the alerting requirements for the preventive, corrective, and warning alerts. The requirement structure for each alert is the same, using the Hazard Zone and Non-Hazard Zone formulations from Subparagraphs 2.2.4.3.2 and 2.2.4.3.3, respectively. Table 2-21 contains the parameter values used for each DAA alert Hazard and Non-Hazard Zone, along with the minimum average alert time and the early and late alert thresholds used in this subparagraph's requirements. The average, early, and late alert times are relative to the time at which the Hazard Zone is violated. The alert times are applicable to the test cases in these MOPS. A different set of test cases may lead to an acceptable system having a different average alert time or not meeting the early or late times. These alerting requirements are used to define the trade space for when alerts are and are not to be generated, but are not meant to imply implementation of a specific alerting algorithm.

Table 2-21 Parameters for DAA Alerting Requirements

Alert Type →		**Preventive Alert**	**Corrective Alert**	**Warning Alert**
Alert Level →		**Caution**	**Caution**	**Warning**
Hazard Zone	**τ^*_{mod} (Seconds)**	35	35	35
	DMOD and HMD* (Feet)	4,000	4,000	4,000
	h* (Feet)	700	450	450

Alert Type →		Preventive Alert	Corrective Alert	Warning Alert
Alert Level →		**Caution**	**Caution**	**Warning**
Hazard Zone Alert Times	**Minimum Average Time of Alert (Seconds)**	55	55	25
	Late Threshold (THR_{Late}) (Seconds)	20	20	15
	Early Threshold (THR_{Early}) (Seconds)	75	75	55
Non-Hazard Zone	**τ^*_{mod} (Seconds)**	110	110	90
	DMOD and HMD*(NM)	1.5	1.5	1.2
	VMOD (Feet)	800	450	450

For more information on the sources of these alerting requirements, see Paragraph L.2.3, DAA Open and Closed Loop Metrics. The alerting requirements may change in future versions of these MOPS with the integration of a non-TCAS Collision Avoidance system.

A specific algorithm is not required for setting these alerts. The following "must-alert" and "must-not-alert" requirements for each alert type are meant to bound the performance of the system while not prescribing any specific algorithm. The test tracks used in Appendix P have been designed so that all tracks can be alerted upon with sufficient time to meet the late alert time and exceed the average alert time. However, there may be other unlikely encounters with high dynamics where these requirements cannot be met.

Implementing an alerting and guidance scheme using simple predictions and the hazard zone values directly from the requirements will result in unacceptable performance and will not pass the average alert time requirements. It will also result in numerous TCAS RAs from an ownship TCAS for Class 2 systems while following DAA guidance and without the presence of DAA alerts. The two major drivers of this behavior are the time-to-co-altitude value used in TCAS, but not in the definition of the hazard zone, and the larger DMOD values for TCAS above 10,000'. The parameter values listed in the reference implementation in Appendix G, including a DMOD of 1.0 NM and 20-second time-to-co-altitude, reduce this undesirable behavior. However, since the reference implementation estimates HMD using a method consistent with the well clear definition that differs from the one used in TCAS (which may inhibit the HMD filter depending on the quality of data and other conditions), there will still be some TCAS RAs that occur without the presence of DAA alerts and guidance.

There are no requirements as to when to stop alerting; the implementation is left up to the manufacturer. However, an implication of combining these alerting requirements with the minimum visual guidance requirements in Subparagraph 2.2.4.4 is that an intruder will remain in alert state from at least the late alert threshold until leaving the hazard zone. Otherwise the guidance would not be consistent with the alerting state of the intruder.

2.2.4.3.4.1 Prioritization of Alert Types

Each intruder **shall (187)** have only one alert status at any point in time. If an intruder meets the criteria of more than one alert, the intruder's alert status **shall (188)** be set in the following order:

1. TCAS II Corrective RA (Equipment Class 2 systems only)
2. Warning Alert
3. Corrective Alert
4. Preventive Alert

Intruder tracks are prioritized for transmissions via the data link and for display. Intruders **shall (189)** be prioritized in the following order for display:

1. TCAS II RA status (Equipment Class 2 systems only)
2. Warning Alert status
3. Corrective Alert status
4. Preventive Alert status
5. Guidance Traffic status (Display Only)
6. Remaining traffic

For Class 2 DAA systems (those integrated with TCAS II), tracks with RA status **shall (190)** be ordered in the track priority assigned by the TCAS II system.

For both Class 1 and Class 2 DAA systems, tracks with the same alert level that have not been ordered by the TCAS II system **shall (510)** be ordered by increasing horizontal range between the ownship and the intruder.

Note: *Prioritization based on range is consistent with RTCA DO-317B, §2.2.2.1.5.1.2.*

Intruders **shall (191)** be prioritized for transmissions via the data link using either the display prioritization order or the order defined in Subparagraph 2.2.3.2.1.2.

Alert status for each intruder **shall (192)** be updated at a minimum rate of 1 Hertz.

2.2.4.3.4.2 Preventive Alert

The DAA preventive alert is intended to draw PIC attention to traffic that would trigger a corrective alert if the ownship and/or the intruder maneuvers in the vertical direction. It is intended to capture aircraft separated by 500' pressure altitude when both aircraft are level, but is specified such that it could capture additional geometries as well. It is not meant to be a pre-alert prior to DAA corrective alerts for non-accelerating encounters. It is expected that the PIC, upon receiving a preventive alert, will maintain altitude unless necessary and will monitor the intruder aircraft for a change in altitude. If an ownship maneuver is required, the PIC will take into account the position and path of the intruder beforehand.

When both the intruder and the ownship remain level within ±128 fpm, no preventive alert **shall (193)** precede a corrective alert.

The preventive alert is a caution-level alert.

Note: *FAA AC 25.1322-1 and FAA AC 23.1311-1 provide more information on alert levels.*

The DAA system **shall (194)** provide a preventive alert at least 20 seconds prior to an intruder entering the preventive hazard zone (as defined in Subparagraph 2.2.4.3.2), using the parameter values in Table 2-21. However, in certain combinations of operational dynamics and geometries the performance required under this requirement is unachievable. For those cases, a preventive alert **shall (195)** be provided prior to 5 seconds after an intruder enters the preventive hazard zone.

This requirement should not be interpreted as a required algorithm implementation, but is only meant to identify a point within an encounter timeline. An example of such a geometry includes flying above to an intruder and the intruder descending towards the ownship, causing a preventive hazard zone violation in less than 20 seconds. Test vectors within Appendix P provide additional examples of geometries where the alternate threshold for determining late alerts is used.

The DAA system **shall (196)** provide preventive alerts with an average time to alert at least 55 seconds prior to intruders entering the preventive hazard zone (as defined in in Subparagraph 2.2.4.3.2) using the parameter values in Table 2-21.

A preventive alert **shall (197)** persist for a minimum of four seconds, unless the intruder is declared a higher priority alert.

Note: *The four-second minimum display is based on Traffic Situational Awareness with Alerts (TSAA) alert duration in RTCA DO-317B, §2.2.4.5.5, except as adjusted based on the expected duration of the DAA audio annunciations. After four seconds, the alert would be removed immediately upon the system's alert criteria no longer being met. Including a minimum alert duration assists in preventing the intruder from visually changing appearance during the aural annunciation of an alert. Consideration should be taken for intruders that may go out of and back into alert status during the annunciation of an alert, thus triggering a second issuance and annunciation of an alert for the same intruder, as alert queuing may not be desirable in this case.*

The DAA system **shall (198)** generate no preventive alerts more than 75 seconds prior to an intruder entering the preventive hazard zone (as defined in in Subparagraph 2.2.4.3.2) using the parameter values in Table 2-21. However, in certain combinations of operational dynamics and geometries the performance required under this requirement is unachievable. For those cases, DAA system **shall (199)** generate no preventive alerts prior to leaving the preventive non-hazard zone (as defined in Subparagraph 2.2.4.3.2).

An example of such a geometry includes an intruder flying towards the preventive hazard zone with predicted entry in less than 75 seconds using linear projections, followed by a maneuver that delays entry to the preventive hazard zone. Test vectors within Appendix P provide additional examples of geometries where the alternate threshold for determining early alerts is used.

The DAA system **shall (200)** generate no preventive alerts when an intruder remains in the preventive non-hazard zone (as defined in in Subparagraph 2.2.4.3.3) using the parameter values in Table 2-21.

Note: *The non-hazard zone is not a non-alert zone. Alerts may occur in the non-hazard zone. This requirement is meant to be evaluated across an entire encounter with an intruder.*

Surveillance sensors onboard the UA have inherent errors, noise, and biases, which will skew the position and velocity state data of the ownship and traffic aircraft. The requirements for generating preventive alerts and generating no preventive alerts are based on the true relative position of the ownship and the intruder; however, the DAA system **shall (201)** be able to provide preventive alerts with surveillance errors up to the errors in Table 2-20. See Appendix Q for more information on surveillance errors.

2.2.4.3.4.3 Corrective Alert

The DAA corrective alert is intended to get the PIC's attention, get the PIC to determine a needed maneuver, start PIC coordination with ATC, and is the earliest point at which the PIC is expected to begin maneuvering, per their judgment, to maintain DWC. The corrective alert necessitates immediate awareness of the PIC and subsequent PIC response.

The corrective alert is a caution-level alert.

Note: *FAA AC 25.1322-1 and FAA AC 23.1311-1 provide more information on alert levels.*

The corrective alert is intended to be provided in sufficient time for the PIC to assess the situation and coordinate a maneuver with ATC. It is also intended to provide enough time when ATC is not providing separation services to the UAS for the PIC to assess the situation and determine an appropriate action to maintain DWC.

The DAA system **shall (202)** provide a corrective alert at least 20 seconds prior to an intruder entering the corrective hazard zone (as defined in in Subparagraph 2.2.4.3.2) using the parameter values in Table 2-21. However, in certain combinations of operational dynamics and geometries the performance required under this requirement is unachievable. For those cases, a corrective alert **shall (203)** be provided prior to 5 seconds after an intruder enters the corrective hazard zone.

This requirement should not be interpreted as a required algorithm implementation, but is only meant to identify a point within an encounter timeline. An example of such a geometry includes flying parallel to an intruder and the intruder turning into the ownship, causing a corrective hazard zone violation in less than 20 seconds. Test vectors in

Appendix P provide additional examples of geometries where the alternate threshold for determining late alerts is used.

The DAA system **shall (204)** provide corrective alerts with an average time to alert at least 55 seconds prior to intruders entering the corrective hazard zone (as defined in in Subparagraph 2.2.4.3.2) using the parameter values in Table 2-21.

A corrective alert **shall (205)** persist for a minimum of four seconds, unless the intruder is declared a higher priority alert.

Note: *The four-second minimum display is based on TSAA alert duration in RTCA DO-317B §2.2.4.5.5, except adjusted based on the expected duration of the DAA audio annunciations. After four seconds, the alert would be removed immediately upon the system's alert criteria no longer being met. Including a minimum alert duration assists in preventing the intruder from visually changing appearance during the aural annunciation of an alert. Consideration should be taken for intruders that may go out of and back into alert status during the annunciation of an alert, thus triggering a second issuance and annunciation of an alert for the same intruder, as alert queuing may not be desirable in this case.*

The DAA system **shall (206)** generate no corrective alerts more than 75 seconds prior to an intruder entering the corrective hazard zone (as defined in in Subparagraph 2.2.4.3.2) using the parameter values in Table 2-21. However, in certain combinations of operational dynamics and geometries the performance required under this requirement is unachievable. For those cases, DAA system **shall (207)** generate no corrective alerts prior to leaving the corrective non-hazard zone (as defined in Subparagraph 2.2.4.3.3).

An example of such a geometry includes an intruder flying towards the corrective hazard zone with predicted entry in less than 75 seconds using linear projections, followed by a maneuver that delays entry to the corrective hazard zone. Test vectors within Appendix P provide additional examples of geometries where the alternate threshold for determining early alerts is used.

The DAA system **shall (208)** generate no corrective alerts when an intruder remains in the corrective non-hazard zone (as defined in in Subparagraph 2.2.4.3.3) using the parameter values in Table 2-21.

Note: *The non-hazard zone is not a non-alert zone. Alerts may occur in the non-hazard zone. This requirement is meant to be evaluated across an entire encounter with an intruder.*

Surveillance sensors onboard the UA have inherent errors, noise, and biases, which will skew the position and velocity state data of the ownship and traffic aircraft. The requirements for generating corrective alerts and generating no corrective alerts are based on the true relative position of the ownship and the intruder; however, the DAA system **shall (209)** be able to provide corrective alerts with surveillance errors up to the errors in Table 2-20. See Appendix Q for more information on surveillance errors.

2.2.4.3.4.4 Warning Alert

The DAA warning alert is intended to inform the PIC that immediate action is required to maintain DWC. The warning alert necessitates immediate awareness of the PIC and a prompt ownship maneuver.

The warning alert is a warning-level alert.

Due to possible ADS-B errors, unvalidated ADS-B position information cannot be used for directive or warning information. Validated or previously validated ADS-B data can be used for warning alerts. If an ADS-B-only intruder is marked unvalidated per Subparagraph 2.2.3.2.1.3.4, the intruder **shall (210)** remain a DAA corrective alert even if it meets the criteria for a DAA warning alert.

The DAA system **shall (211)** provide a warning alert at least 15 seconds prior to an intruder entering the warning hazard zone (as defined in in Subparagraph 2.2.4.3.2) using the parameter values in Table 2-21. However, in certain combinations of operational dynamics and geometries the performance required under this requirement is unachievable. For those cases, a warning alert **shall (212)** be provided prior to 5 seconds after an intruder enters the warning hazard zone.

This requirement should not be interpreted as a required algorithm implementation, but is only meant to identify a point within an encounter timeline. An example of such a geometry includes flying parallel to an intruder and the intruder turning into the ownship, causing a warning hazard zone violation in less than 15 seconds. Test vectors within Appendix P provide additional examples of geometries where the alternate threshold for determining late alerts is used.

The DAA system **shall (213)** provide warning alerts with an average time to alert at least 25 seconds prior to intruders entering the warning hazard zone (as defined in in Subparagraph 2.2.4.3.2) using the parameter values in Table 2-21.

A warning alert **shall (214)** persist for a minimum of four seconds, unless the intruder is declared a TCAS Corrective RA (for Class 2 DAA systems).

Note: *The four-second minimum display is based on TSAA alert duration in RTCA DO-317B §2.2.4.5.5, except adjusted based on the expected duration of the DAA audio annunciations. After four seconds, the alert would be removed immediately upon the system's alert criteria no longer being met. Including a minimum alert duration assists in preventing the intruder from visually changing appearance during the aural annunciation of an alert. Consideration should be taken for intruders that may go out of and back into alert status during the annunciation of an alert, thus triggering a second issuance and annunciation of an alert for the same intruder, as alert queuing may not be desirable in this case.*

The DAA system **shall (215)** generate no warning alerts more than 55 seconds prior to an intruder entering the warning hazard zone (as defined in in Subparagraph 2.2.4.3.2) using the parameter values in Table 2-21. However, in certain combinations of operational dynamics and geometries the performance required under this requirement is unachievable. For those cases, DAA system **shall (216)** generate no warning alerts prior to leaving the warning non-hazard zone (as defined in Subparagraph 2.2.4.3.3).

An example of such a geometry includes an intruder flying towards the warning hazard zone with predicted entry in less than 55 seconds using linear projections, followed by a maneuver that delays entry to the warning hazard zone. Test vectors within Appendix P provide additional examples of geometries where the alternate threshold for determining early alerts is used.

The DAA system **shall (217)** generate no warning alerts when an intruder remains in the warning non-hazard zone (as defined in in Subparagraph 2.2.4.3.3) using the parameter values in Table 2-21.

Note: *The non-hazard zone is not a non-alert zone. Alerts may occur in the non-hazard zone. This requirement is meant to be evaluated across an entire encounter with an intruder.*

Surveillance sensors onboard the UA have inherent errors, noise, and biases, which will skew the position and velocity state data of the ownship and traffic aircraft. The requirements for generating warning alerts and generating no warning alerts are based on the true relative position of the ownship and the intruder; however, the DAA system **shall (218)** be able to provide warning alerts with surveillance errors up to the errors in Table 2-20. See Appendix Q for more information on surveillance errors.

2.2.4.3.5 Alerting Special Cases

In some situations, data from the sensors may not be available to support compliance with the alerting requirements in Subparagraph 2.2.4.3.4. The following subparagraphs specify alerting behavior in those special cases where full information is not available. The normal alerting requirements are required to be met, such as average alerting time, early/late alert times, etc., with the exceptions required by this subparagraph. See Subparagraph 2.2.4.4 for details on how the guidance processing creates different guidance for these special cases.

2.2.4.3.5.1 Radar Only

For aircraft being tracked by the radar only (non-cooperative aircraft), the altitude and vertical rate estimations may have large vertical uncertainties such that vertical predictions of altitude cannot be used for alerting purposes. In the case of high uncertainty, a larger non-hazard zone is defined to allow more flexibility in implementing an alerting system that accounts for the large uncertainty. These requirements use the same horizontal and vertical hazard zone boundaries and horizontal non-hazard zone boundaries as the normal alerting requirements. Using the same horizontal requirements still bounds timeliness and incorrect alerts.

One acceptable means of meeting these requirements is to treat the radar only intruder as co-altitude for alerting when it is estimated to be within 3000’ vertically. Other implementations that take vertical position uncertainty and vertical velocity uncertainty into account may also meet these requirements.

2.2.4.3.5.1.1 Preventive

Since the preventive alert is intended to provide alerts for intruders a certain distance away vertically, the alert is not used for intruders tracked solely by radar with associated altitude uncertainties.

For intruders tracked solely by radar, the DAA system **shall (219)** generate no preventive alerts.

2.2.4.3.5.1.2 Corrective

For intruders being tracked solely by radar, the DAA system **shall (220)** provide corrective alerts normally per Subparagraph 2.2.4.3.4.3. This includes the late, early, average, and persist alert time requirements using the parameter values in Table 2-21, including the normal non-hazard zone VMOD.

For intruders tracked solely by radar, the DAA system **shall (221)** generate no corrective alerts when an intruder remains in the radar corrective non-hazard zone using the parameter values in Table 2-21, with the exception of using a 4,000’ VMOD

2.2.4.3.5.1.3 Warning

For intruders tracked solely by radar, the DAA system **shall (222)** provide warning alerts normally per Subparagraph 2.2.4.3.4.4. This includes the late, early, average, and persist alert time requirements using the parameter values in Table 2-21, including the normal non-hazard zone VMOD.

For intruders tracked solely by radar, the DAA system **shall (223)** generate no warning alerts when an intruder remains in the radar warning non-hazard zone using the parameter values in Table 2-21, with the exception of using a 4,000’ VMOD.

2.2.4.3.5.2 No Bearing

Active surveillance systems may occasionally provide intruder reports with no bearing information. Other surveillance sources may also degrade in angular accuracy or velocity direction accuracy such that the DAA tracker flags the bearing information for particular intruders as invalid (see Subparagraph 2.2.3.2.1.1). In that case, the following requirements specify the alerting behavior. These requirements use the same boundaries as the normal alerting requirements, but omit the requirements related to generating no alerts due to HMD since HMD cannot be easily estimated without bearing or velocity direction information. Alerting may be generated by using a HMDp of 0’, which results in an alerting zone larger than the hazard zone.

2.2.4.3.5.2.1 Preventive

Due to the limited information available, SC-228 deemed preventive alerts to be a nuisance for no-bearing intruders.

For intruders without bearing information, the DAA system **shall (224)** generate no preventive alerts.

2.2.4.3.5.2.2 Corrective

For intruders without bearing information, the DAA system **shall (225)** provide corrective alerts per Subparagraph 2.2.4.3.4.3. This includes the late, early, average, and persist alert time requirements.

For intruders without bearing information, the DAA system **shall (226)** generate no corrective alerts when an intruder remains in the corrective non-hazard zone using the parameter values in Table 2-21, with the exception of only evaluating the $[r > S^*]$ term in the horizontal. Therefore the $[\mathrm{HMD_p} > \mathrm{HMD}^*]$ term in the definition of the non-hazard zone is ignored for these intruders.

2.2.4.3.5.2.3 Warning

For intruders without bearing information, the DAA system **shall (227)** provide warning alerts per Subparagraph 2.2.4.3.4.4. This includes the late, early, average, and persist alert time requirements.

For intruders without bearing information, the DAA system **shall (228)** generate no warning alerts when an intruder remains in the warning non-hazard zone using the parameter values in Table 2-21, with the exception of only evaluating the $[\mathrm{r} > \mathrm{S}^*]$ term in the horizontal. Therefore the $[\mathrm{HMD_p} > \mathrm{HMD}^*]$ term in the definition of the non-hazard zone is ignored for these intruders.

2.2.4.3.5.3 No Altitude

Active surveillance and ADS-B may provide intruder reports with no altitude information, in which case the DAA tracker flags the altitude information for particular intruders as invalid (see Subparagraph 2.2.3.2.1.1). In that case, the following requirements specify the alerting behavior. These requirements use the same horizontal boundaries as the normal alerting requirements, but treat the intruder as co-altitude and omit the requirements related to generating no alerts due to vertical separation.

2.2.4.3.5.3.1 Preventive

Since the preventive alert is intended to provide alerts for intruders a certain distance away vertically, the alert is not used for intruders without altitude information.

For intruders without altitude information, the DAA system **shall (229)** generate no preventive alerts.

2.2.4.3.5.3.2 Corrective

For intruders without altitude information, the DAA system **shall (230)** provide corrective alerts per Subparagraph 2.2.4.3.4.3 by treating an intruder as co-altitude. This includes the late, early, average, and persist alert time requirements.

For intruders without altitude information, the DAA system **shall (231)** generate no corrective alerts when an intruder remains in the corrective non-hazard zone using the parameter values in Table 2-21, with the exception of only evaluating the horizontal terms. Therefore the $[\mathrm{d_h} > \mathrm{V}]$ term in the definition of the non-hazard zone is ignored for these intruders.

2.2.4.3.5.3.3 Warning

For intruders without altitude information, the DAA system **shall (232)** provide warning alerts per Subparagraph 2.2.4.3.4.4 by treating an intruder as co-altitude. This includes the late, early, average, and persist alert time requirements.

For intruders without altitude information, the DAA system **shall (233)** generate no warning alerts when an intruder remains in the warning non-hazard zone using the parameter values in Table 2-21, with the exception of only evaluating the horizontal terms. Therefore the $[d_h > V]$ term in the definition of the non-hazard zone is ignored for these intruders.

2.2.4.4 Guidance Processing Requirements

The Guidance Processing subfunction generates the guidance information that is the basis for the DAA maneuvers provided visually to the PIC to maintain and regain DWC. The Guidance Processing subfunction will provide the DAA traffic display subsystem with DAA horizontal and vertical guidance information as described below. Refer to DAA Display System in Subparagraph 2.2.5.7 for information about how the display system is to display maneuver guidance to the PIC.

Preventive guidance information refers to a range or ranges of horizontal and vertical maneuvers (i.e., heading or track angles, and vertical rates and/or altitudes) predicted to result in the intruder entering the preventive hazard zone prior to the late threshold for a preventive alert.

Corrective guidance information refers to a range or ranges of horizontal and vertical maneuvers (i.e., heading or track angles, and vertical rates and/or altitudes) predicted to result in the intruder entering the corrective hazard zone prior to the late threshold for a corrective alert.

Warning guidance information refers to a range or ranges of horizontal and vertical maneuvers (i.e., heading or track angles, and vertical rates and/or altitudes) predicted to result in the intruder entering the warning hazard zone prior to the late threshold for a warning alert.

Hazard zones are defined in Subparagraph 2.2.4.3.2. Alert thresholds are defined in Table 2-21.

Peripheral guidance information is guidance information corresponding to an intruder not in an alert status. This will occur when DWC is predicted to be maintained based on current ownship and intruder tracks, and therefore, the intruder is not in alert status, but a particular maneuver or maneuvers by the ownship are predicted to lose DWC with that intruder.

Guidance information to regain DWC refers to a range of horizontal maneuvers (heading or track angles) that will increase the predicted horizontal CPA and a range of vertical maneuvers (vertical rates and/or altitudes) that will increase the predicted vertical CPA for an intruder with whom the ownship has lost DWC or is about to lose DWC. In the case of a loss of DWC, these range of maneuvers are expected to lead to a timely resumption of DWC.

Positive guidance information refers to the range or ranges of maneuvers determined by the Guidance processing system to either a) be free of conflict with all known intruders, and therefore, allowed to be followed by the PIC, or b) minimize conflict with an intruder and therefore, intended to be followed by the PIC. For example, those ranges of maneuvers beyond the edges of the preventive, corrective, and warning maneuver guidance bands out to the limits examined by the DAA system are allowed to be followed and are, therefore, considered positive guidance. Guidance information to regain DWC depicts ranges of maneuvers the PIC should follow and is also positive guidance information. The Guidance Processing subfunction should continuously provide positive maneuver guidance information throughout an encounter so that the PIC is never without maneuver options.

The Guidance Processing subfunction will ensure that maneuver guidance information and traffic alerting symbols are coordinated and consistent. For example, when an intruder aircraft is shown with a caution alert symbol, the corresponding maneuver guidance information will be displayed (e.g., “bands” showing a range of maneuver options).

All guidance information provided by the Guidance Processing subfunction is subject to the following requirements:

Horizontal guidance information **shall (234)** be output as heading or track angles.

Vertical guidance information **shall (235)** be output as vertical rates and/or altitudes.

Note: *For vertical guidance information, providing altitude is recommended. If the vertical rate is adjustable by the PIC, vertical guidance information should also include rate, and both rate and altitude are preferred; altitude alone is not acceptable. If the vertical rate is not adjustable by the PIC, the calculation may assume a known standard rate, and altitude guidance information alone is acceptable.*

The Guidance Processing subfunction **shall (236)** update this output at no less than a 1 Hz update rate.

The Guidance Processing subfunction **shall (237)** be triggered within 400 ms of the time of applicability associated with the data output received from the DAA tracker. This limits the amount of total latency added before the tracker output data is used for DAA guidance processing. It should be noted that the latency contributed by the data link can be up to 2 seconds; however, under nominal conditions, the latency added by the data link is 200 ms.

The DAA system **shall (238)** always provide positive guidance information, until or unless there is a Near Mid-Air Collision (NMAC).

The Guidance Processing subfunction **shall (239)** take into consideration the impact of winds aloft when computing horizontal DAA guidance.

Note: *An acceptable assumption in this case would be that ownship wind information (derived from the ownship air and ground speed) also applies to intruders, and therefore horizontal DAA calculations would be made using a fixed wind field. When winds aloft are used, horizontal guidance may be provided as ranges of heading rather than track.*

Maneuver guidance information should be computed using turn, climb, and descent rates that the UA is capable of performing.

Note

1. *Maneuver guidance information may be computed using an instantaneous heading change and vertical rate change assumption, but the resulting guidance will be increasingly incorrect and misleading as the range to the intruder decreases.*

2. *The PIC is responsible to be aware of the UA's performance limits and should make decisions for remaining well clear consistent with those limits.*

Assumed performance minimums (from Subsection 1.3):

- A sustainable turn rate of either 1.5 degrees/second or 3 degrees/second.
- 0.25 g vertical acceleration
- A minimum climb/descent rate of 500 fpm
- A roll-in/out rate of 5 degrees/second
- Command-to-execute latency ≤ 2 seconds.

Note:

1. *"Command-to-execute" means the time from entering a maneuver command on the CS to the beginning of execution of the maneuver by the UA.*
2. *An example of formulas and algorithm for the Guidance Processing subfunction is provided in Appendix G. Additional information on minimum performance assumptions is provided in Appendix D.*

Surveillance sensors onboard the UA have inherent errors, noise, and biases, which will skew the position and velocity state data of the ownship and traffic aircraft. In order for the DAA guidance information to be accurate and timely enough to enable the DAA system to pass the alerting and guidance tests that use sensor-degraded tracks, the Guidance Processing subfunction **shall (240)** account for sensor error characteristics up to the limits in Table 2-20.

2.2.4.4.1 DAA Maneuver Guidance to Maintain DWC

DAA maneuver guidance is intended to provide a range of trajectory options (e.g., horizontal tracks or vertical velocities) that will maintain DWC within the DAA alert time for all alerting aircraft. DAA guidance is intended to be used/interpreted by the PIC to maintain DWC both by avoiding trajectories that would result in a loss of DWC and by executing maneuvers to trajectories required to maintain DWC (see Appendix A).

2.2.4.4.1.1 Preventive Maneuver Guidance

Preventive maneuver guidance is optional.

If preventive maneuver guidance is implemented, the DAA system **shall (241)** provide the range or ranges of horizontal and vertical maneuvers (i.e., heading or track angles, and vertical rates and/or altitudes) predicted to result in the intruder entering the preventive hazard zone (as defined in Subparagraph 2.2.4.3.2) prior to the late threshold for a preventive alert (as defined in Table 2-21).

If preventive maneuver guidance is implemented, the DAA system **shall (242)** provide preventive guidance information for an intruder at or before the time a preventive alert is generated for that intruder.

If preventive maneuver guidance is implemented, the DAA system **shall (243)** provide no preventive guidance information for trajectories that, if captured, would result in the intruder entering the preventive hazard zone (as defined in Subparagraph 2.2.4.3.2) prior to the early threshold for a preventive alert (as defined in Table 2-21).

If preventive maneuver guidance is implemented, the DAA system **shall (244)** provide no preventive guidance information for trajectories that, if captured, would result in the intruder remaining in the preventive non-hazard zone (as defined in Subparagraph 2.2.4.3.2) within the τ^*_{mod} time of the preventive non-hazard zone (as defined in Table 2-21).

2.2.4.4.1.2 Corrective Maneuver Guidance

The DAA system **shall (245)** provide the range or ranges of horizontal and vertical maneuvers (i.e., heading or track angles, and vertical rates and/or altitudes) predicted to result in the intruder entering the corrective hazard zone (as defined in Subparagraph 2.2.4.3.2) prior to the late threshold for a corrective alert (as defined in Table 2-21).

The DAA system **shall (246)** provide corrective guidance information for an intruder at or before the time a corrective alert is generated for that intruder.

The DAA system **shall (247)** provide no corrective guidance information for trajectories that, if captured, would result in the intruder entering the corrective hazard zone (as defined in Subparagraph 2.2.4.3.2) prior to the early threshold for a corrective alert (as defined in Table 2-21).

The DAA system **shall (248)** provide no corrective guidance information for trajectories that, if captured, would result in the intruder remaining in the corrective non-hazard zone (as defined in Subparagraph 2.2.4.3.3) within the look-ahead time.

The DAA system **shall (249)** provide no corrective guidance information for trajectories that, if captured, would result in the intruder remaining in the corrective non-hazard zone (as defined in Subparagraph 2.2.4.3.2) within the τ^*_{mod} time of the corrective non-hazard zone (as defined in Table 2-21).

Corrective maneuver guidance **shall (250)** be prioritized higher than preventive maneuver guidance.

Figure 2-3 illustrates an example of a corrective alert with associated corrective guidance information presented as a range of heading angles, see (a), and a range of altitudes, see (b), to be avoided by the PIC in order to maintain DWC.

An example of peripheral corrective guidance information is presented in Figure 2-4. In this example, Aircraft 1 (AC01) is causing peripheral corrective guidance information to the left of the ownship's current heading, because this range of heading angles is predicted to result in AC01 entering the corrective hazard zone prior to the late threshold for a corrective alert. AC02 is causing peripheral corrective guidance information above the ownship's current altitude level, because this range of altitudes is predicted to result in AC02 entering the corrective hazard zone prior to the late threshold for a corrective alert.

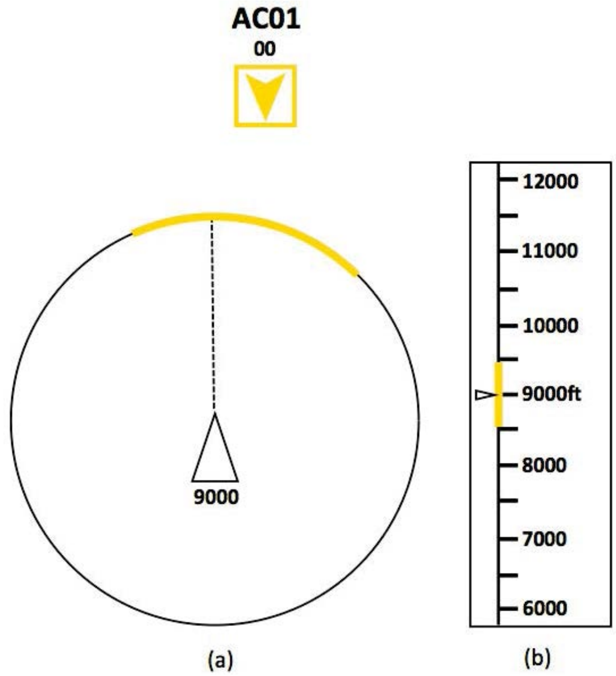


Figure 2-3 **Illustration of Corrective Guidance Information**

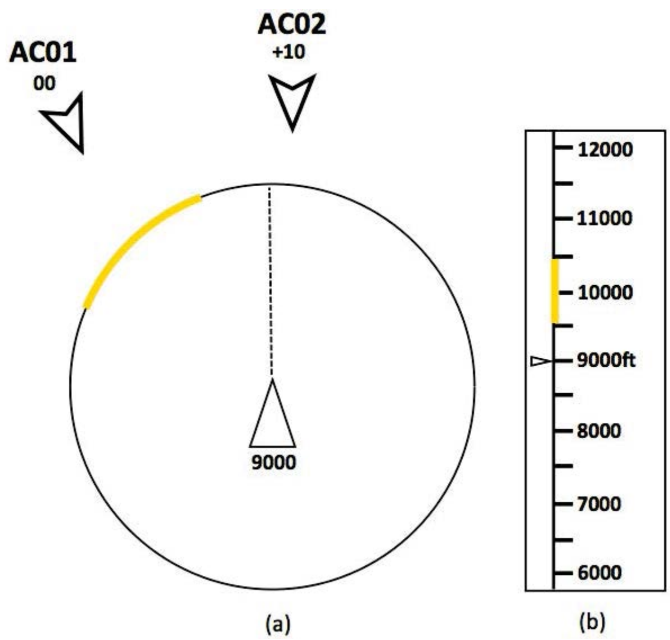


Figure 2-4 **Illustration of Peripheral Corrective Guidance Information**

2.2.4.4.1.3 Warning Maneuver Guidance

The DAA system **shall (251)** provide the range or ranges of horizontal and vertical maneuvers (i.e., heading or track angles, and vertical rates and/or altitudes) predicted to result in the intruder entering the warning hazard zone (as defined in Subparagraph 2.2.4.3.2) prior to the late threshold for a warning alert (as defined in Table 2-21).

The DAA system **shall (252)** provide warning guidance information for an intruder at or before the time a warning alert is generated for that intruder.

Due to possible ADS-B errors, unvalidated ADS-B position information cannot be used for warning guidance information. Validated or previously validated ADS-B data can be used for warning guidance information. If an ADS-B Only intruder is marked unvalidated per Subparagraph 2.2.3.2.1.3.4, the DAA system **shall (253)** provide corrective guidance information for the associated intruder when it meets the criteria for producing warning guidance information.

The DAA system **shall (254)** provide no warning guidance information for trajectories that, if captured, would result in the intruder entering the warning hazard zone (as defined in Subparagraph 2.2.4.3.2) prior to the early threshold for a warning alert (as defined in Table 2-21).

The DAA system **shall (255)** provide no warning guidance information for trajectories that, if captured, would result in the intruder remaining in the warning non-hazard zone (as defined in Subparagraph 2.2.4.3.2) within the τ^{*}_{mod} time of the warning non-hazard zone (as defined in Table 2-21).

Warning maneuver guidance **shall (256)** be prioritized higher than corrective maneuver guidance.

Figure 2-5 illustrates an example of a warning alert with associated warning guidance information presented as a range of heading angles, see (a), and a range of altitudes, see (b), to be avoided by the PIC in order to maintain DWC.

Peripheral warning guidance information is not illustrated here; however, the example would be similar to Figure 2-4, except warning guidance information would appear on the horizontal and vertical peripheries.

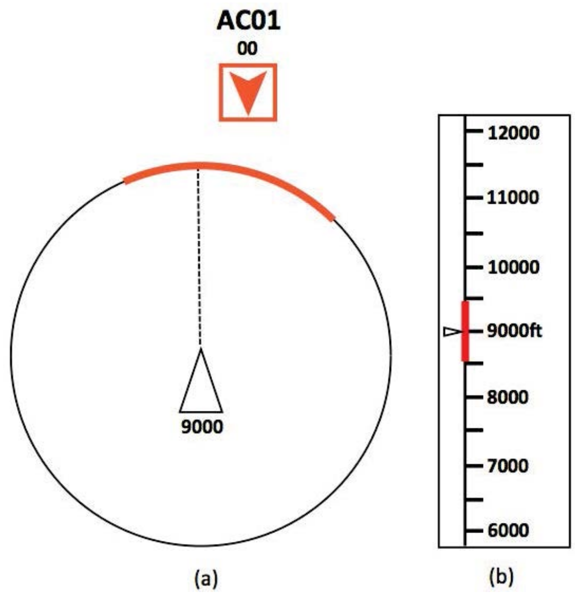


Figure 2-5 **Illustration of Warning Guidance Information**

2.2.4.4.2 DAA Maneuver Guidance to Regain DWC

Guidance to regain DAA well clear is positive guidance information intended to provide the PIC with a range of horizontal and vertical maneuvers that would expedite resumption of DWC. The range of horizontal and vertical maneuvers are to be provided at the same time; however, the intended function is for the PIC to execute either a horizontal or vertical maneuver to regain DWC. Guidance to regain DWC is to be provided when DWC has been lost.

The DAA system **shall (257)** continuously provide guidance to regain DWC no later than when a loss of DWC occurs (criteria for a loss of DWC is described in Appendix C).

Note:

1. *This serves as the latest point at which guidance to regain DWC must begin to be provided. However, there is a threshold prior to losing DWC at which the PIC can no longer execute a maneuver to prevent a loss of DWC given the encounter's predicted separation and closure rate, based on the ownship's maneuver capability. For DAA systems that assume turn, climb, and descent rates that the UA is capable of performing, guidance to maintain DWC will exhaust all maneuver options close to this threshold. When this happens, Requirement 238 (i.e., to always provide positive guidance information) requires that guidance to regain DWC begin at this point. For DAA systems that assume instantaneous heading and vertical rate changes, guidance to maintain DWC will not exhaust all displayed maneuver options until DWC is lost, at which point guidance to regain DWC must be provided.*
2. *It is recommended that guidance to regain DWC be provided at the point where a loss of DWC cannot be avoided in order for the PIC to take full advantage of the time available to minimize the severity of loss of DWC. However, it is acceptable to initiate guidance to regain DWC after this point,*

because in both situations a loss of DWC will occur, and the intent is to impart design flexibility to applicants.

The DAA system **shall (258)** continuously provide guidance to regain DWC no earlier than when a DAA warning alert is allowed per Subparagraph 2.2.4.3.4.4 and a DAA warning alert is provided by the DAA system.

Note: *Guidance to regain DWC is to be provided to the PIC and executed with urgency, therefore it cannot be provided during the absence of a DAA warning alert.*

The DAA system **shall (259)** continuously provide guidance to regain DWC up until the time DWC has been restored.

Due to possible ADS-B errors, unvalidated ADS-B position information cannot be used for guidance to regain DWC. Validated or previously validated ADS-B data can be used for guidance to regain DWC. If an ADS-B-only intruder is causing guidance to regain DWC and is marked unvalidated per Subparagraph 2.2.3.2.1.3.4, the DAA system **shall (530)** exclude the associated intruder from guidance to regain DWC processing.

Note: *During this situation, maneuvers that would regain DWC for the intruder with unvalidated ADS-B position information will not be provided to the PIC. The PIC will be aware of this possibility well before guidance to regain DWC is provided due to the requirement to modify the alert symbology for traffic with unvalidated ADS-B.*

Guidance to regain DWC **shall (260)** provide a range of maneuvers in the horizontal plane as follows:

1. For an intruder causing guidance to regain DWC, increases predicted horizontal separation at the CPA, and
2. For secondary intruders not causing guidance to regain DWC, does not result in any secondary intruders entering the warning hazard zone, as defined in Subparagraph 2.2.4.3.2, prior to the late threshold for a warning alert (as defined in Table 2-21), or
3. If there are multiple intruders causing guidance to regain DWC, results in predicted horizontal separation greater than 4,000’ at the CPA for all intruders.

Figure 2-6 (a) illustrates an example of horizontal guidance to regain DWC within the range ring.

Note:

1. *There may be some circumstances where guidance to regain DWC cannot meet all these requirements, for example, when the intruder is already within 4,000’ horizontally. In these situations the DAA system should provide guidance to regain DWC that maximizes separation at the CPA and regains DWC in a timely fashion.*
2. *The requirement to provide horizontal guidance to regain DWC do not modify the requirements on guidance to maintain DWC beyond those specified in Subparagraph 2.2.4.4.4.1. Specifically, it does not levy the requirement that all ranges of maneuvers to maintain DWC are shown as corrective or warning*

maneuver guidance when guidance to regain DWC is shown. Calculation of a single horizontal direction should include logic (e.g., hysteresis) to prevent changes in the calculated direction due to surveillance noise or small changes in the track angle of the traffic. Subparagraph 2.2.5.7.2 specifies how guidance to regain DWC is to be displayed to the PIC.

Given a non-accelerating encounter between an ownship and an intruder and no secondary intruders, when guidance to regain DWC provides a range of horizontal maneuvers and the direction of the maneuver range changes (putting it on the opposite side of the ownship's current heading, i.e., a "reversal"), then any subsequent change in maneuver magnitude **shall (261)** remain in that direction. For example, if the range of maneuvers is initially located on the right side of the ownship's heading and the direction changes to the left side, it must remain on the left side.

Note: *This requirement is to prevent undesirable behavior in which the direction of horizontal guidance to regain DWC repeatedly switches from one direction to another.*

When guidance to regain DWC provides a range of horizontal maneuvers (i.e., heading or track angles), the range **shall (262)** be at least 10 degrees.

When guidance to regain DWC provides a range of horizontal maneuvers (i.e., heading or track angles), the range **shall (263)** be no greater than 90 degrees.

Guidance to regain DWC **shall (264)** provide a range of maneuvers in the vertical plane as follows:

1. For an intruder causing guidance to regain DWC, increases predicted vertical separation at the CPA, and
2. For secondary intruders not causing guidance to regain DWC, does not result in any secondary intruders entering the warning hazard zone, as defined in Subparagraph 2.2.4.3.2, prior to the late threshold for a warning alert, or
3. If there are multiple intruders causing guidance to regain DWC, results in predicted vertical separation greater than 450' at the CPA for all intruders.

Figure 2-6 (b) illustrates an example of vertical guidance to regain DWC within the DAA altitude tape.

Note:

1. *There may be some circumstances where guidance to regain DWC cannot meet all these requirements, for example, in situations when the intruder is already within 450' vertically. In these situations the DAA system should provide guidance to regain DWC that maximizes separation at the CPA and regains DWC in a timely fashion.*
2. *The requirement to provide vertical guidance to regain DWC does not place any additional requirements on the display of guidance to maintain DWC beyond those specified in Subparagraph 2.2.4.4.4.1. Specifically, it does not levy the requirement that all ranges of maneuvers to maintain DWC are shown as corrective or warning maneuver guidance when guidance to regain DWC is shown. Calculation of a single vertical direction should include logic (e.g.,*

hysteresis) to prevent changes in the calculated direction due to surveillance noise or small changes in the vertical rate of the traffic. This requirement for vertical guidance to regain DWC is further constrained by the TCAS interoperability requirements in Subparagraph 2.2.4.5. Subparagraph 2.2.5.7.2 provides information about how guidance to regain DWC should be displayed to the PIC.

Given a non-accelerating encounter between an ownship and an intruder and no secondary intruders, when guidance to regain DWC provides a range of vertical maneuvers (i.e., vertical rates or altitude levels), if the direction of the maneuver range changes putting it on the opposite side of the ownship's current vertical velocity, then any subsequent change in rate or altitude **shall (265)** remain on that side. For example, if the range of maneuvers is initially to increase vertical velocity and the direction changes to decrease vertical velocity it must remain within the lower vertical velocity range.

Note: *This requirement is to prevent undesirable behavior where a single direction of vertical guidance to regain DWC repeatedly switches from one direction to another.*

When guidance to regain DWC provides a range of vertical maneuvers using altitude levels, the range **shall (266)** be at least 300'.

When guidance to regain DWC provides a range of vertical maneuvers using vertical velocity, the range **shall (267)** be at least 500 fpm.

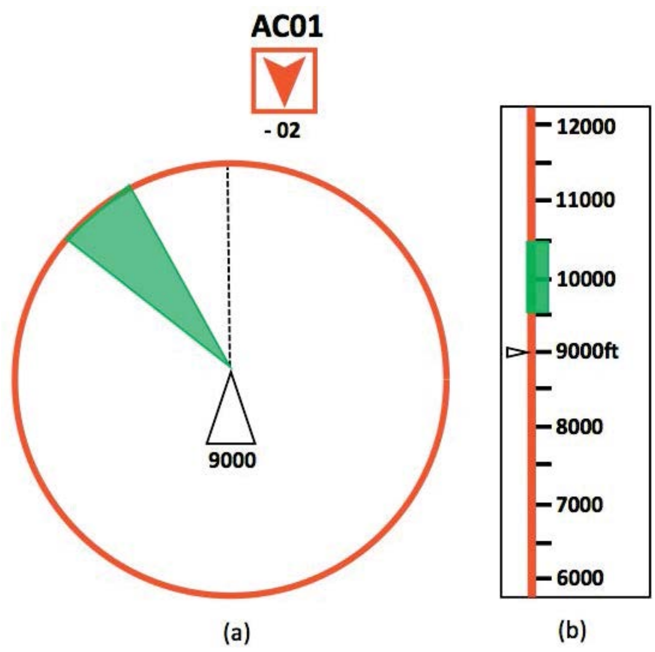


Figure 2-6 **Illustration of (a) Horizontal and (b) Vertical Guidance to Regain DWC**

Note: *In Figure 2-6, the "-02" underneath the icon for intruder AC01 indicates that the intruder is approximately 200' below the ownship's current altitude when quantized by 100'.*

These MOPS specify a requirement to provide regain well clear guidance in a single direction in both dimensions (vertical and horizontal). The conceptual guidance depictions described herein are analogous to that for TCAS II Resolution Advisories in that green guidance is provided to the pilot indicating the flight path to be flown, and red guidance indicates the flight paths to be avoided. There are two concerns associated with this requirement:

1. The stated purpose of this requirement is to provide salience to the pilot in the horizontal dimension when TCAS II may also be providing Resolution Advisories in the vertical. Although Human-In-The-Loop experiments showed a high rate of pilot compliance for two axis guidance when implemented as required, more work could be done to consider potential negative effects on operational suitability, system complexity, and safety. Funding and schedule constraints prevented this additional work from being completed to the total satisfaction of the community.
2. Collision Avoidance community best practice is to validate directive guidance using Monte Carlo simulation, where a large collection of realistic encounters (typically millions) are evaluated in fast time to assess safety and operational suitability. However, the test procedures proposed in these MOPS require less than a couple hundred, with the consequence that the safety and operational suitability of the guidance implementation cannot be fully ascertained by the required MOPS tests alone. Additional testing is left as the responsibility of the manufacturer and individual implementation performance may vary as a result.

Work on the Airborne Collision Avoidance System Model X for unmanned aircraft (ACAS Xu) in Phase 2 is expected to address many if not all of these concerns.

2.2.4.4.3 Guidance Processing for Multi-AC Encounter w/ Corrective RA and DAA Warning Alert

For Class 2 DAA systems, an active Corrective RA could occur at the same as a DAA warning alert for a secondary non-cooperative intruder because TCAS II does not consider this type of traffic. The secondary intruder may not have lost DWC, but eventually could lead to this, thus the requirement in this subparagraph addresses guidance to maintain and regain DWC for when a multi-aircraft Corrective RA and DAA warning alert encounter occurs.

When an Corrective RA is provided, the PIC has the responsibility to maintain or regain DWC with the secondary intruder while also following the corrective RA maneuver guidance. In some cases, the pilot will have to make a horizontal maneuver in order to maintain or regain DWC with the secondary intruder.

1. In order to facilitate a horizontal maneuver to maintain DWC with secondary intruder(s) when an active Corrective RA from the ownship and a DAA warning alert for a secondary intruder are present, the DAA system will provide positive horizontal guidance information intended to be followed by the PIC to assure DWC is maintained. If the secondary intruder has not lost DWC in these situations, the DAA system **shall (268)** provide positive guidance information for a range of maneuvers in the horizontal plane as follows:

a. For an intruder causing a Corrective RA, increases predicted horizontal separation at the CPA, and

b. For all intruders not causing a Corrective RA, does not result in any secondary intruders entering the warning hazard zone, as defined in Subparagraph 2.2.4.3.2, prior to the late threshold for a warning alert (as defined in Table 2-21).

Alternatively, if DWC has been lost with the secondary intruder causing a DAA warning alert when an active Corrective RA from the ownship is present then the DAA system **shall (269)** provide positive guidance information for a range of maneuvers in the horizontal plane as follows:

1. For the intruders causing the Corrective RA and DAA warning alert, increases predicted horizontal separation at the CPA, and
2. Does not result in any secondary intruders entering the warning hazard zone prior to the late threshold for a warning alert.

Note: *The DAA system may not be able to meet this requirement when there is an active Corrective RA from the ownship and multiple intruders having lost DWC. In these situations the DAA system should provide positive guidance information to regain DWC that maximizes separation at the CPA and regains DWC in a timely fashion.*

An illustration of this situation is provided in Figure 2-7. During this situation vertical DAA maneuver guidance is inhibited per TCAS interoperability requirements in Subparagraph 2.2.4.5.1.

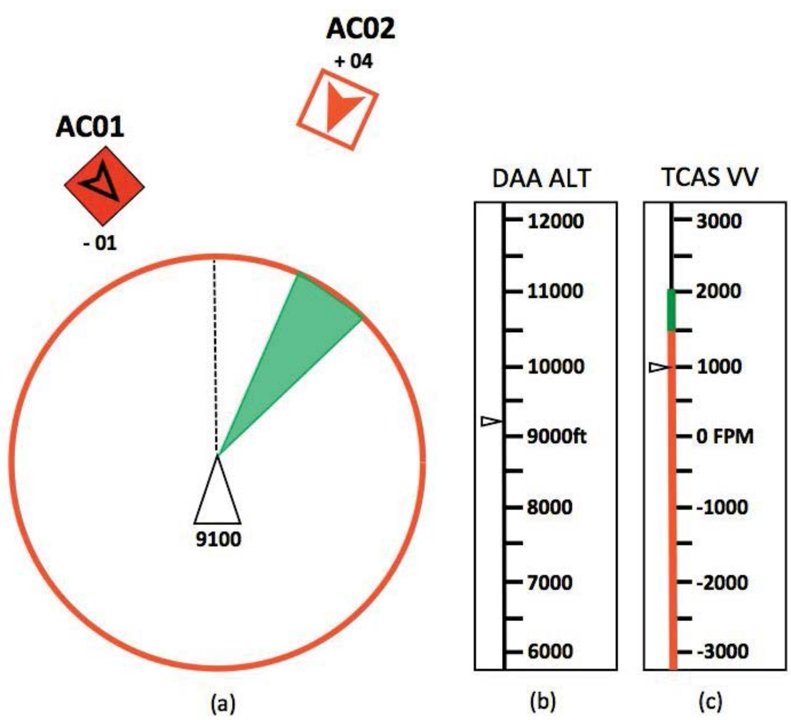


Figure 2-7 **Illustration of Guidance During a Corrective RA and Warning Alert**

Note:

1. *In Figure 2-7, (a) illustrates horizontal DAA maneuver guidance, (b) illustrates vertical DAA maneuver guidance, (c) illustrates TCAS vertical velocity(VV) guidance.*
2. *Maneuver guidance to maintain and regain DWC is provided in because a Corrective TCAS RA (AC01) exists in a multi-aircraft encounter where there is also a DAA Warning alert (AC02). The illustration indicates TCAS vertical velocity guidance to climb at +1,500 fpm in (c) as well as horizontal guidance to turn right to maintain DWC against AC02 in (a). Vertical velocity guidance is provided by the TCAS RA only, without altitude DAA maneuver guidance in (b), consistent with TCAS interoperability requirements in Subparagraph 2.2.4.5.*

2.2.4.4.4 Guidance Processing Special Cases

In some situations, data from the sensors may not be available or accurate enough to support compliance with the guidance processing requirements in Subparagraph 2.2.4.4. The following subparagraphs specify guidance behavior in those special cases.

2.2.4.4.4.1 Maintain DAA Well Clear

The following subparagraphs specify the guidance to maintain DAA well clear behavior in those special cases where compliant surveillance information is not available.

2.2.4.4.4.1.1 Radar Only

Comparable to the special alerting requirements in Subparagraph 2.2.4.3.5.1, the following requirements specify modifications to normal guidance to maintain DWC behavior for intruders tracked solely by the radar. Under these circumstances, the VMOD for corrective and warning non-hazard zones is increased to expand the range or ranges of vertical maneuvers where corrective and warning guidance information can be provided to account for altitude and vertical velocity uncertainties with the radar.

2.2.4.4.4.1.1.1 Preventive Maneuver Guidance

For intruders being tracked solely by radar, the DAA system **shall (270)** provide no preventive guidance information.

Note: *Since preventive guidance information, if implemented, is intended to indicate ranges of maneuvers predicted to result in the intruder being within a certain distance vertically, preventive guidance information is not used for intruders tracked solely by radar with associated altitude uncertainties.*

2.2.4.4.4.1.1.2 Corrective Maneuver Guidance

For intruders being tracked solely by radar, the DAA system **shall (271)** provide guidance to maintain DWC as follows:

1. No corrective guidance information for those maneuvers where intruders are predicted to remain in the corrective non-hazard zone when VMOD is treated as 4,000’ within the look-ahead time, or
2. If the intruder is estimated to be within the corrective hazard zone when treating h* as 4,000’ and a DAA corrective alert is provided per Subparagraph 2.2.4.3.4.3, then

corrective guidance information is provided for all ranges of vertical maneuvers, i.e., complete saturation of vertical guidance to maintain DWC, indicating that no vertical maneuvers can be assured to maintain DWC.

Note: *Increasing the VMOD of the corrective non-hazard zone from 450' to 4,000' expands the range of vertical guidance to maintain DWC where corrective guidance information may be provided, and is often necessary due to altitude and vertical velocity uncertainties. Alternatively, an applicant can choose an implementation that saturates all vertical guidance to maintain DWC with corrective guidance information if the intruder's relative altitude is estimated to be within 4,000', therefore only providing positive guidance information in the horizontal plane. This, however, does not restrict an applicant from providing a relatively smaller, more optimal range of corrective guidance information if the state estimates for altitude and vertical velocity uncertainty are met as per Table 2-20.*

2.2.4.4.4.1.1.3 Warning Maneuver Guidance

For intruders being tracked solely by radar, the DAA system **shall (272)** provide guidance to maintain DWC as follows:

1. No warning guidance information for those maneuvers where intruders are predicted to remain in the warning non-hazard zone when VMOD is treated as 4,000' within the look-ahead time, or
2. If the intruder is estimated to be within the warning hazard zone when treating h* as 4,000' and a DAA warning alert is provided per Subparagraph 2.2.4.3.4.4, then warning guidance information is provided for all ranges of vertical maneuvers indicating that no vertical maneuvers can be assured to maintain DWC.

Note: *Increasing the VMOD of the warning non-hazard zone from 450' to 4,000' expands the range of vertical guidance to maintain DWC where warning guidance information may be provided, and is often necessary due to altitude and vertical velocity uncertainties. Alternatively, an applicant can choose an implementation that saturates all vertical guidance to maintain DWC with warning guidance information if the intruder's relative altitude is estimated to be within 4,000', therefore only providing positive guidance information in the horizontal plane. This, however, does not restrict an applicant from providing a relatively smaller, more optimal range of corrective guidance information if the state estimates for altitude and vertical velocity uncertainty are met as per Table 2-20.*

2.2.4.4.4.1.2 No Bearing

If bearing information is not available for an intruder or declared invalid by the DAA tracker then the following requirements specify the appropriate guidance to maintain DWC behavior.

2.2.4.4.4.1.2.1 Preventive Maneuver Guidance

If the bearing of an intruder is invalid, the DAA system **shall (273)** provide no preventive guidance information. Due to the limited information available, preventive maneuver guidance were deemed a nuisance for no bearing intruders.

Note: *Due to the limited information available, preventive guidance information is deemed a nuisance for no bearing intruders.*

2.2.4.4.4.1.2.2 Corrective Maneuver Guidance

To specify that horizontal maneuvers cannot be assured to maintain DWC, if the bearing of an intruder is invalid and the other surveillance information is used to determine that a DAA corrective alert is provided as per Subparagraph 2.2.4.3.5.2.2, then the DAA system **shall (274)** produce corrective guidance information for all ranges of horizontal maneuvers.

Note: *The extent to which this requirement is applicable is determined by the Modified Tau (τ^*_{mod}) and Vertical Separation (h*) thresholds for a permissible DAA corrective alert per Subparagraph 2.2.4.3.4.3.*

2.2.4.4.4.1.2.3 Warning Maneuver Guidance

To specify that horizontal maneuvers cannot be assured to maintain DWC, if the bearing of an intruder is invalid and the other surveillance information is used to determine that a DAA warning alert is provided as per Subparagraph 2.2.4.3.5.2.3, then the DAA system **shall (275)** produce warning guidance information for all ranges of horizontal maneuvers.

Note: *The extent to which this requirement is applicable is determined by the Modified Tau (τ^*_{mod}) and Vertical Separation (h*) thresholds for a permissible DAA warning alert per Subparagraph 2.2.4.3.4.4.*

2.2.4.4.4.1.3 No Altitude

If altitude information is not available for an intruder or declared invalid by the DAA tracker then the following requirements specify the appropriate guidance to maintain DWC behavior.

2.2.4.4.4.1.3.1 Preventive Maneuver Guidance

If the relative altitude of an intruder is invalid, the DAA system **shall (276)** provide no preventive guidance information.

Note: *Since preventive guidance information, if implemented, is intended to indicate ranges of maneuvers predicted to result in the intruder being within a certain distance vertically, preventive guidance information is not used for intruders without altitude information.*

2.2.4.4.4.1.3.2 Corrective Maneuver Guidance

To specify that vertical maneuvers cannot be assured to maintain DWC, if the relative altitude of an intruder is invalid and a DAA corrective alert is provided as per Subparagraph 2.2.4.3.5.3.2, then the DAA system **shall (277)** produce corrective guidance information for all ranges of vertical maneuvers.

Note: *The extent to which this requirement is applicable is determined by the Modified Tau (τ^*_{mod}) and HMD* thresholds for a permissible DAA corrective alert per Subparagraph 2.2.4.3.4.3*

2.2.4.4.4.1.3.3 Warning Maneuver Guidance

To specify that vertical maneuvers cannot be assured to maintain DWC, if the relative altitude of an intruder is invalid, and a DAA warning alert is provided as per Subparagraph 2.2.4.3.5.3.3, then the DAA system **shall (278)** produce warning guidance information for all ranges of vertical maneuvers.

Note: *The extent to which this requirement is applicable is determined by the Modified Tau (τ^*_{mod}) and HMD* thresholds for a permissible DAA warning alert per Subparagraph 2.2.4.3.4.4.*

2.2.4.4.4.2 Regain DAA Well Clear

Surveillance uncertainty will affect whether or not a loss of DWC can be accurately observed. Some actual losses of DWC may go undetected and some could be incorrect. This could have adverse effects on positive guidance information provided to the PIC to regain DWC. The following subparagraphs specify the guidance to regain DWC behavior in those special cases where compliant surveillance information is not available.

2.2.4.4.4.2.1 Radar Only

To specify that vertical maneuvers cannot be assured to regain DWC for intruders being tracked solely by radar, the DAA system **shall (279)** only produce horizontal maneuver guidance to regain DWC when the envelope of projected uncertainty exceeds the expected separation at the CPA:

$$\frac{1}{2}\left(E_{\Delta\dot{h}}\mathrm{t_{cpa}} + E_{\Delta h}\right) > \left|\left(\dot{h}_{own\_maneuver} - \dot{h}_{own} - \Delta\dot{h}_{tracker}\right)\mathrm{t_{cpa}} - \Delta h_{tracker}\right|$$

where:

$E_{\Delta\dot{h}}$ is the 95% metric threshold of the relative vertical velocity accuracy as estimated by the DAA tracker (e.g., see Table 2-20).

tcpa is the estimated time to closest point of approach.

$E_{\Delta h}$ is the 95% metric threshold of the relative vertical position accuracy as estimated by the DAA tracker (e.g., see Table 2-20).

$\dot{h}_{own\_maneuver}$ is the planned vertical velocity of the maneuver used by the ownship. By default, 500 fpm should be used as the minimum allowable performance unless the applicant specifies that a larger value is used by guidance to regain DWC. Different values may be used for climbs and descents, in which case the inequality above should be checked for each value.

$\dot{h}_{own}$ is the current vertical velocity of the ownship as estimated by the DAA tracker.

$\Delta\dot{h}_{tracker}$ is the current relative vertical velocity between the intruder and the ownship as estimated by the DAA tracker. For consistency with the output of the tracker as specified in Subparagraph 2.2.3.2.3 the relative vertical velocity is equal to the intruder's vertical velocity minus the ownship's vertical velocity.

$\Delta h_{\text{tracker}}$ is the current relative vertical position between the intruder and the ownship as estimated by the DAA tracker. For consistency with the output of the tracker as specified in Subparagraph 2.2.3.2.3, the relative vertical position is equal to the intruder's vertical position (altitude) minus the ownship's vertical position (altitude).

Note:

1. *This equation ensures that vertical maneuver guidance to regain DWC will be provided only when it presents an acceptable risk of an NMAC (Reference I, J.*
2. *This requirement allows for positive vertical guidance information to regain DWC when the estimated achievable vertical separation based on the vertical velocity performance used by the DAA system for the ownship exceeds the bounds of the altitude and vertical velocity uncertainty at the predicted CPA. If the uncertainty is too large, then vertical maneuvers cannot be assured to regain DWC. Depending on the encounter geometry (ownship and intruder vertical rates and relative altitude) the inequality in the above equation may be satisfied by a climb but not a descent, or vice versa. In these cases, only the guidance that results in predicted separation at the CPA greater than the projected uncertainty should be provided.*

2.2.4.4.4.2.2 No Bearing

To indicate that horizontal maneuvers cannot be assured to regain DWC, if the bearing of an intruder causing guidance to regain DWC is invalid, then the DAA system **shall (280)** only produce vertical maneuver guidance to regain DWC.

2.2.4.4.4.2.3 No Altitude

To indicate that vertical maneuvers cannot be assured to regain DWC, if the relative altitude of an intruder causing guidance to regain DWC is invalid, then the DAA system **shall (281)** only produce horizontal maneuver guidance to regain DWC.

2.2.4.5 Collision Avoidance Interoperability Requirements for Guidance

The requirements in this subparagraph provide a means for the DAA system to comply with the Interoperability of Airborne Collision Avoidance Systems requirements in Appendix M, prepared jointly with RTCA SC-147.

For both DAA equipment with (Class 2) and without (Class 1) a vertical CA function (TCAS II), DAA guidance will need to be modified in certain situations to maintain interoperability with existing vertical and future vertical and horizontal CA systems on intruder aircraft. Vertical DAA guidance needs to be interoperable with TCAS II or future ACAS X RAs issued by the intruder, or TCAS II RAs issued by the ownship. See Appendix M for more information on the rationale behind the requirements in this subparagraph. Subsection M.14 includes a cross reference table for how the Appendix M requirements map to these Subsection 2.2 MOPS requirements.

Adjusting DAA guidance assists the DAA-equipped aircraft with not maneuvering in ways that degrade the performance of CA systems on intruders.

In this subparagraph DAA guidance refers to both maintain and regain DWC guidance.

2.2.4.5.1 Class 2 Collision Avoidance (CA) RA Guidance

TCAS II systems have two types of RAs: corrective and preventive (see Table 2-22 and Table 2-23 for details). These two types of RAs are treated differently for interoperability with Class 2 DAA systems.

Table 2-22 Types of Corrective TCAS II RAs

Upward Sense		Downward Sense	
RA	**Required Vertical Rate (fpm)**	**RA**	**Required Vertical Rate (fpm)**
Climb	+1500	Descend	-1500
Altitude Crossing Climb	+1500	Altitude Crossing Descend	-1500
Reduce Climb	0	Reduce Descent	0
RA Reversal (Descend to Climb)	+1500	RA Reversal (Climb to Descend)	-2500
Increase Climb	+2500	Increase Descent	-2500
Maintain Rate RA (Climb)	Existing Vertical Sense (V/S)	Maintain Rate RA (Descent)	Existing V/S
Altitude Crossing Maintain Climb	Existing V/S	Altitude Crossing Maintain Descend	Existing V/S
Weakening of Positive RAs (After Up Sense RA)	0	Weakening of Positive RAs (After Down Sense RA)	0

Table 2-23 Types of Preventive TCAS II RAs

Upward Sense		Downward Sense	
RA	**Required Vertical Rate (fpm)**	**RA**	**Required Vertical Rate (fpm)**
Limit Climb (Do Not Climb)	< 0	Limit Descent (Do Not Descend)	> 0
Limit Climb (Do Not Climb > 500 fpm)	< 500	Limit Descent (Do Not Descend > 500 fpm)	> -500

Upward Sense		Downward Sense	
RA	**Required Vertical Rate (fpm)**	**RA**	**Required Vertical Rate (fpm)**
Limit Climb (Do Not Climb > 1000 fpm)	< 1000	Limit Descent (Do Not Descend > 1000 fpm)	> -1000
Limit Climb (Do Not Climb > 2000 fpm)	< 2000	(Limit Descent Do Not Descend > 2000 fpm)	> -2000

For Class 2 DAA systems, vertical DAA guidance **shall (282)** be consistent with active Preventive RAs from the ownship TCAS II.

Note: *Being consistent does not mean replacing. For example, during a "Do Not Descend" RA, vertical DAA guidance indicating that a climb will prevent a loss of DWC is acceptable. See Subparagraph 2.2.4.4 for more information.*

For Class 2 DAA systems, DAA guidance on vertical velocity **shall (283)** be consistent with active Corrective RAs from the ownship TCAS II. This allows for the DAA system to recommend vertical velocity maneuvers in excess of the vertical velocity required by TCAS II. Alternatively, DAA vertical velocity guidance may be inhibited during TCAS II Corrective RAs.

For Class 2 systems, all vertical altitude DAA guidance **shall (284)** be inhibited during active Corrective RAs from the ownship TCAS II. This is so only vertical velocity guidance is depicted to ensure timely pilot compliance with the RA.

Note: *The use of altitude commands to comply with TCAS II RAs was not considered in these MOPS. Additional human factors and aircraft integration work would be required to use altitude commands to comply with RAs. If altitude commands are used for RAs, DAA vertical guidance may involve altitude DAA guidance, but would need to be consistent with the RA to ensure timely compliance with the RA.*

For Class 2 systems, horizontal DAA guidance **shall (285)** take own TCAS II Corrective RA maneuvers into account to ensure in multi-aircraft encounter horizontal guidance is provided continuously through the Corrective RA for remaining traffic not causing the Corrective RA.

One means of achieving these requirements is during an active Corrective RA, the intruder(s) causing the RA is excluded from the horizontal and vertical DAA guidance processing as documented in the reference implementation, Appendix G.

Note:

1. *These requirements are intended to account for multi-aircraft encounters, particularly those involving aircraft not detected by the TCAS system, and to ensure compliance with TCAS II RAs. The rationale for inhibiting horizontal guidance for the aircraft causing the Corrective RA is the assumption that the PIC will resolve the encounter with that aircraft by following the RA vertical*

velocity guidance. Therefore, DAA horizontal guidance will be provided continuously through the Corrective RA problem for remaining traffic not causing the Corrective RA. The rationale for inhibiting vertical DAA guidance is to avoid providing contradicting guidance between the DAA and TCAS systems. For example, in a multi-intruder encounter DAA vertical guidance could provide descending trajectories as invalid maneuvers due to a non-cooperative target below the ownship while the TCAS RA is to descend.

2. *TCAS II regulations and guidance allow, but do not require, pilots to maneuver horizontally during a vertical RA as long as the TCAS II-directed vertical velocity can be maintained.*

3. *The depiction of predicted conflict space in the vertical or horizontal dimension is not regarded as "guidance" but as special awareness support and hence is not affected by these requirements.*

2.2.4.5.2 Vertical DAA Guidance

Table 2-24 summarizes the ways to maintain and regain DWC in which vertical guidance is adjusted to maintain collision avoidance interoperability and coordination for Class 1 and Class 2 DAA implementations. For "DAA Only" intruders in the table, the maintain and regain DWC functions provide alerts and guidance. For "DAA and CA" intruders in the table, the maintain and regain DWC functions and the CA function provide alerts and guidance with active CA Corrective RAs replacing DAA guidance per the requirements above.

Table 2-24 DAA Vertical Interoperability and Coordination Summary

		DAA Ownship Type	
		DAA Only (Equipment Class 1) (or Class 2 in TA Mode)	**DAA with CA in RA Mode (Equipment Class 2)**
Intruder Equipage	**No Altitude (Mode C, S, or Non-cooperative)**	DAA Only	DAA Only
	Mode C	DAA Only	DAA and CA
	Mode S	DAA Only	DAA and CA
	TCAS II No 1090ES	DAA while maintaining ±500 fpm of the current vertical sense in the CA region of the intruder	DAA modified by coordination VRC from intruder and coordinated CA from the ownship TCAS II

		DAA Ownship Type	
		DAA Only (Equipment Class 1) (or Class 2 in TA Mode)	**DAA with CA in RA Mode (Equipment Class 2)**
	TCAS II and ACAS X with RTCA DO-260B	DAA modified by RA broadcast VRC* from intruder (or maintaining ±500 fpm of the current vertical sense in the CA region during an MTE)	DAA modified by coordination VRC from intruder and coordinated CA from the ownship TCAS II
	Airborne Collision Avoidance System with updated architecture (ACAS X_a)/ Airborne Collision Avoidance System with operation-specific alerts (ACAS X_o) with RTCA DO-260C	DAA modified by coordination VRC from intruder obtained by active surveillance	DAA modified by coordination VRC from intruder and coordinated CA from the ownship TCAS II
	Future Passive CA Systems	DAA modified by coordination VRC from intruder OCM	DAA modified by coordination VRC from intruder OCM and CA from the ownship TCAS II

* VRC is inferred by the intruder's vertical sense.

The columns in Table 2-24 represent two possible configurations of the DAA system. The first Equipment Class 1 DAA ownship type, DAA Only, is for a system that does not have a CA system, or the CA system is in TA mode so TCAS II coordination messages cannot be used. The second DAA ownship type is for Equipment Class 2 DAA systems integrated with a TCAS II system in RA mode, capable of coordinating RA selection.

Note: *Another possible coordination method for Class 1 equipment is to use the active surveillance system to request Register 30 from TCAS II intruders through the Mode S cross-link capability. This method would require a new interrogation scheme that was not used by TCAS II systems as of the publishing date of these MOPS. This capability has not been evaluated for impact on the 1030/1090 spectrum, but would allow the DAA system to obtain the VRC from TCAS II equipped intruders without ADS-B Out. Implementation and approval of such a scheme is not covered by these MOPS.*

The rows in Table 2-24 represent the possible intruder equipage combinations. While RTCA DO-260C had not been published as of the publication of these MOPS, these MOPS contain explicit requirements for coordinating with expected future ACAS systems as agreed upon with RTCA SC-147. The publication of RTCA DO-260C is not needed for certification of equipment built to these MOPS.

2.2.4.5.2.1 Determining Intruders' Vertical RA Capability

Vertical guidance **shall (286)** be modified per the requirements in Subparagraph 2.2.4.5.2.3, for intruders capable of vertical RAs.

Note: *The DAA vertical guidance does not need to be modified for intruders incapable of vertical RAs.*

Because the DAA system is capable of transmitting Mode S interrogations and receiving Mode S replies through active surveillance, it is capable of determining whether intruders are capable of vertical RAs.

Intruders capable of vertical RAs **shall (287)** be determined by checking the Reply Information (RI) field in Downlink Format (DF)=0 and DF=16 replies. If the RI field is equal to 3 (Onboard TCAS II with vertical-only resolution capability) or 4 (Onboard TCAS II with vertical and horizontal resolution capability), the intruder is capable of vertical RAs; otherwise the intruder is incapable of vertical RAs.

Note: *RTCA DO-260B intruders capable of vertical RAs may also be determined by checking the "TOP" field of DF=17 Type Code 29, Subtype 01. If TOP=1, then the intruder is capable of vertical RAs.*

2.2.4.5.2.2 Determining Intruders' Vertical Resolution Advisory Complement (VRC) Information

It is expected that ACAS Xa/Xo will send CA resolution messages via active surveillance if the DAA aircraft is equipped with RTCA DO-260C configured to indicate DAA equipment onboard in the CA Coordination Capability Bits (CCCB) and if the ACAS X intruder is able to receive those ADS-B messages. Else, the ACAS X aircraft will just send out RTCA DO-260B RA broadcast messages, which will be used by the DAA equipment (except in multi-threat encounters).

The VRC of intruders capable of vertical RAs is determined by one of the following methods (in order of preference):

1. For intruder aircraft being tracked by an RA-capable CA system onboard (Class 2 DAA with TCAS II in RA mode), the VRC **shall (288)** be determined by checking the "MU" field of the intruder's UF=16 interrogation addressed to the ownship Mode S address (see Subparagraph 2.2.2.1.5). A VRC=1 means "Do not pass below" and a VRC=2 means "Do not pass above." If no VRC is received, VRC=0, or VRC=3, the VRC is "none."
2. If a CA resolution message is received through active surveillance (Class 1 DAA or Class 2 DAA with TCAS II not in RA mode), the VRC **shall (289)** be determined by checking the MU field of the intruder's UF=16 interrogation addressed to the ownship Mode S address (see Subparagraph 2.2.2.1.3). A VRC=1 means "Do not pass below" and a VRC=2 means "Do not pass above." If VRC=0 or VRC=3, the VRC is "none."

3. If an OCM is received through ADS-B In, the VRC **shall (290)** be determined by checking the OCM (DF=17, Type Code 28, Subtype 3) with the traffic Mode S address equal to the ownship Mode S address (see Subparagraph 2.2.2.1.4.5). A VRC=1 means "Do not pass below" and a VRC=2 means "Do not pass above." If VRC=0 or VRC=3, the VRC is "none."

   Note:

   1. *Per RTCA SC-147, OCM messages will be used by future Passive CAS systems.*
   2. *For Methods 2 and 3. above, the DAA ownship will need RTCA DO-260C ADS-B Out to indicate to ACAS X systems or future passive CA systems via the CA CCCBs that it is capable of receiving information via active surveillance or the OCM.*

4. For intruder aircraft broadcasting in compliance with RTCA DO-260B ADS-B Out, the VRC **shall (291)** be determined by checking the 1090ES TCAS II RA broadcast message (DF=17, Type Code 28, Subtype 002) with TID equal to the ownship Mode S address, MTE=0 (no more than one threat), and TTI=1 (Mode S transponder address) (see Subparagraph 2.2.2.1.4.4). Bit 43 of the ARA field when ARA Bit 41=1 implies a VRC. If Bit 43=0 (upward sense RA has been generated) then the VRC is "Do not pass above." If Bit 43=1 (downward sense has been generated) then the VRC is "Do not pass below." If no RA broadcast message is received, the VRC is "none."

Note: *VRC cannot be inferred from the TCAS II RA broadcast message in multiple-threat encounters (MTE=1).*

For all other vertical RA-capable aircraft, the intruder's vertical sense **shall (292)** be *unknown.*

Note

1. *This case should only apply to Class 1 DAA systems with a TCAS II intruder that isn't broadcasting RTCA DO-260B ADS-B Out, or when an RA is broadcast with MTE=1 (more than one threat) for RTCA DO-260B ADS-B Out intruders.*
2. *A VRC of "none" is known (since the intruder is known not to be in an RA state). This case is only for Class 2 equipment per Method 1, above, and intruders with RTCA DO-260B ADS-B Out per Method 4. above.*

DAA systems interfaced with (or including) a vertical RA-capable CA system in RA mode will always know the VRC per Method 1, above. For DAA systems without a vertical RA-capable CA system in RA mode, the VRC will be unknown for an intruder in a MTE that doesn't transmit the CA Resolution Message via active surveillance or transmit an OCM. The VRC will also be unknown for vertical RA-capable TCAS II intruders not broadcasting ADS-B RA broadcasts in accordance with RTCA DO-260B.

Figure 2-8 outlines one possible method for implementing the requirements in this subparagraph for determining an intruder's VRC information.

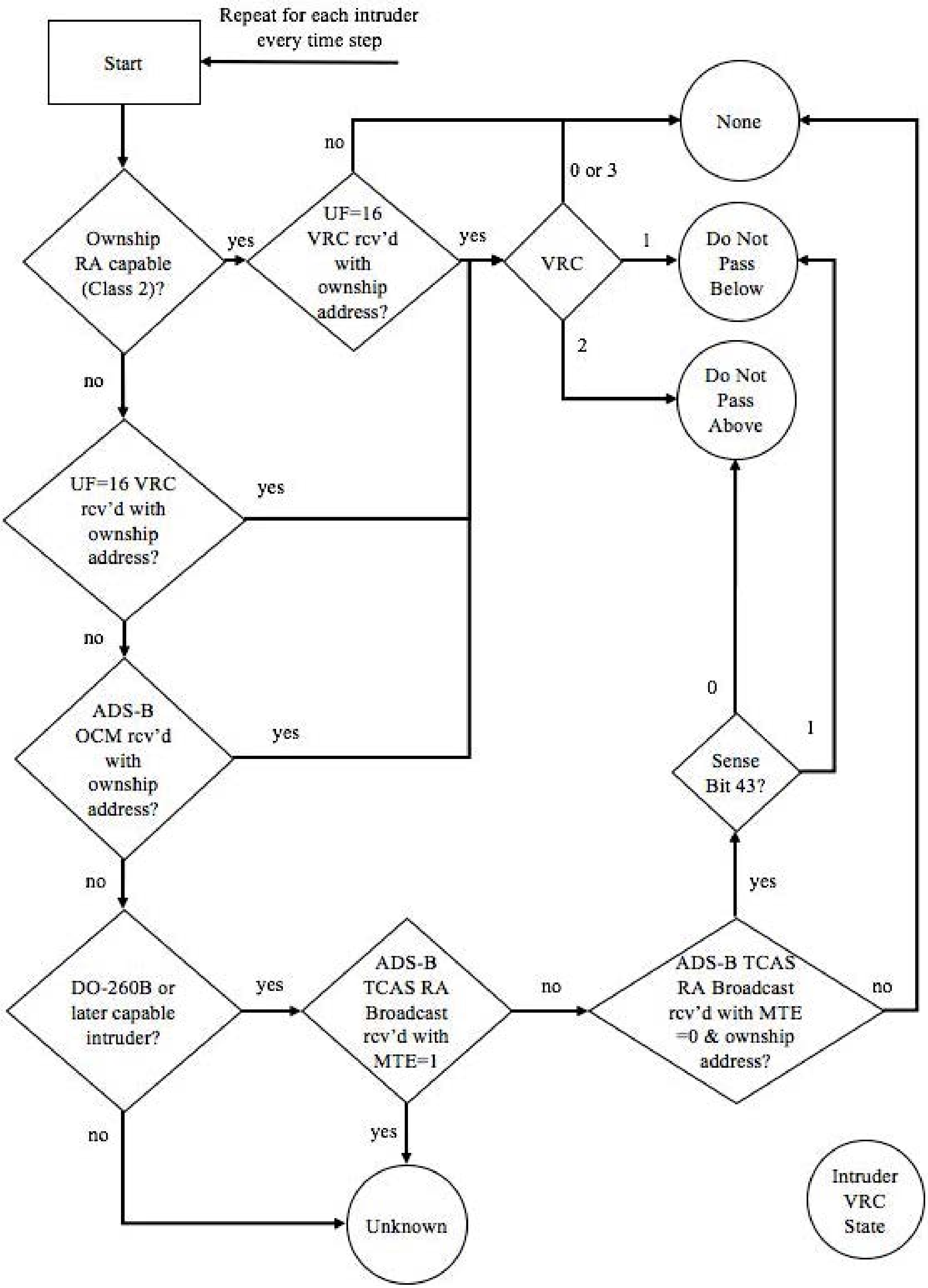


Figure 2-8 Example Means of Determining Intruder VRC Information

2.2.4.5.2.3 Vertical DAA Guidance Modification

For both Equipment Class 1 and Class 2 DAA systems, once it is determined that an intruder is capable of vertical RAs, the following requirements describe how the guidance information needs to be modified to ensure DAA guidance doesn't conflict with vertical RAs occurring on intruder aircraft. These RAs may occur prior to an ownship RA being generated with Class 2 equipment. Likewise, this guidance may occur without the intruder being declared an alert by the DAA system. See Appendix M for more information.

If the VRC from a DAA corrective alert or non-alert intruder capable of vertical RAs indicates "Do not pass above," then corrective guidance information **shall (293)** be provided for vertical velocities greater than 0 fpm and altitudes above the current altitude.

If the VRC from an DAA warning alert intruder capable of vertical RAs indicates "Do not pass above," warning guidance information **shall (294)** be provided for vertical velocities greater than 0 fpm and altitudes above the current altitude.

If the VRC from a DAA corrective alert or non-alert intruder capable of vertical RAs indicates "Do not pass below," then corrective guidance information **shall (295)** be provided for vertical velocities less than 0 fpm and altitudes below the current altitude.

If the VRC from a DAA warning alert intruder capable of vertical RAs indicates "Do not pass below," then warning guidance information **shall (296)** be provided for vertical velocities less than 0 fpm and altitudes below the current altitude.

If a DAA corrective alert or non-alert intruder capable of vertical RAs is within the CA region as defined below and the VRC is unknown, then corrective guidance information **shall (297)** be provided for all altitudes and vertical velocities outside of the current vertical velocity ±500 fpm.

If a DAA warning alert intruder capable of vertical RAs is within the CA region as defined below and the VRC is unknown, then warning guidance information **shall (298)** be provided for all altitudes and vertical velocities outside of the current vertical velocity ±500 fpm.

The current vertical velocity used to determine the vertical velocity guidance **shall (299)** be the vertical velocity when the VRC from a vertical RA-capable intruder is first received.

If an intruder capable of vertical RAs is within the CA region as defined below and the VRC is unknown, all absolute or relative altitude-based vertical guidance **shall (500)** be removed. In some cases, DAA guidance may not be displayed prior to the intruder entering the CA region.

If the VRC is "none" then no modifications to Vertical DAA guidance are necessary.

The CA region for a given intruder is defined as:

$$0 \leq \tau_{mod} < \tau_{mod}^{*}.and.(0 \leq \tau_{v} < \tau_{v}^{*}.or.d_{h} < h^{*})$$

with

$\tau_{mod}^{*} = 50\ seconds$, $DMOD = 1.1\ NM$, $\tau_{v}^{*} = 50\ seconds$, .and $h^{*} = 800'$

where

τ_{mod} is the Modified Tau,

τ_{mod}^{*} is the Modified Tau Threshold,

τ_{v} is the Vertical Tau,

τ_{v}^{*} is the Vertical Tau Threshold,

DMOD is the Distance Modification of Modified Tau,

d_h *is the current Vertical Separation, and*

h^{*} is the Vertical Separation Threshold.

Note: *The 50-second tau threshold value, 1.1 NM DMOD, and 800' h^{*} were chosen by SC-147 based on the largest TCAS II RA sensitivity level (above 42,000' pressure altitude) plus 15 seconds for pilot response and TCAS II altitude tracker response. Smaller values based on TCAS II sensitivity levels could be used for aircraft at lower altitudes. Likewise, lower tau threshold values at lower altitudes and reduced assumptions for pilot response time could be used for DAA systems with automatic DAA response, but this is out of the Phase 1 scope. While ACAS X does not use the same logic as TCAS II, ACAS X will send CA Resolution Messages to DAA systems, so the CA region is not used.*

Modified Tau (τ_{mod}) is defined in Subsection C.5 (Mathematical DAA Well Clear (DWC) Definition).

Vertical Tau (τ_{v} also known as time to co-altitude) is defined as:

$$\tau_v = -\frac{d_h}{v_{rh}}$$

where:

$$d_h = abs(h_2 - h_1)$$

$$v_{rh} = \dot{h}_2 - \dot{h}_1$$

Note:

1. v_{rh} *is negative for closing geometries and therefore,* τ_v *is positive for closing geometries.*
2. *For more information on the CA region definition, see: http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20160010603.pdf*

2.2.4.5.3 Horizontal DAA Guidance

Since it is unknown how future horizontal CA systems will state their capabilities, the DAA system does not need to check whether an intruder is horizontal CA-capable prior to accepting valid horizontal complement data via active surveillance or the ADS-B OCM. Since no legacy TCAS II units use horizontal RAs, there is no unknown horizontal state. The RA Broadcast message does not contain horizontal complement data, so it cannot be used. The following requirements describe how the guidance information needs to be modified to ensure DAA guidance doesn't conflict with horizontal RAs occurring on intruder aircraft. This guidance may occur without the intruder being declared an alert by the DAA system. See Appendix M for more information.

Note: *Any CA system that provides horizontal RAs will need to coordinate to comply with Paragraph M.4.2 of Appendix M.*

The Horizontal RA Complement (HRC) of intruders is determined by one of the following methods (in order of preference):

1. For intruder aircraft being tracked by an RA-capable CA system onboard (Class 2 DAA with TCAS II in RA mode), the HRC **shall (501)** be determined by checking the MU field of the intruder's Uplink Format (UF)=16 interrogation addressed to the ownship Mode S address (see Subparagraph 2.2.2.1.5).
2. If a CA resolution message is received through active surveillance (Class 1 DAA or Class 2 DAA with TCAS II not in RA mode), the HRC **shall (502)** be determined by checking the MU field of the intruder's UF=16 interrogation addressed to the ownship Mode S address (see Subparagraph 2.2.2.1.3).
3. If an Operational Coordination Message (OCM) is received through ADS-B In, the HRC **shall (503)** be determined by checking the OCM (DF=17, Type Code 28, Subtype 3) with the traffic Mode S address equal to the ownship Mode S address (see Subparagraph 2.2.2.1.4.5).

Note: *Per RTCA SC-147, OCM messages will be used by future Passive CAS systems.*

If the Horizontal RA Complement (HRC) field is 1 (Other ACAS sense is turn left; do not turn left) or 5 (Other ACAS sense is turn right; do not turn left), the horizontal complement is "Do not turn left." If the HRC field is 2 (Other ACAS sense is Turn left; do not turn right) or 6 (Other ACAS sense is Turn right; do not turn right), then the horizontal complement is "Do not turn right."

Note:

1. *The definition of the OCM has been agreed upon by RTCA SC-147 and the RTCA Combined Surveillance Committee (SC-186 and SC-209) and is expected to be consistent with the definition in this document.*

2. *As of the publishing date of these MOPS, no systems used horizontal coordination. Listening and adjusting guidance based on active coordination and the OCM message is sufficient to comply with the goal of not restricting future CA systems from taking advantage of technological advances and innovative designs. It is assumed that all future horizontal RA systems will broadcast a coordination message if they deem it necessary.*

If a DAA corrective alert or non-alert intruder has a known horizontal complement of "Do not turn right" then corrective guidance information **shall (504)** be provided for relative headings of +1 to +180 degrees from the current heading.

If a DAA warning alert intruder has a known horizontal complement of "Do not turn right" then warning guidance information **shall (505)** be provided for relative headings of +1 to +180 degrees from the current heading.

If a DAA corrective alert or non-alert intruder has a known horizontal complement of "Do not turn left" then corrective guidance information **shall (506)** be provided for relative headings of -1 to -180 degrees from the current heading.

If a DAA warning alert intruder has a known horizontal complement of "Do not turn left" then warning guidance information **shall (507)** be provided for relative headings of -1 to -180 degrees from the current heading.

2.2.5 DAA Traffic Display Subsystem Requirements

2.2.5.1 General DAA Traffic Display Requirements

The Ground Control Station (GCS) Display of Traffic Information (GDTI) is defined as the displays and controls necessary to support the applications included in this document. GDTI functions may be integrated into a number of display and control sub-elements. At a minimum, the GDTI includes a graphical plan-view (top down) traffic display, hereafter referred to as the DAA traffic display, in addition to the controls for the display and applications (as required).

One intended function of the DAA traffic display is to provide intruder information for maintaining DWC, with a validity and reliability such that the UAS PIC is authorized to maneuver against nearby aircraft based solely on displayed information.

The DAA traffic display is required (in Subparagraph 2.2.5.3) to indicate the ownship position, and, to show the positions, relative to the ownship, of traffic. The DAA traffic display is also required to provide specific traffic information elements in associated data tags (in Subparagraph 2.2.5.6.2.1), traffic symbology (in Subparagraph 2.2.5.6.2.3) and DAA alerts (in Subparagraph 2.2.5.6.2.3.2.5), and maneuver guidance to maintain and regain DWC (in Subparagraph 2.2.5.7).

<u>Note:</u> *Data supporting the inclusion of maneuver guidance as a minimum requirement comes from a series of studies conducted by NASA and the US Air Force, which are detailed in References A through I (in Subsection 1.9).*

The GDTI may be a stand-alone display or displays (dedicated display(s)) or the GDTI information may be present on (an) existing display(s) (e.g., a multi-function display). The controls may be a dedicated GDTI control panel or it may be incorporated into other controls (e.g., a multi-function control display unit). Additional display surfaces and controls may be used.

2.2.5.2 Traffic Display Criteria (TDC) Requirements

The surveillance range of the surveillance applications will frequently include more traffic than is of interest to the flight crew. Displaying too many traffic elements on the DAA traffic display may result in clutter, and compromise the intended function of the DAA traffic display. To determine the traffic of interest to the flight crew, a set of TDC is used to filter the traffic. Criteria generally include range and altitude. Additional criteria may also be used. The flight crew may change the TDC.

Note: *The traffic elements shown on the DAA traffic display are subject to the traffic priorities specified in Subparagraph 2.2.4.3.4.1, including the maximum number of traffic elements that can be shown on the display (see Subparagraph 2.2.5.6.3), and the parameters of the TDC.*

All traffic causing DAA alerts or TCAS II RAs **shall (300)** be displayed on the DAA traffic display, subject to the maximum number of traffic elements that can be displayed.

When a DAA alert or TCAS II RA is present, all intruders within ±4000’ altitude and 6 NM range **shall (301)** be displayed on the DAA traffic display, subject to the maximum number of traffic elements that can be displayed.

2.2.5.2.1 Default Traffic Display Criteria

The default range at power-up is defined by the manufacturer. UAS PICs normally adjust the range to suit their preference. The default TDC is dynamic with respect to range, but uses a static altitude band.

It is desirable that the supported altitude bands are consistent between all CS displays i.e., that the same altitude bands be used for TCAS II and DAA traffic displays. The standard for TCAS II displays is ±2700’; however, for DAA, the minimum filtering range is ±4000’ (Subparagraph 2.2.5.8.3) to accommodate the larger thresholds for the DAA alerts compared to TCAS II alerts. Therefore, the recommended default altitude band for the DAA traffic display is ±4000’.

All non-default TDC **shall (302)** be annunciated visually.

Note: *For example, if the non-default TDC uses an altitude band of +9900’ and -4500’, display “ALT +99/-45” at a place reserved for indicating the non-default TDC on the display.*

2.2.5.3 DAA Traffic Display Information Requirements

At a minimum, all DAA traffic display installations provide the information needed to support the Basic Airborne Situational Awareness (AIRB) application.

The DAA traffic display **shall (303)** display the following information:

- Display range/map scale
- Ownship position
- Altitude bands.

Note: *The default altitude band need not be depicted on the DAA traffic display; it can be displayed by observing the indication of a selector knob.*

The DAA traffic display **shall (304)** provide the following traffic information for each displayed traffic element:

- Horizontal position (range and azimuth of traffic symbol on display)
- Traffic directionality (if available)
- Traffic altitude (see Subparagraph 2.2.5.6.4.3)
- Traffic vertical direction indicator (an indication of climb or descent) when vertical rate is available and is equal to or more than 500 fpm

Note: *A smaller vertical rate threshold (e.g., 300 fpm) may be used.*

- Horizontal velocity trend (e.g., predictor line or history trail).

Unless specifically noted elsewhere (e.g., see Subparagraph 2.2.5.9), the information can be conveyed graphically (e.g., in the traffic symbol) or as part of a data tag.

2.2.5.4 Interface Requirements

2.2.5.4.1 DAA Traffic Display Latency Requirements

The maximum total latency between the CS DAA processor data and the display **shall (305)** be 0.5 seconds.

Human Interface Latency: The DAA control system latency from activation of a control input to the appearance of the response on the DAA traffic display should be fast enough to prevent undue concentration by the flight crew (see AC 20-175). The specific acceptable response times depend on the intended function. Generally, if this value exceeds 0.25 seconds, an indication that the system has recognized the input should be provided until the response appears on the DAA traffic display.

2.2.5.4.2 Time of Applicability of Traffic State Vector (SV) Data

The DAA traffic display **shall (306)** update the traffic data at a minimum of 1 Hz.

2.2.5.5 Display Design Requirements – General

2.2.5.5.1 Display Characteristics

DAA traffic display and guidance information should be discernable, legible, and unambiguous within all flight environments (e.g., ambient illumination), even when displayed in combination with other information (e.g., an electronic map).

The operating range of display luminance and contrast **shall (307)** be sufficient to ensure display readability through the full range of normally expected illumination conditions for the CS (Reference Society of Automotive Engineers (SAE) Aerospace Recommended Practice (ARP) 4256A).

2.2.5.5.2 Dynamics

Movement of DAA traffic and guidance information on the display should not result in objectionable jitter, jerkiness, or ratcheting effects.

Movement of DAA traffic and guidance information on the display should not blur, shimmer, or produce unintended dynamic effects such that the information becomes distracting or difficult to interpret.

Filtering or coasting of DAA traffic and guidance data intended to smooth the movement of DAA traffic display information should not introduce significant positioning errors or create system lag that makes it difficult to perform the intended task.

2.2.5.5.3 Labels

Labels are descriptions of information elements. Labels include text such as "NM" for nautical miles and icons. Standard or unambiguous abbreviations, symbols and nomenclature should be used for labeling. (Reference ICAO Doc 8400 "ICAO Abbreviations and Codes, eight edition" 2010)

2.2.5.5.4 Symbols

Each DAA traffic and guidance display symbol **shall (308)** be identifiable and distinguishable from other DAA traffic display symbols.

The shape, color, dynamics, and other symbol characteristics should have the same meaning within the DAA traffic display.

DAA traffic and guidance display symbol modifiers should follow rules that are consistent across the symbol set.

2.2.5.6 Requirements for Display Elements

This subparagraph describes and includes requirements for the ownship symbol and traffic symbols and their variations, data tags and data blocks.

Note: *Symbols, controls, and alerting are expected to be consistent with current CS design philosophy.*

2.2.5.6.1 Ownship Symbol

The DAA traffic display **shall (309)** display a symbol indicating the location of the ownship.

If valid ownship position is not available the DAA traffic display will be unable to display ADS-B traffic. In that event, the DAA traffic display **shall (310)** display an indication that ADS-B has failed but that the DAA system is still operating in a degraded mode (e.g., the DAA traffic display shows an "Ownship Data Quality Failure/Degraded DAA Mode" or "Ownship Nav Position Failure/Degraded DAA Mode" message).

Note: *Systems integrated with TCAS II may revert to a TCAS II Only display.*

The ownship symbol **shall (311)** be distinctive from all other symbols on the traffic display.

The ownship symbol should be unobstructed.

If ownship directionality is valid, the ownship symbol **shall (312)** be directional (e.g., not a circle or square).

The use of a horizontal velocity vector for the ownship is optional.

The manufacturer must specify (e.g., in the system manual) the ownship horizontal position reference point location on the ownship symbol (i.e., the point on the ownship symbol that represents the ownship's reported horizontal position).

Note: *The location of the ownship with reference to the ownship symbol is expected to be consistent with current CS design philosophy.*

The position of the ownship symbol should allow the display of airborne traffic in all directions around the ownship.

2.2.5.6.2 Traffic Information Formats

The primary purpose of the DAA traffic display is to display intruder information. Traffic symbols provide a graphical representation of traffic information. The position of traffic symbols on the DAA traffic display represents horizontal position of traffic relative to the ownship. The traffic symbology may also indicate other traffic information, such as traffic directionality or alert status.

Additional information about individual traffic may be contained in either data tags or data blocks displayed on the same display unit as the traffic symbols. Data blocks typically reside in a fixed location on the DAA traffic display (or other displays), independent of the traffic symbol location. In contrast, data tags are always located on the DAA traffic display near the traffic symbol or somehow linked to the associated traffic symbol.

Traffic information can be displayed in one or more of these formats:

- Data tags
- Data blocks
- Traffic symbology

2.2.5.6.2.1 Data Tags

Data tags are implemented with the traffic symbol to provide additional information, such as altitude, vertical direction, and Traffic ID. Data tags are generally associated with all traffic symbols.

If data tag information is available, then:

1. A data tag **shall (313)** be provided for all displayed airborne traffic.
2. A means **shall (314)** be provided to associate the data tag with the traffic symbol.

<u>***Note:***</u> *For example – association can be achieved by consistently positioning the data tag near the traffic symbol.*

A data tag for airborne traffic **shall (315)** include:

- Traffic altitude (see Subparagraph 2.2.5.6.4.3)
- Traffic vertical direction indicator (an indication of climb or descent) when vertical rate is available and is equal to or more than 500 fpm

<u>***Note:***</u> *A smaller vertical rate threshold (e.g., 300 fpm) may be used.*

The color of the traffic altitude and traffic vertical direction indicator **shall (316)** match the associated traffic symbol

Data tag information that is invalid or unavailable should be indicated in the respective field of the data tag

<u>***Note:***</u> *A blank field may be a method of conveying invalid status.*

2.2.5.6.2.2 Data Blocks

A data block is associated with a traffic symbol to provide more detailed information on selected aircraft, such as ground speed, range, category, and traffic ID. Data blocks may also be used to persistently display application-specific information. More than one data block may be displayed. Data block(s) should be displayed at a fixed location on the DAA traffic display or other display unit, and should not move with the traffic symbol.

If a data block is implemented, a means **shall (317)** be provided to associate the data block with corresponding traffic symbol (e.g., association may be achieved by use of the same border, color, or a line).

If traffic selection is implemented, the DAA traffic display **shall (318)** have the capability to display all additional traffic information required by the installed applications.

The DAA traffic display may have the capability to provide the following traffic information in the data block:

- Traffic application capability (see Subparagraph 2.2.5.6.4.2).
- Which sensors detect the target and an indication of whether the target is cooperative (detected by ADS-B and/or a Mode C/S transponder) or non-cooperative (only detected by airborne radar).
- Whether a traffic element is tracked by TCAS II.

2.2.5.6.2.3 Traffic Symbols

The DAA traffic display **shall (319)** display one traffic symbol for each traffic report received from the DAA processor that meets the TDC, subject to the maximum number of traffic elements.

Note: *The DAA processor normally provides a single traffic report for each aircraft, based on data from multiple surveillance sources. If the DAA processor is unable to correlate the data from these sources, it will create more than one traffic report. The GDTI function assumes these are different traffic elements.*

2.2.5.6.2.3.1 Traffic Symbol Location

The DAA traffic display **shall (320)** position each traffic symbol at a location representing its relative position with respect to the ownship.

The manufacturer must specify (e.g., in the system manual) the traffic horizontal position reference point location on the traffic symbol (i.e., the point on the traffic symbol that represents the reported traffic horizontal position).

The traffic horizontal position reference point, when using non-directional symbols, should be the center of the symbol.

Note: *A traffic symbol is an abstract representation and does not reflect the physical extent of the aircraft. This is an important consideration when correlating the aircraft symbol with a highly magnified/zoomed-in (small range on a large display) map. The length and width codes, if available, can be used to display the physical extent of the aircraft.*

2.2.5.6.2.3.2 Traffic Symbols and Variations

The “basic” traffic symbol is used to depict general airborne traffic, including non-alert or non-proximate traffic. Traffic symbols can be modified from the basic symbols to provide additional information, such as directionality and alert status.

The symbology in the following subparagraphs is intended to limit the symbol variations across aircraft platforms. It is desirable to limit this variation to foster comprehension of the information conveyed by the symbols to the flight crews. Manufacturers may propose alternate symbols; however, these alternate symbols will need to be justified by human factors analysis as part of the certification process. Alternate symbol sets are not allowed without additional justification.

2.2.5.6.2.3.2.1 Basic Directional Traffic

If directionality is valid, the basic directional traffic symbol **shall (321)** be depicted with an unfilled arrowhead shape oriented by the directionality.

Note: *Directionality is considered valid when the intruder has not been declared a “bearingless intruder” (see Subparagraph 2.2.3.2.1.1)*

The color **shall (322)** be cyan or white.

The color **shall (323)** be the same color as the basic non-directional symbol.

The color **shall (324)** be in a different color from the ownship symbol.

Figure 2-9 provides an example depiction.

Figure 2-9 Basic Directional Traffic Symbol (Example)

2.2.5.6.2.3.2.2 Basic Non-directional Traffic

If directionality is invalid, the basic non-directional traffic symbol **shall (325)** be depicted with an unfilled diamond shape.

Note: *Non-directional symbols should not rotate with the display orientation.*

The color **shall (326)** be cyan or white.

The color **shall (327)** be the same color as the basic directional symbol.

The color **shall (328)** be in a different color from the ownship symbol.

Figure 2-10 provides an example depiction.

Figure 2-10 Basic Non-directional Traffic Symbol (Example)

2.2.5.6.2.3.2.3 Traffic Directionality Depiction

If the traffic symbol indicates directionality, the directionality of the traffic symbol **shall (329)** be displayed relative to the display orientation.

Note: *Non-directional symbols should not rotate with the display orientation.*

Traffic directionality **shall (330)** be displayed with a resolution of 15 degrees or better (i.e., a maximum of ±7.5-degrees display quantization error).

Note: *The traffic directionality in air is based on traffic ground track angle, and not necessarily traffic heading. This is important for monitoring traffic such as helicopters that can fly backwards and sidewards to account for winds.*

2.2.5.6.2.3.2.4 Maneuver Guidance Traffic

If traffic is associated with maneuver guidance, the basic traffic symbol **shall (331)** be displayed as filled. Figure 2-11 provides example depictions.

Figure 2-11 **Directional and Non-directional Guidance Traffic Symbols (Example)**

2.2.5.6.2.3.2.5 Alert Types and Symbols

The following requirements apply generally to alerts based on DAA systems (see Subparagraph 2.2.4.3.4 of these MOPS).

Traffic that triggers an alert **shall (332)** be indicated on the DAA traffic display with a symbol variation. The following requirements only apply to the alerted traffic symbol:

1. If traffic directionality is valid, directionality information **shall (333)** remain during alerts.
2. The traffic symbol **shall (334)** change to amber/yellow for caution-level alerts.
3. The traffic symbol **shall (335)** change to red for warning-level alerts.
4. The traffic symbol **shall (531)** be modified when an ADS-B-only intruder is marked unvalidated per Subparagraph 2.2.3.2.1.3.4.

Note: *Unvalidated ADS-B intruders cannot be Warning Alert traffic, so the requirement will only apply to Preventive and Corrective Alert traffic*

Alerting traffic that lies outside the configured DAA traffic display range **shall (336)** be positioned at the measured relative bearing, and at the configured display maximum range (i.e., edge of display), and with a symbol shape modification that indicates that the traffic is off-scale.

Note: *A half-symbol at the display edge is one acceptable indication method.*

Circle and square shapes should not be used to depict other traffic information.

2.2.5.6.2.3.2.5.1 Preventive Alert

If traffic has a preventive alert, the traffic symbol **shall (337)** be modified by adding an amber/yellow circle around the filled amber/yellow directional symbol, as shown in Figure 2-12.

Figure 2-12 **Preventive Alert Symbol**

2.2.5.6.2.3.2.5.2 Corrective Alert

If traffic has a corrective alert, the traffic symbol **shall (338)** be modified by adding a filled amber/yellow circle containing the black outline of the directional symbol, as shown in Figure 2-13.

Figure 2-13 Corrective Alert Symbol

2.2.5.6.2.3.2.5.3 Warning Alert

If traffic has a warning alert, the traffic symbol **shall (339)** be modified by adding an unfilled red square to a filled red directional symbol, as shown in Figure 2-14.

Figure 2-14 Warning Alert Symbol

2.2.5.6.2.3.2.6 Alerting Special Cases

In some situations, data from the sensors may not be available to support compliance with the alerting requirements in Subparagraph 2.2.4.3. The following subparagraphs specify how to depict alerts in those special cases where full information is not available. See Subparagraph 2.2.4.3.5 for details on how alerts are determined and output by the DAA processor for these special cases.

2.2.5.6.2.3.2.6.1 No Bearing

Alerts issued against an intruder for which bearing information is not available (No Bearing alerts, Subparagraph 2.2.4.3.5.2) **shall (340)** be presented on the DAA traffic display for traffic generating either a corrective or warning alert.

The no bearing alert should be in a location readily visible to the PIC. It should be clear and legible, and not obstructing of other DAA information.

The alert **shall (341)** be an alphanumeric string that presents the information in the following order: "No Bearing" in text; range in NM; relative altitude (hundreds of feet); the intruder vertical velocity arrow; and threat level (e.g., Corrective (CORR) or Warning (WARN)).

- For example, "No Bearing 5.2 -06↑ CORR" represents an intruder causing a corrective alert at 5.2 NM with a relative altitude of -600', and climbing.

The alphanumeric characters **shall (342)** be written in the colors corresponding to the level of the threat, i.e., red for a warning alert and amber/yellow for a corrective alert.

The no bearing alert may also be written using slashes to separate the different information fields and using NM after the range,

- For example, "No Bearing/5.2 NM/-06↑/CORR)

The altitude data in a no bearing alert **shall (343)** be consistent with the selected altitude mode, i.e., relative altitude or actual altitude.

The capability **shall (344)** exist to display at least the two highest priority no bearing alerts simultaneously.

2.2.5.6.2.3.2.6.2 No Altitude and Altitude High Uncertainty

When an alert is issued against an intruder that is not reporting altitude, the altitude field of the message and the intruder vertical trend arrow **shall (345)** no longer be displayed.

Note: *If a no-bearing alert is issued against an intruder that is also not reporting altitude, the altitude field of the message and the intruder vertical trend arrow would no longer be displayed. For example, a corrective alert issued against a non-altitude reporting intruder at a range of two NM would be visually annunciated as "2.0 CORR."*

When an alert is issued against an intruder that is reporting altitude, but the altitude uncertainty is greater than relative altitude, the altitude field of the message and the intruder vertical trend arrow **shall (346)** no longer be displayed.

2.2.5.6.2.3.2.7 TCAS II Alert Symbols for TCAS II/DAA Integrated Systems

For TCAS II Corrective Resolution Advisories, the DAA system **shall (347)** display these alerts as defined in RTCA DO-185B.

1. Traffic with valid directionality **shall (348)** be a filled red square containing the black outline of the directional symbol, as shown in Figure 2-15.
2. The size of RA traffic symbols may be increased to accommodate the shape modification.
3. Line widths and fill may be changed to improve color interpretation and saliency.
4. The corresponding aural alerts, as defined in RTCA DO-185B, should not be affected by these requirements.

Figure 2-15 Directional TCAS II RA Symbol

Note: *TCAS II Corrective and Preventive Resolution Advisory types are shown in Table 2-22 and Table 2-23.*

For TCAS II Preventive Resolution Advisories, the DAA system **shall (349)** display a DAA Preventive Alert, if it has not already been declared a Preventive alert or higher by the DAA processor (in Subparagraph 2.2.4.3.4).

Note: *The depiction of a DAA Preventive Alert should trigger the appropriate aural alert specified in Subparagraph 2.2.5.11.1.1.*

TCAS II Traffic Advisories **shall (350)** be suppressed by the DAA traffic display.

2.2.5.6.3 Number of Traffic Elements

A traffic element is an aircraft.

The DAA traffic display **shall (351)** be capable of displaying at least the highest eight priority traffic elements (Subparagraph 2.2.4.3.4.1).

The DAA traffic display should provide an indication when the number of traffic elements meeting the TDC exceeds the maximum number of traffic elements that can be displayed.

Note: *Traffic will be displayed based on the TDC (see Subparagraph 2.2.5.2). Traffic of interest to the flight crew may not be included within the first eight elements in this list.*

2.2.5.6.4 Information Elements

The following subparagraphs describe requirements associated with the display of information in data tags, data blocks, or traffic symbols.

2.2.5.6.4.1 Traffic Monitored by TCAS II

In TCAS II/ Aircraft Surveillance Application (ASA) integrated systems, the flight crew may be interested to know if CA protection is being provided by TCAS II against a particular traffic element. A means may be provided for the flight crew to determine if traffic of interest is monitored by TCAS II (i.e., is either a TCAS II Only or a TCAS II correlated traffic element). This information should be conveyed as part of the data block, and does not have to be continuously displayed.

2.2.5.6.4.2 Traffic Application Capability

Each application specifies minimum requirements for traffic elements to support the application. The traffic application capability generally has the states: "valid for use by the application," and "invalid for use by the application."

The DAA traffic display provides general traffic situational awareness within the surveillance range. Traffic not meeting the DAA data quality thresholds is not forwarded to the DAA traffic display and therefore is not displayed.

Note: *For systems integrated with TCAS II, tracks provided by TCAS II have already been filtered for data quality and the DAA systems does not do any additional data quality filtering of those tracks.*

Additional applications are optional, and may have different (more strict) data quality thresholds. If any additional applications are installed, there **shall (352)** be a means to determine the traffic's application capability with respect to each installed application. This can be accomplished graphically, by simple flight crew action to select an application, or by other means.

2.2.5.6.4.3 Traffic Altitude

Traffic altitude includes four types of altitudes; traffic relative altitude (see Subparagraph 2.2.5.6.4.3.1), traffic actual altitude (see Subparagraph 2.2.5.6.4.3.2), traffic geometric altitude (see Subparagraph 2.2.5.6.4.3.3) or traffic pressure altitude (see Subparagraph 2.2.5.6.4.3.4). Traffic altitude must be continuously displayed in the data tag.

The data tag on the DAA traffic display **shall (353)** display traffic relative altitude as the nominal case.

Note: *The display may have the capability to change the data tag altitude format to actual or pressure altitude.*

Data blocks, or locations other than the DAA traffic display, may display traffic relative altitude, traffic actual altitude, traffic geometric altitude or traffic pressure altitude.

If the capability exists to display an altitude type other than traffic relative altitude, each DAA traffic display **shall (354)** indicate which altitude type is displayed.

Traffic altitude **shall (355)** be removed if traffic altitude is unavailable.

Traffic altitude **shall (356)** be displayed with a resolution in hundreds of feet.

2.2.5.6.4.3.1 Traffic Relative Altitude

Traffic relative altitude is the difference between ownship and traffic altitude. Traffic relative altitude is calculated by either (1) using the pressure altitude of both aircraft, (2) if valid traffic pressure altitude is unavailable, using the geometric altitude of both aircraft or (3) directly by the ATAR. The relative altitude shown for traffic is positive when the traffic is higher than the ownship and negative when traffic is lower than the ownship.

Note: *An indication should be made available to the PIC when traffic geometric altitude is used.*

For traffic above the ownship, the traffic relative altitude value in the data tag **shall (357)** be preceded by a "+" sign and be placed above the traffic symbol.

For traffic below the ownship, the traffic relative altitude value in the data tag **shall (358)** be preceded by a "-" sign and be placed below the traffic symbol.

Note: *The "+" or "-" character may be emphasized (e.g., by using a slightly larger character set than that used for digits).*

The traffic relative altitude **shall (359)** consist of at least two digits indicating the altitude difference in hundreds of feet. For example, "+70" would represent 7000' above the ownship and "-01" would represent 100' below the ownship.

The data tag for co-altitude traffic (traffic at the same altitude as the ownship) **shall (360)** be displayed as the digits "00."

Note: *The "+" or "-" tag may be retained with the "00" indication to denote that the system is in the relative altitude mode.*

The "00" characters should be placed above the traffic symbol if the traffic descended from above; below the symbol if the traffic climbed from below to the ownship altitude.

If the ownship climbed to the traffic altitude, the "00" characters should be placed above the traffic symbol, if the ownship descended to the traffic altitude, the "00" characters should be placed below the traffic symbol.

If traffic is at co-altitude with the ownship when initially displayed, the "00" characters should be placed below the traffic symbol.

2.2.5.6.4.3.2 Traffic Actual Altitude

Traffic actual altitude is the altitude reported by the traffic adjusted for local barometric pressure, using the same correction used by the ownship. The following requirements apply if the traffic actual altitude feature is implemented.

Traffic actual altitude tags **shall (361)** be positioned above or below the traffic symbol in a manner consistent with relative altitude data tags.

Traffic actual altitude **shall (362)** be displayed as a 3-digit number representing hundreds of feet above MSL (e.g., "007" represents 700' MSL and "250" represents 25,000' MSL.)

The display of traffic actual altitude **shall (363)** be corrected for the local barometric pressure using the same correction used by the ownship.

2.2.5.6.4.3.3 Traffic Geometric Altitude

Traffic Geometric Altitude is defined in this document as the height above the WGS-84 ellipsoid as measured using the GNSS.

When used (optional), Traffic Geometric Altitude **shall (364)** only be displayed in a data block or locations other than the DAA traffic display (i.e., not in the data tag).

When used (optional), Traffic Geometric Altitude **shall (365)** be labeled to indicate that it is geometric altitude. An example of such labeling is "HAE" (3241' HAE)."

2.2.5.6.4.3.4 Traffic Pressure Altitude

Pressure altitude is the (uncorrected) altitude relative to the standard sea-level pressure reference (29.92 inches of Mercury/1013.25 hectopascals (hPa)). Traffic pressure altitude is the pressure altitude transmitted by a target.

Below the transition altitude, traffic pressure altitude may be displayed in a data tag for 30 seconds or less. Traffic pressure altitude **shall (366)** only be displayed for greater than 30 seconds in a data tag when above the transition altitude. Traffic pressure altitude may be displayed indefinitely in the data block or locations other than the DAA traffic display.

The display of traffic pressure altitude **shall (367)** carry a clear altitude reference label to indicate that no correction is being made to this altitude. Examples of such labeling are "FL" (where FL 007 represents 700' pressure altitude) or "Press Alt" (Press Alt: 700'.

2.2.5.6.4.4 Traffic Vertical Direction

The traffic vertical direction indicator shows that the traffic is climbing or descending at a rate faster than a specified threshold. This information must be included in the data tag.

Traffic with a climb or descent rate greater than or equal to 500 fpm **shall (368)** include a traffic vertical direction indicator (e.g., indicated using an up or down arrow, as appropriate). (see data tag requirements in Subparagraph 2.2.5.6.2.1).

Note:

1. *Traffic vertical direction is not applicable for On-ground traffic.*
2. *A smaller vertical rate threshold (e.g., 300 fpm) may be used.*

The traffic vertical direction indicator **shall (369)** be a vertical arrow placed to the immediate right of the traffic symbol.

2.2.5.6.4.5 Traffic Identification

Traffic identification may also be referred to as flight identification or flight ID (e.g., the aircraft flight number or the tail number). This information may be conveyed in a data tag or data block or by other means, and does not have to be continuously displayed. When implemented, the following requirements apply for traffic identification:

The traffic identification field **shall (370)** be capable of displaying eight alphanumeric characters.

The location of the traffic identification field with respect to the traffic symbol should be consistent for all displayed traffic.

Note:

1. *Traffic identification may not be available for all traffic.*
2. *International Civil Aviation Organization (ICAO) terminology for Traffic Identification is Aircraft Identification.*
3. *The ICAO standard for aircraft identification is a maximum of eight alphanumeric characters.*

2.2.5.6.4.6 Traffic Ground Speed

Traffic ground speed may be conveyed in a data tag or data block or by other means. When implemented, the following requirements apply for traffic ground speed:

The DAA traffic display **shall (371)** be capable of displaying ground speeds up to at least 999 knots.

An indication should be displayed if ground speed exceeds the indicator limit.

Ground speed **shall (372)** be displayed with a resolution of 1 knot or less.

2.2.5.6.4.7 Traffic Category (Emitter Category)

If traffic category is implemented, it may be conveyed in a data tag or data block or by other means, and the following requirements apply:

The DAA traffic display **shall (373)** be capable of displaying the traffic category.

The traffic category (emitter category), when displayed, should be displayed with sufficient descriptive quality (e.g., “LIGHT,” “HEAVY,” “ROTOR_CFT,” (Rotorcraft) “SPACE_VEH,” (Space Vehicle) or “EMERG_VEH” (Emergency Vehicle)) for the flight crew to understand without additional cross-references.

2.2.5.6.4.8 Traffic Emergency Priority Status

The DAA traffic display may display the emergency status information of traffic. The emergency status may be displayed as a traffic symbol variation (i.e., some characteristic of the symbol changes, such as shape), and/or as part of a data tag or data block.

2.2.5.6.4.9 Traffic Horizontal Velocity Vector

Horizontal velocity vector is the instantaneous magnitude and direction of the horizontal velocity.

The DAA traffic display **shall (374)** graphically depict traffic horizontal velocity as a predictor/leader line or history trail.

The same scale (e.g., 60 seconds) **shall (375)** be used for all displayed horizontal velocity vectors or history trails.

If the length of the horizontal velocity vector represents a set prediction or history time (e.g., 60 seconds), the velocity vector’s size **shall (376)** scale according to a fixed time when the display’s range is changed.

If the flight crew has the capability to change the scale of the velocity vector or history trail, the scaling value **shall (377)** be accessible for display.

Horizontal velocity vectors or history trails **shall (378)** be distinguishable from traffic vertical direction indicators.

2.2.5.6.4.10 Traffic Range

Traffic range, the horizontal range between the ownship and individual traffic, may be conveyed in a data tag, data block or by other means. When implemented, the following requirements apply for traffic range:

The DAA traffic display **shall (379)** display a numeric traffic range indication with a resolution of 0.1 NM for values less than 10 NM and with a resolution of 1 NM or less for values greater than or equal to 10 NM.

An indication should be displayed if traffic range exceeds the indicator limit.

2.2.5.7 Guidance Display Requirements

DAA guidance information is provided by the Guidance Processing subfunction of the DAA system (Subparagraph 2.2.4.4). It is intended to assist the PIC in maintaining and/or regaining DWC when DWC has been lost or is about to be lost. The next subparagraphs detail how guidance information to maintain and regain DWC will be depicted on the DAA traffic display.

2.2.5.7.1 DAA Guidance to Maintain DWC

DAA maneuver guidance to maintain DWC continuously provides the PIC with information about the range of maneuvers that are, and are not, predicted to result in a loss of DWC. DAA maneuver guidance differentiates between trajectory options that are predicted to result in the intruder entering the corrective or warning hazard zones. Trajectory options that are assessed but not predicted to result in entering the hazard zones are referred to as "positive guidance." DAA maneuver guidance to maintain DWC is calculated by the DAA processor Guidance Processing subfunction (Subparagraph 2.2.4.4) and depicted on the DAA traffic display as maneuver guidance bands.

Maneuver guidance bands are color-coded markings on instrument displays (such as heading, altitude, vertical velocity, ground speed) that explicitly indicate the ranges on those displays to avoid (red or yellow/amber) or fly to (green/no bands).

DAA corrective and warning maneuver guidance bands **shall (380)** be distinct from other DAA information (e.g., instrument markings), and from each other.

1. DAA Maneuver guidance bands should be clear and legible.
2. DAA Maneuver guidance bands should use a second visual encoding technique (e.g., patterns) besides color, when feasible, to enhance distinctiveness.

   Note:

   1. *The recommendation to apply a second means of encoding is to address the existence of factors that influence color perception (e.g., pilot color vision deficiencies, lighting, display viewing angle, background colors).*
   2. *The application of a second means of encoding to maneuver guidance bands may include differentiating bands associated with alerts from other bands. This philosophy is consistent with other awareness/alerting systems such as the Terrain Awareness and Warning System (TAWS).*

3. Corrective maneuver guidance bands **shall (381)** be depicted in yellow/amber.
4. Warning maneuver guidance bands **shall (382)** be depicted in red.

The horizontal maneuver guidance bands **shall (383)** be depicted relative to the ownship symbol position on the DAA traffic display and the ownship's current heading.

1. At a minimum, horizontal maneuver guidance bands **shall (384)** be displayed for headings ±90 degrees from the ownship's current heading.
2. Horizontal maneuver guidance bands may overlay a range ring on the DAA traffic display

Note: *It is recommended that the reference used for the horizontal maneuver guidance include heading markers at regular intervals (e.g., 30 degrees).*

The vertical maneuver guidance bands should be located on the right side of the DAA traffic display, when feasible.

Note: *Positioning the vertical maneuver guidance on the right of the display is intended to keep the vertical information location consistent with pilot expectations. However, integration of the vertical maneuver guidance in primary flight, or other, displays may make placement on the right infeasible.*

The vertical maneuver guidance bands should be located in close proximity to the horizontal guidance bands without obscuring intruder information on the DAA traffic display.

Vertical maneuver guidance bands may be depicted within a vertical velocity and/or altitude tape.

1. If vertical maneuver guidance bands are depicted overlaying an altitude tape, at a minimum, vertical maneuver guidance bands **shall (385)** be displayed for altitudes ±2000' from the current ownship altitude.
2. If vertical maneuver guidance bands are depicted overlaying a vertical velocity tape, at a minimum, vertical maneuver guidance bands **shall (386)** be displayed for vertical velocities ±3000 fpm, or the maximum value achievable by the aircraft, whichever is greater.

Note: *For vertical guidance information, providing altitude is recommended. If the vertical rate is adjustable by the PIC, vertical guidance information should also include rate, and both rate and altitude are preferred; altitude alone is not acceptable. If the vertical rate is not adjustable by the PIC, the calculation may assume a known standard rate, and altitude guidance information alone is acceptable.*

Preventive maneuver guidance providing information about trajectories that would result in the intruder entering the preventive hazard zone may also be provided (Subparagraph 2.2.4.3.4.2). If preventive maneuver guidance bands are being calculated and output by the guidance processing function, then the bands **shall (387)** be depicted in yellow/amber.

The depiction of the preventive maneuver guidance bands may be modified (e.g., dashed lines) so as to be distinguishable from corrective maneuver guidance bands.

The range of trajectories predicted to not result in the intruder entering the corrective or warning hazard zones (i.e., positive guidance) may be depicted using green bands or no bands.

Note: *While designers may leave blank any trajectory options that are being assessed by the DAA system but are determined to be conflict-free, the use of green bands is recommended.*

If no bands are implemented for assessed but conflict-free trajectories, the DAA traffic display **shall (388)** differentiate the trajectory options that are not being assessed or when guidance is not being provided by the guidance processing subfunction with a distinct pattern and/or color (that is not red, yellow/amber or green).

Note:

1. *Since the DAA processor is not required to assess all possible trajectories (e.g., 360 degrees horizontal), the intent of this requirement is to differentiate between trajectories that are assessed by the DAA processor and determined to be conflict-free and those that have not been assessed, and therefore the conflict status is unknown.*

2. *For example, DAA vertical maneuver guidance is not provided during TCAS II RAs for Class 2 systems (Subparagraph 2.2.4.5).*

Figure 2-16 and Figure 2-17 provide notional depictions of vertical and horizontal maneuver guidance. In both examples, trajectories predicted to result in the intruder entering the corrective or warning hazard zones are represented by yellow/amber and red maneuver guidance bands, respectively. In Figure 2-16 positive maintain-DWC guidance is indicated by the absence of maneuver guidance bands, while Figure 2-17 shows a notional depiction of vertical and horizontal maneuver guidance banding using green bands for positive maintain-DWC guidance. The horizontal maneuver guidance bands in both examples are overlaid on the inner range ring of the DAA traffic display, while the vertical maneuver guidance bands are presented within the altitude tape (Figure 2-16) or the vertical velocity tape (Figure 2-17) located on the DAA traffic display.

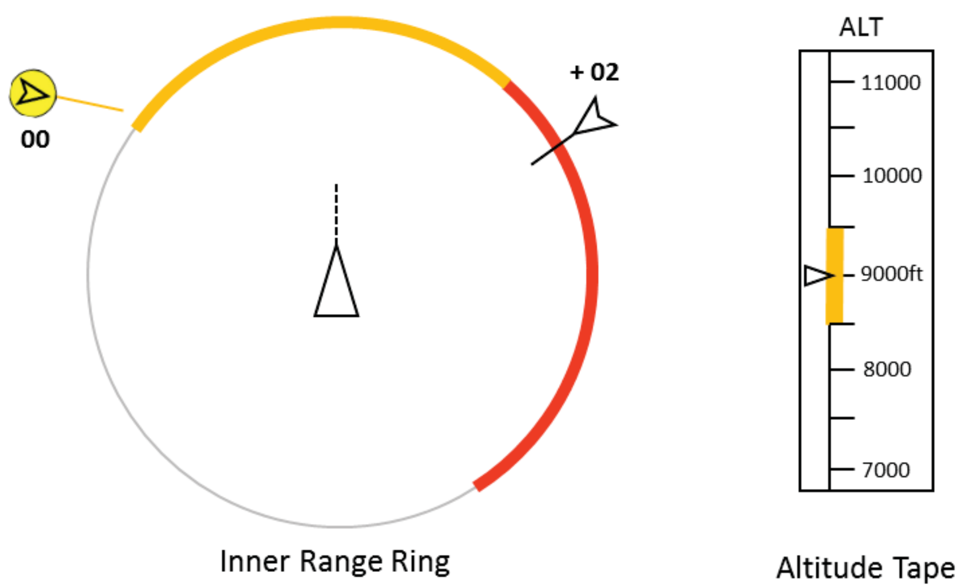


Figure 2-16 **Using No Bands for Positive Maintain-DWC Guidance**

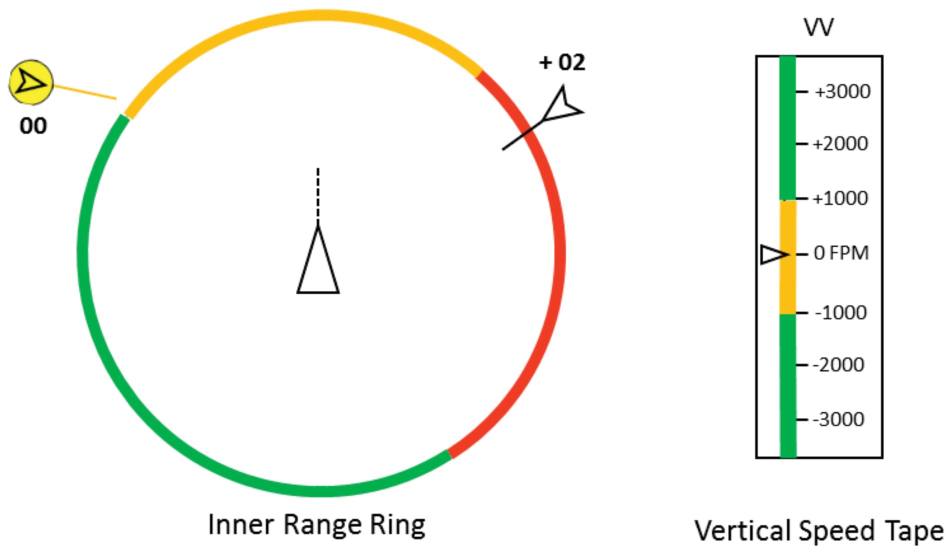


Figure 2-17 **Using Green Bands for Positive Maintain-DWC Guidance**

Figure 2-18 and Figure 2-19 provide notional depictions of vertical and horizontal maneuver guidance to maintain DWC when not all trajectories are being assessed by the DAA processor. In Figure 2-18, positive maintain-DWC guidance is indicated by green maneuver guidance bands, while trajectories not being assessed by the DAA processor are depicted by the absence of bands. In Figure 2-19, positive maintain-DWC guidance is indicated by the absence of maneuver guidance bands, while those not being assessed by the DAA processor are depicted by the dashed grey bands on both the horizontal and vertical dimensions.

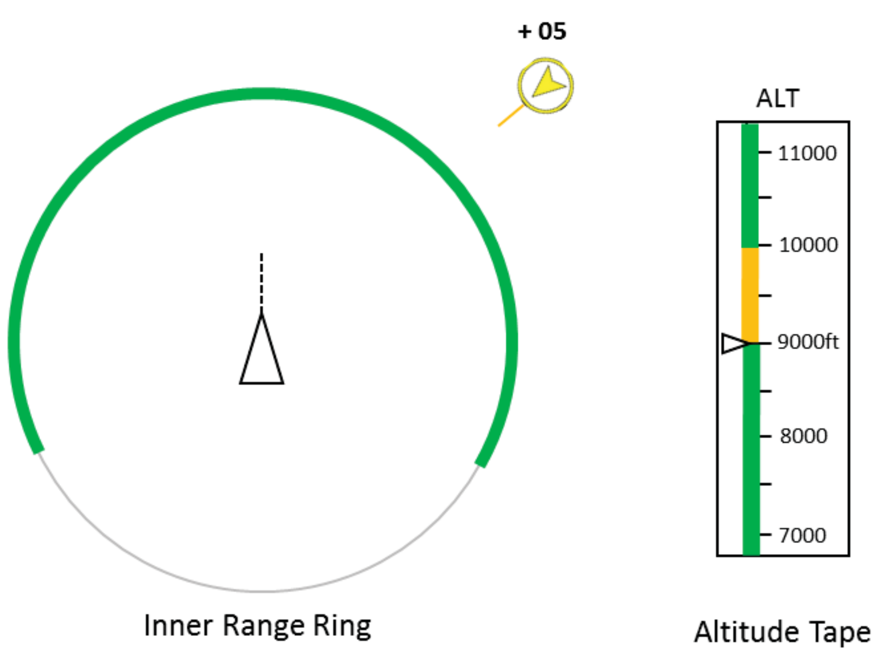


Figure 2-18 **Using No Bands for Unassessed Trajectories**

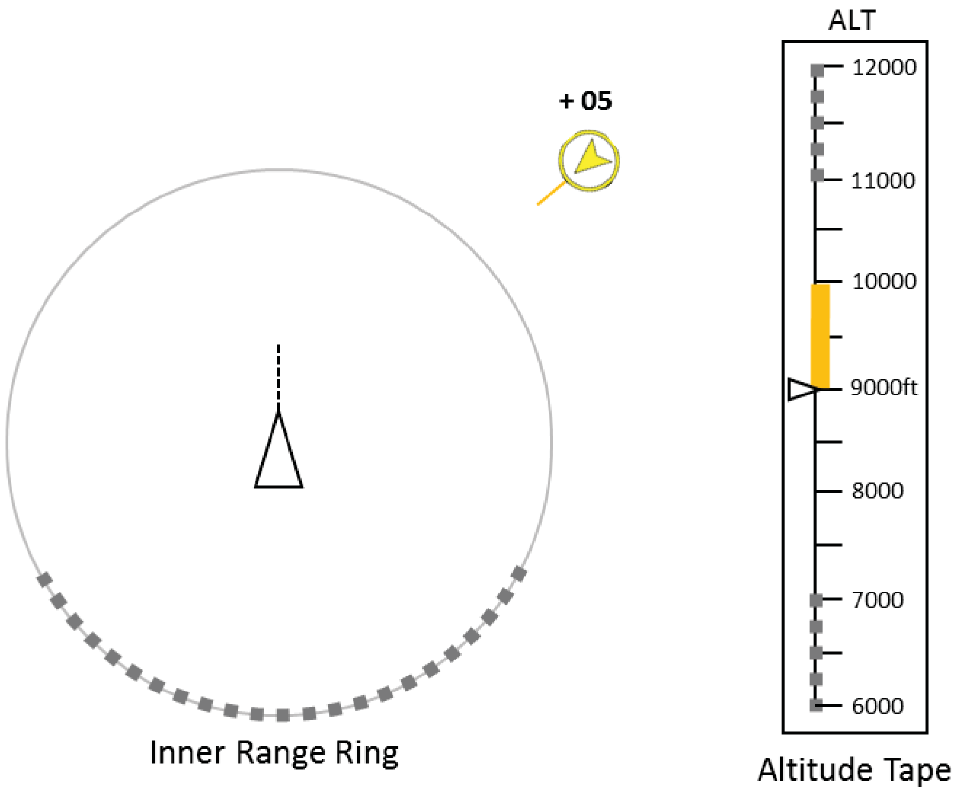


Figure 2-19 **Using Dashed Grey Bands for Unassessed Trajectories**

2.2.5.7.2 DAA Guidance to Regain DWC

In the event that a loss of DWC occurs or is about to occur, DAA guidance to regain DWC is provided by the Guidance processing subfunction (see Subparagraph 2.2.4.4).

Guidance to regain DWC is positive guidance information intended to provide the PIC with a range of horizontal and vertical maneuvers that would expedite resumption of DWC. The range of horizontal and vertical maneuvers are to be provided at the same time; however, the intended function is for the PIC to execute either a horizontal or vertical maneuver to regain DWC.

Guidance to regain DWC **shall (389)** be distinct from other DAA information (e.g., instrument markings).

1. Guidance to regain DWC should be clear and legible.
2. Guidance to regain DWC should use a second visual encoding technique (e.g., patterns, size, etc.) besides color, when feasible, to enhance distinctiveness.

Note: *If guidance to regain DWC is depicted as bands, they cannot replace the existing maneuver guidance bands but must instead be displayed separately and contain distinct features, such as a unique size.*

3. Guidance to regain DWC **shall (390)** be depicted in green.

Guidance to regain DWC **shall (391)** depict the range trajectories provided by the DAA processor.

Note: *See Figure 2-20 for a notional depiction.*

The horizontal guidance to regain DWC **shall (392)** be depicted relative to the ownship symbol position and the ownship's current heading on the DAA traffic display.

Note: *The horizontal guidance to regain DWC may use the same range ring as the horizontal guidance to maintain DWC, such as the wedge pictured in Figure 2-20.*

The vertical guidance to regain DWC should be located near the horizontal guidance bands without obscuring intruder information on the DAA traffic display.

Note: *The vertical guidance to regain DWC may use the same altitude or vertical velocity tape as the vertical maneuver guidance bands to maintain DWC.*

Figure 2-20 provides a notional depiction of horizontal and vertical guidance to regain DWC. The horizontal guidance to regain DWC is depicted as a green wedge with the target headings located within, and bound by, the inner range ring of the DAA traffic display. The vertical guidance to regain DWC is depicted as a green wedge (or large band) that overlays the range of target altitudes within an altitude tape located on the DAA traffic display.

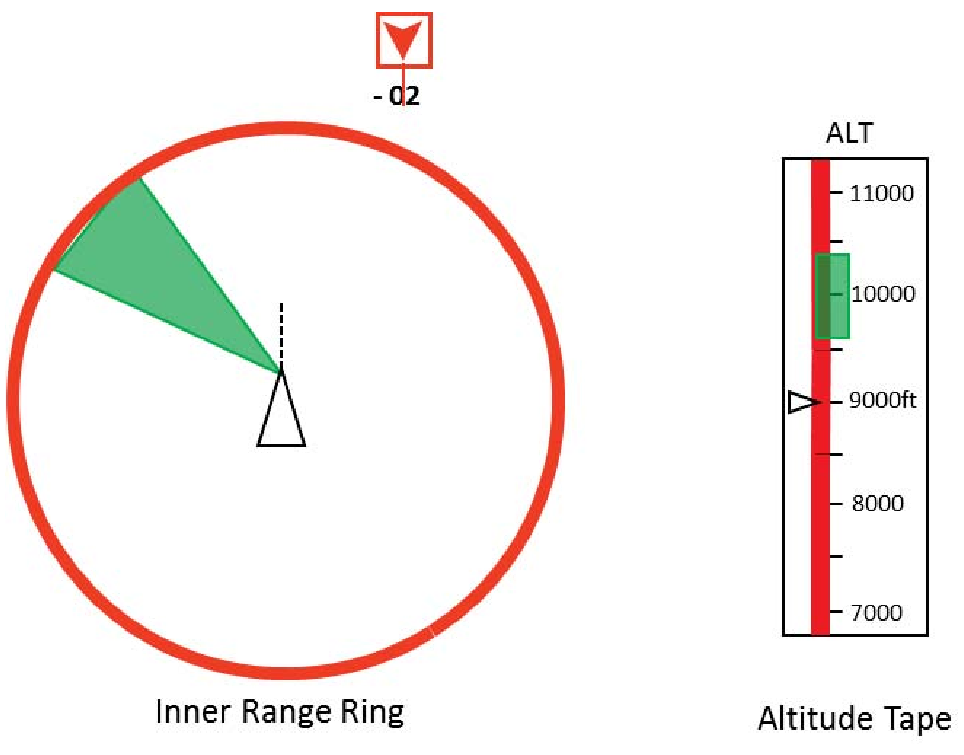


Figure 2-20 Vertical and Horizontal Maneuver Guidance to Regain DWC

2.2.5.7.3 TCAS II Resolution Advisory Guidance for TCAS II/DAA Integrated Systems

For Class 2 DAA systems, Resolution Advisory vertical rate guidance for Corrective Resolution Advisories **shall (393)** be implemented in compliance with Subparagraph 2.2.6.2 of RTCA DO-185B.

Note:

1. *TCAS II Corrective and Preventive Resolution Advisory Types are shown in Table 2-22 and Table 2-23.*
2. *Refer to Subparagraph 2.2.4.5 for how DAA vertical guidance is provided during TCAS II Corrective and Preventive Resolution Advisories*

If a vertical velocity tape is implemented for vertical guidance to maintain and regain DWC, the RA guidance should be displayed on the same vertical velocity tape.

If an altitude tape is implemented for vertical guidance to maintain and regain DWC, then the RA guidance should be displayed on a separate vertical velocity tape (see Figure 2-21 and Figure 2-22)

Figure 2-21 provides a notional depiction of horizontal and vertical maneuver guidance to maintain DWC when a TCAS II RA has been issued. In this configuration, positive maintain-DWC guidance information provided by the DAA processor is depicted by no bands. The vertical maneuver guidance to maintain DWC is presented within an altitude tape, while the RA guidance is displayed within a separate vertical velocity tape. Figure 2-22 provides a notional depiction of horizontal and vertical maneuver guidance to maintain DWC when a TCAS II RA is being issued and positive maintain-DWC guidance information is depicted by green bands. As in Figure 2-21, the vertical maneuver guidance to maintain DWC is presented within an altitude tape, while the RA guidance is displayed within a separate vertical velocity tape. Subparagraph 2.2.4.5 specifies how to provide horizontal guidance information to maintain DWC during an active corrective RA.

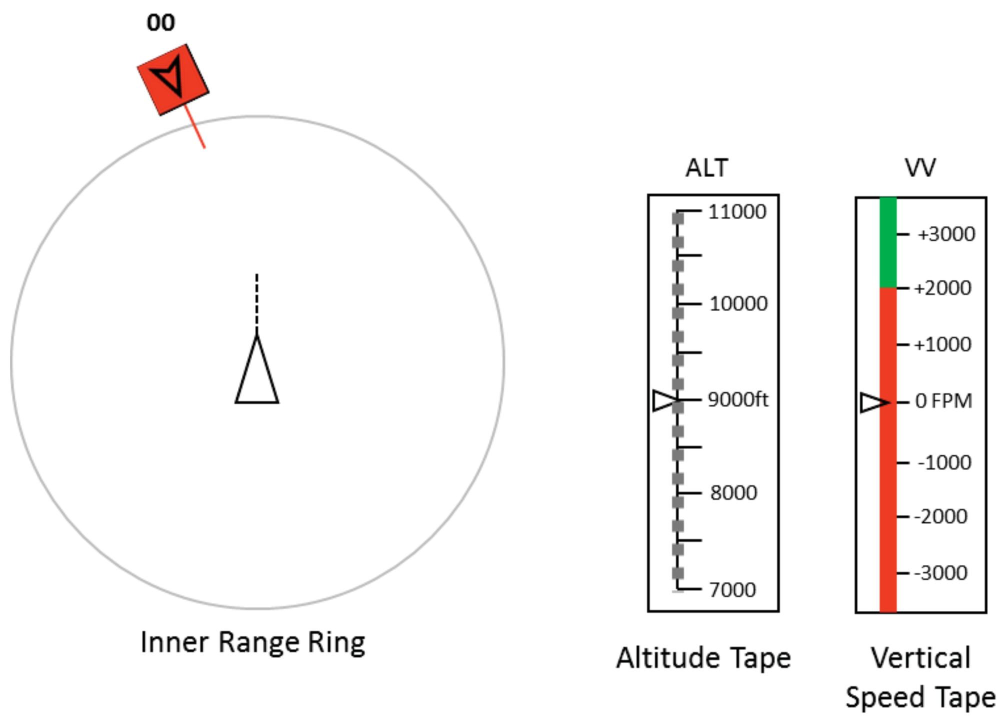


Figure 2-21 **RA Vertical Guidance: Altitude Tape with No Bands for Positive Guidance**
(When an Altitude Tape is Implemented for DAA Guidance and No Bands Indicate Positive Maintain-DWC Guidance)

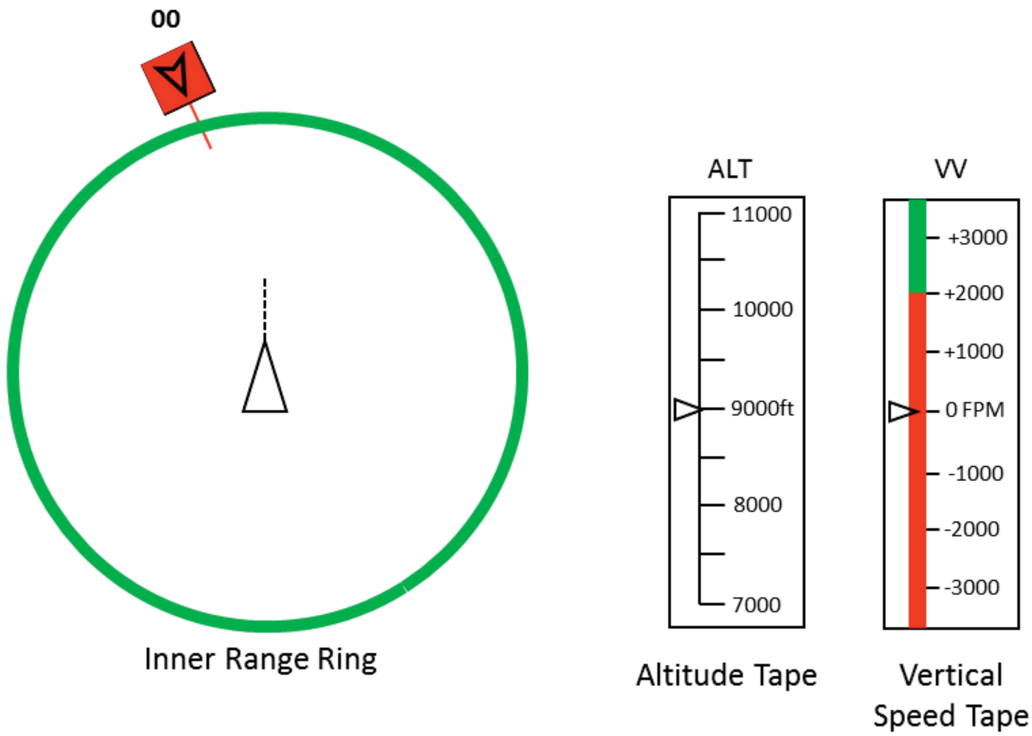


Figure 2-22 **RA Vertical Guidance: Altitude Tape with Green Bands for Positive Guidance (When an Altitude Tape is Implemented for DAA Guidance and Green Bands Indicate Positive Maintain-DWC Guidance)**

2.2.5.8 Requirements for DAA Traffic Display Characteristics

2.2.5.8.1 Display Range

The DAA traffic display **shall (394)** be adjustable to a minimum range of 6 NM in the direction of ownship travel as measured from the ownship position to the edge of the viewable screen.

The DAA traffic display **shall (395)** be adjustable to a maximum range of at least 40 NM in the direction of ownship travel as measured from the ownship position to the edge of the viewable screen.

The selected display range **shall (396)** be indicated on the traffic display.

2.2.5.8.2 Range Rings

One or more range rings **shall (397)** be placed at specified radii from the ownship aircraft symbol.

The inner range ring **shall (398)** be comprised of discrete markings at each of the twelve clock positions.

1. The markings **shall (399)** be the same color as the own aircraft symbol
2. The size and shape of the inner range ring should not clutter the display

2.2.5.8.3 Altitude Band

The DAA traffic display minimum vertical display filtering range **shall (400)** be ±4000' altitude relative to the ownship.

The DAA traffic display maximum vertical display filtering **shall (401)** be at least ±9900' altitude relative to the ownship.

Note: *An installer may tailor the maximum altitude volume as appropriate for the installed applications.*

2.2.5.8.4 Display Orientation

The DAA traffic display **shall (402)** be capable of displaying the same orientations as other navigation displays in the CS.

The DAA traffic display **shall (403)** display the current ownship orientation (e.g., heading-up, track-up, or north-up).

The DAA traffic display **shall (404)** display all traffic with respect to the selected display orientation.

Note:

1. *When ownship GNSS position is not available, the system may lose the ability to display track-up presentations. In this case, the system should revert to heading-up or north-up mode.*
2. *When ownship heading is not available, the system will lose the ability to display heading up presentations. The system will also lose the ability to properly display ADS-B traffic and radar tracks and active surveillance tracks in the same reference frame as both heading and track angle are required to correct for the wind correction (a.k.a. crab angle). In this degraded mode, it is acceptable to continue to display all tracks but the display should indicate that heading is failed.*
3. *Track-up vs. heading-up orientation mode affects the orientation of the earth reference (e.g., compass rose) and the bearing of traffic relative to the ownship symbol. True vs. Magnetic mode affects only the zero point on the compass rose but does not affect where the traffic is displayed (i.e., no effect on relative bearing).*

2.2.5.8.5 Traffic Coasting Indicator

The coasting indicator is used to show that traffic position data age is sufficient for display but is approaching the maximum data age that would require dropping the target from the display.

When implemented, "CST" should be displayed in the data tag when the coasting flag is set.

2.2.5.9 Display Design Requirements – Other

2.2.5.9.1 Traffic Display Symbol Prioritization for Overlay

To ensure visibility of the most important symbols and their data tags, the following prioritization should be followed for information overlay, from highest to lowest priority:

1. Ownship
2. Traffic prioritized according to Subparagraph 2.2.4.3.4.1.

Note: *Altitude, range, and other information may be used for further prioritization and tie-breaking, as appropriate for the application.*

2.2.5.9.2 DAA System Health Display Monitoring Function

The GDTI **shall (405)** be capable of displaying the health of the DAA system to the flight crew.

2.2.5.9.3 Display of Status Indication

Status indications displayed on the GDTI can come from several sources, such as the DAA processor, the CS processing function, the CS processing application(s), the DAA traffic display function, or the system self-test and monitoring functions. Status indication may be displayed on the same display device showing traffic information, or on a fault page accessible to the user.

The list below contains the DAA display requirements for reporting system status:

1. The GDTI **shall (406)** indicate the absence of electrical power (e.g., blank display) to any DAA displays.
2. The GDTI **shall (407)** indicate any non-normal status from the DAA subsystems listed in Table 2-26 (see Paragraph 2.2.8).
3. The GDTI **shall (408)** provide an indication of any non-normal DAA status from the high-level DAA operational monitoring function (see Paragraph 2.2.9).
4. The GDTI **shall (409)** provide an indication of any non-normal DAA subsystem status from the operational status reporting requirement (Subparagraph 2.2.8.1).
5. The GDTI **shall (410)** remove traffic from the display if the following occurs:
   a. The GDTI display monitor indicates DAA display failure (see Subparagraph 2.2.5.9.2).
   b. The GDTI monitor indicates DAA system failure.
6. The GDTI **shall (411)** display when alerts and guidance are automatically being suppressed, such as during the takeoff, landing, and/or airport VFR traffic pattern phases of flight (see Subparagraph 2.2.4.1).
7. The GDTI **shall (412)** provide a visual indication that the radar is transmitting.
8. The GDTI **shall (413)** display an appropriate input failure message when the DAA system indicates an input has failed (e.g., DAA failure/ADS-B failure/TCAS II input failure/CNPC link failure/radar failure).

Note: *System integrators may provide a method and appropriate controls to use the same display as a TCAS II Only display; however, this is outside the scope of these MOPS.*

2.2.5.10 Input and Control Requirements – General

This subparagraph provides requirements and guidance on the operation and function of flight crew inputs and controls to the DAA system.

2.2.5.10.1 Display Range

A control **shall (414)** be provided to adjust the display range between the minimum and maximum values.

2.2.5.10.2 Altitude Band

A control **shall (415)** be provided to adjust the altitude band between the minimum and maximum values, if DAA traffic display is capable of ranges greater than ±4000’ (Subparagraph 2.2.5.8.1).

It should be possible to independently control the altitude band above and below the ownship.

2.2.5.10.3 Traffic Altitude Selection

If the capability to display traffic actual altitude or traffic pressure altitude in the data tag on the DAA traffic display is implemented, a control **shall (416)** be provided to select the altitude type displayed.

2.2.5.10.4 Traffic Selection

If traffic selection is implemented, a means **shall (417)** be provided for the flight crew to select at least one traffic element.

2.2.5.10.5 De-cluttering

A de-clutter function is used to remove optional traffic information when display of the information is not desired. This subparagraph identifies input and control requirements necessary to accomplish traffic de-clutter function.

If de-cluttering is implemented:

1. A means **shall (418)** be provided for the flight crew to turn the de-clutter function on and off.
2. The flight crew **shall (419)** be able to perform the de-clutter operation using a simple action.
3. The flight crew should be able to return the displays to the previous state by a simple action.

2.2.5.10.6 Brightness Control

A means **shall (420)** be provided to adjust the brightness of the display.

2.2.5.11 CS Integration Requirements

The DAA traffic display system should be consistent with the rest of the CS in terms of color, standardization, automation, symbology, interaction techniques and operating philosophy. Reference AC 25-11B, AC 23.1311-1C, AC 25.1302-1, AC 25.1322-1 and AC 20-175.

2.2.5.11.1 Multi-function Display

A multi-function display is one in which multiple functions such as traffic, weather and terrain share the same display hardware. If the DAA traffic display is implemented as part of a multi-function display the requirements in this subparagraph apply.

If the DAA traffic display is part of a multi-function display, the DAA traffic display **shall (421)** be made visible at all times (i.e., be a full-time display that occupies one part of the larger display).

If non-traffic information is integrated with the traffic information on the display, the directional orientation, range, and position of the ownship **shall (422)** be consistent among the different information sets.

Note: *For example, heading-up oriented data will not be displayed simultaneously with track-up oriented data. If a Multi-Function Display (MFD) is displaying traffic and weather radar information, the design will not allow the range-scale of the displayed weather data to be different from the range-scale of the traffic data that is simultaneously displayed.*

Symbols, colors, and other encoded information that have a certain meaning in the DAA traffic display function should not have a different meaning in another MFD function.

The MFD system should provide the capability to enable and disable display of traffic information (i.e., to overlay traffic or turn traffic information off).

A means should be provided to select the display of traffic information by simple action(s) by the PIC.

An indication that the DAA traffic display function is active and included as part of the MFD, other than the display of traffic itself, **shall (423)** be present during normal operation (when displaying of traffic is enabled) so that if display of traffic is inoperable, it is obvious to the PIC.

DAA traffic display cautions and warnings **shall (424)** be displayed regardless of the active MFD function.

A mechanism may be provided to select to remove the non-DAA functions from the MFD and enter a DAA traffic display-Only mode of operation.

Traffic and other DAA traffic display information should be easily discernible across all MFD functions.

2.2.5.11.1.1 DAA Aural Alerts

The audio system (e.g., speaker or headphones) provides aural traffic alerts from the DAA system to the PIC. The system may be integrated with the DAA traffic display.

The voice levels, alert levels and alert durations should be appropriate for the application of the information.

When an intruder triggers a DAA preventive alert, “TRAFFIC, MONITOR” **shall (425)** be audibly annunciated.

When an intruder triggers a DAA corrective alert, “TRAFFIC, AVOID” **shall (426)** be audibly annunciated.

When an intruder is triggers a DAA warning alert, “TRAFFIC, MANEUVER NOW; TRAFFIC, MANEUVER NOW” **shall (427)** be audibly annunciated.

DAA aural alerts **shall (428)** be prioritized according to the alert prioritization scheme in Subparagraph 2.2.4.3.4.1.

1. For alerts occurring simultaneously for multiple intruders, the highest priority aural alert **shall (429)** be annunciated first with the remaining aural alerts queueing according to priority.
   a. Queued aural alerts **shall (430)** be subsequently annunciated according to priority.
   b. Aural alerts **shall (431)** be removed from the queue when the alert is no longer active.
2. When a higher priority alert occurs subsequent to a lower priority alert, the higher priority aural alert **shall (432)** interrupt the lower priority aural alert.

Note: *When a lower priority aural alert is interrupted, it is not subsequently put into the aural alert queue.*

3. When a lower priority alert occurs subsequent to a higher priority alert, the lower priority aural alert **shall (433)** be put into the aural alert queue.

DAA aural alerts **shall (434)** be suppressed for downgraded alerts triggered by the same intruder.

2.2.6 DAA Pilot Selected Mode

DAA Pilot Selected Modes are the operating modes that may be selected by the pilot.

1. An Equipment Class 1 DAA system **shall (435)** at a minimum have the following operational modes:

Table 2-25 Minimum DAA Control Panel Data – Equipment Class 1

DAA Mode Control Data	Notes
DAA Standby	
DAA Traffic Only	
DAA Guidance	See Note 1
DAA Self-Test	See Note 2, 3

Note:

1. Even if DAA is in Guidance mode, alerts and guidance can temporarily be inhibited depending on the phase of flight. To avoid mode confusion, manufacturers should provide feedback to the pilot in situations when the mode *displayed on the control panel does not match the actual DAA pilot selected mode of operation in accordance with FAR, Part 25, §1302(b)(3). See Subparagraph 2.2.4.1 for detailed requirements on alert suppression. This applies to both Equipment Class 1 and Equipment Class 2 DAA systems.*

2. *System Self-Test is a mandatory mode for DAA systems, but it is not required to be a permanent control element on the DAA control panel. Refer to Paragraph 2.2.8.*

3. *See Subparagraph 2.2.8.2 for Initiation Test output data.*

2. There **shall (436)** be a clear indication to the pilot of all DAA Pilot Selected Modes the pilot can select (except for maintenance type modes), including all additional modes that may have been added by the manufacturer or operator and not listed in Table 2-26.

3. There **shall (437)** be a clear display indication to the pilot of which DAA Pilot Selected Modes the DAA system is operating in, including all additional modes (as well as all maintenance type modes) that may have been added by the manufacturer or operator and not listed in Table 2-26.

2.2.6.1 DAA Subsystem Pilot Selected Mode

Because DAA is a federated system, there may be individual DAA subsystems with their own DAA subsystem control panels and pilot select modes.

1. An Equipment Class 2 DAA system, in addition to the pilot selected modes of a Class 1 system, **shall (438)** have the following additional DAA subsystem Pilot Selected Modes specific to the operation of the DAA TCAS II subsystem:
   a. RA Off
   b. RA Manual
   c. RA Auto – only required if the system is equipped with automatic execution of the TCAS II RAs.
2. The DAA system **shall (439)** at a minimum have the following radar DAA subsystem pilot selected modes:
   a. Radar Off
   b. Radar Standby
   c. Radar Transmit

Note: *Due to the risk of irradiation of personnel on the ground, it is advised the "Transmit" mode is automatically inhibited when the aircraft is on the ground. If transmission on the ground is desired, Ground Transmit – On serves as an override.*

   d. Radar Ground Transmit

Note: *Ground Transmit – On, does not need to be accessible from the DAA Control Panel.*

3. When individual subsystems have their own control panels and pilot-selected modes, there **shall (440)** be a clear indication to the pilot of all the DAA subsystem pilot-selected modes the pilot can select (except for maintenance type modes).
4. When individual subsystems have their own control panels and pilot-selected modes, there **shall (441)** be a clear indication to the pilot of the DAA subsystem pilot-selected mode in which the DAA system is operating (including all maintenance type modes).
5. The DAA system **shall (442)** inform the pilot if one or more DAA pilot selected modes becomes unavailable (e.g., due to a subsystem failure).

2.2.7 Pilot Entry Subsystem

All requirements regarding pilot entries have been allocated to other subdivisions of Subsection 2.2. This paragraph heading has been retained to maintain the structural outline of the document.

2.2.8 DAA Subsystem Operational Status

The subsystem operational status is the operational status of the subsystems listed in Table 2-26 at a given time. (e.g., Standby, Normal, Transmit, Receive, Failed, Degraded, etc.). In general, each subsystem operational status is determined by the individual subsystem Health Monitoring Function (2.2.8.1-1), and all subsystems are required to report their status (2.2.8.1-2) to the high-level DAA Operational Monitoring Function (2.2.9-1) about every second (2.2.8.1-3).

1. DAA subsystems **shall (443)** have at a minimum the operating statuses listed in Table 2-26.

Table 2-26 DAA Subsystems and Operating Statuses

DAA Subsystem Equipment	Operating Status	Note
Radar	(1) Standby (2) Transmit (3) Failed (4) Ground Transmit – On	Note 1, 2, 3, 4
Active Surveillance (Equipment Class 1) (if equipped)	(1) Standby (2) Normal (3) Failed	
TCAS II (Equipment Class 2)	(1) Standby (2) TA Only (3) TA/RA (4) Failed	Note 5, 6
ADS-B In, 1090ES	(1) Receive (2) Failed	
ADS-B In, UAT (if equipped)	(1) Receive (2) Failed	

DAA Subsystem Equipment	Operating Status	Note
UA DAA Processor	(1) Standby (2) Traffic Only (3) Alerts and Guidance (4) Failed (5) Degraded	Note 7
CS DAA Processor	(1) Standby (2) Traffic Only (3) Alerts and Guidance (4) Failed	
Equipment Providing Ownship State Data	1) Standby (2) Normal (3) Failed (4) Degraded	Note 7
CNPC Link	(1) Standby (2) Normal (3) Failed (4) Degraded	Note 7
CS DAA Traffic Display	(1) Normal (2) Failed	

Note:

1. *Due to the risk of irradiation of personnel on the ground, it is advised the Transmit mode is automatically inhibited when the aircraft is on the ground. If transmission on the ground is desired, Ground Transmit – On serves as an override. This is a DAA function that disables/enables the radar.*
2. *Ground Transmit – On, does not need to be accessible from the DAA control panel.*
3. *Normal radar operational status is defined by radar status of Ready and Transmit Enable On (transmitting). Standby operational status is defined as radar status of Ready and Transmit Enable Off. .*
4. *Failed Radar operational status is defined by radar status of Faulted. A radar status of Faulted with Transmit Enable On (transmitting) is possible serious failure condition that should be accounted for in the system design due to the risk of irradiation of personnel.*
5. *If an Equipment Class 2 system is operated solely with the TCAS II in TA Only mode it is equivalent to a Class 1 equipment system.*
6. *For a TCAS II system compliant with RTCA DO-185B, a failed transponder will cause the TCAS II system to change its operational status to Failed also. An optional functionality would be for the TCAS II system to enter into a degraded status where it continues using active surveillance to validate ADS-B for DAA. This degraded status would be similar to TA Only mode, allowing the DAA system to continue operating with Class 1 equipment functionality.*

   For a TCAS II system pilot mode selection causes the following operational status:

a. *TA Only operational status when pilot selects RA Off*

b. *TA/RA operational status when selects Pilot RA Manual*

c. *TA/RA operational status when Pilot selects RA Auto (only required if the system is equipped with automatic execution of the TCAS II RAs)*

7. *Degraded operational status indicates that the parts of the system/subsystem have failed or are not operating to specifications for some reason; however, with precautions or additional mitigations, continual operation of the DAA system is possible.*

2. If an individual subsystem has an additional operational status not listed in Table 2-26, that subsystems status **shall (444)** be made available to (reported to) the Subsystem Health Monitoring Function when the subsystem is operating in that additional status (2.2.8.1-2).

2.2.8.1 DAA Subsystem Operational Status Reporting Requirement

1. Each DAA subsystem listed in Table 2-26 **shall (457)** have its own health monitoring function to run in the background of its run-time environment.
2. The subsystem health monitoring function **shall (458)** determine the subsystem's current operational status (Table 2-26).

   Note: *"Degraded" is used for failures where the system remains operationally safe, and "Failed" is used where the system is no longer capable of operating safely.*

3. At a minimum, each DAA subsystem listed in Table 2-26 **shall (459)** continuously determine and report its current operational status (about every second) to the high-level DAA operational monitoring function (as described in *Paragraph 2.2.9*).

Note: *In some systems, the health monitoring may interfere with normal operation, and reporting rates may be less than 1 second. In these cases, the operational status will continue to report the last status (coasted status report), every second, until the status is updated. It is, however, important that the system continuously report its operational status, as a failure to report could indicate a system failure (see Subparagraph 2.2.8.5). It is also important to limit how long a status report is allowed to coast before it is deemed a failure to report status. The intent of this subparagraph is to allow some equipment flexibility in operational status reporting, while still ensuring a failure to report status is still captured as such.*

2.2.8.2 DAA Subsystem Initiation Test (Similar to or the same as a BIT)

Each DAA subsystem listed in Table 2-26, during initiation, power-on, or before flight, **shall (460)** perform a comprehensive set of tests to check hardware, software, and firmware, to evaluate that the components and functions of the subsystems will operate according to the expectations defined by the requirements and specifications within these MOPS. These tests may be accomplished, all or in part, automatically or manually by the flight crew.

For the subsystems listed in Table 2-26 that have a separate MOPS, the DAA subsystem initiation test **shall (461)** ensure during initiation, power-on, or before flight, a comprehensive set of tests to check hardware, software, and firmware, to evaluate that the components and functions of that subsystem in accordance with the requirements and specifications within that applicable equipment MOPS. These tests may be accomplished, all or in part, automatically or manually by the flight crew.

2.2.8.3 DAA Subsystem Initiation Operational Status Test Report

Any failure or degradation detected by the initiation test of any DAA subsystem listed in Table 2-26 **shall (462)** change its operational status to “Failed” or “Degraded” and report the change in operational status to the to the high-level DAA operational monitoring function.

2.2.8.4 DAA Subsystem Operational Status Display

Any report to the high-level DAA operational monitoring function of an off-nominal operational status of “Failed,” “Degraded,” or “Standby” **shall (463)** be displayed to the pilot.

2.2.8.5 DAA Subsystem Lack of Operating Mode Report

Any DAA subsystem listed in Table 2-26 that fails to report its operational status to the high-level DAA operational monitoring function after 5 reports, **shall (464)** be registered as a “Failed” subsystem.

2.2.9 High-level DAA Operational Monitoring Function

Because DAA is a federated system, the DAA system **shall (465)** have a high-level DAA operational monitoring function to run in the background of its run-time environment that collates and processes all of the subsystem operational status reports and updates the DAA operational state. The DAA operational state is the current operational condition of the DAA system as a whole (Normal, Degraded, Standby, Failed). Where in “Nominal Mode” all systems are operational, in “Standby Mode” all functional system suspended, in “Degraded Mode” there are failures but the system remains operationally safe, and in “Failure: System,” DAA is functionally inoperative.

1. The DAA system **shall (466)** set the DAA system operational state on the reported DAA subsystem operating status; Failed, Degraded, Standby, or Normal.

Note: *How the high-level DAA operational monitoring function determines operational state is not straightforward. For example, a failure in one subsystem may only cause the DAA system, as a whole, to be degraded; where a failure in another subsystem may cause DAA system, as a whole, to fail. The determination as to what subsystem degradations or failures effects on the DAA system as a whole, will need to be understood and codified into the high-level DAA operational monitoring function.*

2. In Equipment Class 2 systems, the high-level DAA operational monitoring function **shall (467)** report to the display if the FCS indicates an inability to execute an RA (e.g., aircraft unable to execute minimum climb or decent rate required by TCAS, etc.).

2.2.9.1 High-level DAA Operational Monitoring Function Display

The DAA system **shall (468)** update and display in a prominent place, the current DAA operational state (output of the high-level DAA operational monitoring function).

2.2.9.2 High-level DAA Operational Monitoring Function, Master Caution Warning Light/System

Any high-level DAA operational monitoring state of "Failed" or "Degraded" **shall (469)** cause the Master Caution warning light to be illuminated.

2.2.10 Restart after Power Interruption while in Flight

In the case of a power interruption beyond those allowed in RTCA DO-160G[15] or Military Standard (MIL-STD)-4824 704, which causes a restart of the DAA system as a whole or restart of one or more DAA subsystem(s) while in flight, the DAA system should be made to restart the system, or subsystem(s) to the nominal operating mode as quickly as possible (i.e., warm or soft restart).

2.3 DAA Equipment Environmental Testing – Overview

The environmental tests and performance requirements described in this subsection are intended to provide a laboratory means of determining the overall performance characteristics of the airborne and CS equipment under conditions representative of those that may be encountered in actual operations. Airborne and CS articles of the DAA system **shall (470)** be tested as described in Paragraph 2.3.2 and Paragraph 2.3.3, respectively.

2.3.1 Use of Special Purpose Software

It is acceptable but not necessary to use FAA-approved software or production software compliant with recognized industrial standard during the environment tests. Special purpose test software is acceptable and may be a more appropriate way to ensure that the hardware and interfaces are comprehensively exercised during environmental excursions. When using this approach, the applicant **shall (471)** show by inspection or analysis that the hardware functions necessary to meet all applicable requirements of Subsections 2.1 and 2.2 of these MOPS are thoroughly exercised and **shall (472)** establish appropriate pass/fail criteria consistent with the performance requirements and test procedures of Subsection 2.4. In addition, configuration of the special purpose software **shall (473)** be controlled.

2.3.2 DAA Airborne Equipment Required Performance – Environmental Test Conditions

Unless otherwise specified, the environmental conditions and test procedures contained in RTCA DO-160G, *Environmental Conditions and Test Procedures for Airborne Equipment* will be used to demonstrate equipment compliance.

RTCA DO-160G contains environmental test categories for each environmental condition to be tested. Many of the environmental conditions offer multiple categories of exposure, which vary in severity. The equipment manufacturer is allowed to choose the environmental category to which each article is to be qualified and should select a category that best represents the most severe environment in which the equipment is expected to be regularly exposed to during its service life. The manufacturer's certification **shall (474)** specifically state the environmental categories for which the article is qualified. System components designed to be located in different parts of the aircraft may be tested separately using the appropriate categories for each component.

[15] RTCA DO-160G Change 1, Environmental Conditions and Test Procedures for Airborne Equipment, 16 December 2014

Table 2-27 lists all of the environmental conditions and test procedures for airborne equipment contained in RTCA DO-160G. Table 2-27 also lists the performance requirements and recommended performance tests, which are intended to be run subject to the various environmental procedures of RTCA DO-160G. The performance tests for active surveillance are specified as references to RTCA DO-185B. RTCA Subsection 2.3 of DO-185B contains the environmental test and performance requirements that will be used to determine the overall performance characteristics of the airborne equipment under the conditions as specified in Table 2-27. The performance tests for the UA DAA processor are specified as references to Paragraphs 2.4.8 and 2.4.11 of this document. If an entry is blank, then performance testing is left to the manufacturer to determine applicable performance criteria in conjunction with that environmental test.

Tests identified by the phrase, “when required,” apply when the manufacturer wishes to qualify the equipment to additional environmental conditions such as may be required by contractual obligations or environments applicable only to specific aircraft. Tests identified by the phrase “if applicable,” apply to equipment expected to be exposed to that environment during its service life. For example, Lightning Direct Effects testing is only applicable to externally mounted equipment. Some of the performance requirements in Subsection 2.2 are not tested by the test procedures herein. Moreover, not all tests are required to be conducted in each of the environmental conditions in RTCA DO-160G. Judgment and experience have indicated that these particular performance parameters are not susceptible to certain environmental conditions and that the level of performance specified in Subsection 2.2 will not be measurably degraded by exposure to these particular environmental conditions.

Additional tests may have to be performed to determine performance of particular design requirements not specified in this document. It is the responsibility of the manufacturer to determine appropriate tests for these functions.

Table 2-27 DAA Airborne Equipment Environmental Test Requirements

Function		Active Surveillance	UA DAA Processor	Remarks
Environmental Test Conditions	**RTCA DO-160G Paragraph**	**2.2.3.1.1 DAA Active Surveillance**	**2.2.2.1 and 2.2.2.2 UA DAA Processor I/O**	
Temperature/ Altitude	4.0			Section Heading
Ground Survival Low Temperature Test and Short-Time Operating Low Temperature Test	4.5.1	DO-185B, §2.3.1.1	Paragraph 2.4.11 Env. Qual for UA DAA Processor Test 4Procedure	
Operating Low Temperature Test	4.5.2	DO-185B, §2.3.1.1	Paragraph 2.4.11	
Ground Survival High Temperature Test and Short-Time Operating High Temperature Test	4.5.3	DO-185B, §2.3.1.2	Paragraph 2.4.11	
Operating High Temperature Test	4.5.4	DO-185B, §2.3.1.2	Paragraph 2.4.11	
In-Flight Loss of Cooling Test	4.5.5	DO-185B, §2.3.1.2	Paragraph 2.4.11	(1) When Required
Altitude Test	4.6.1	DO-185B, §2.3.1.3	Paragraph 2.4.11	
Decompression Test	4.6.2	DO-185B, §2.3.1.4	Subparagraph 2.4.8.1 DAA Subsystem Operational Status Reporting Test*+	When Required
Overpressure Test	4.6.3	DO-185B, §2.3.1.5	Subparagraph 2.4.8.1*+	When Required
Temperature Variation	5.0	DO-185B, §2.3.2	Paragraph 2.4.11	
Humidity	6.0	DO-185B, §2.3.3	Subparagraph 2.4.8.2 DAA Subsystem Initiation Test*	
Operational Shocks and Crash Safety	7.0			Section Heading
Operational Shock Test	7.2	DO-185B, §2.3.4.1	Subparagraph 2.4.8.1*+	(2)
Crash Safety Shock Test	7.3	DO-185B, §2.3.4.2		(2)
Vibration	8.0	DO-185B, §2.3.5	Paragraph 2.4.11	
Explosive Atmosphere	9.0	DO-185B, §2.3.6	Subparagraph 2.4.8.1*+	When Required
Waterproofness	10.0			Section Heading
Condensing Water Drip Proof Test	10.3.1	DO-185B, §2.3.7.1	Subparagraph 2.4.8.2*	When Required
Drip Proof Test	10.3.2	DO-185B, §2.3.7.1	Subparagraph 2.4.8.2*	When Required
Spray Proof Test	10.3.3	DO-185B, §2.3.7.2	Subparagraph 2.4.8.2*	When Required
Continuous Stream Proof Test	10.3.4	DO-185B, §2.3.7.2	Subparagraph 2.4.8.2*	When Required

Function		Active Surveillance	UA DAA Processor	Remarks
Environmental Test Conditions	**RTCA DO-160G Paragraph**	**2.2.3.1.1 DAA Active Surveillance**	**2.2.2.1 and 2.2.2.2 UA DAA Processor I/O**	
Fluids Susceptibility	11.0			Section Heading
Spray Test	11.4.1	DO-185B, §2.3.8.1	Subparagraph 2.4.8.2*	When Required
Immersion Test	11.4.2	DO-185B, §2.3.8.2	Subparagraph 2.4.8.2*	When Required
Sand and Dust	12.0	DO-185B, §2.3.9	Subparagraph 2.4.8.2*	When Required
Fungus Resistance	13.0	DO-185B, §2.3.10	Subparagraph 2.4.8.2*	When Required
Salt Fog	14.0	DO-185B, §2.3.11	Subparagraph 2.4.8.2*	When Required
Magnetic Effect	15.0	DO-185B, §2.3.12	Subparagraph 2.4.8.1*+	(3)
Power Input	16.0			Section Heading
Normal Operating Conditions	16.5.1 16.6.1	DO-185B, §2.3.13.1	Paragraph 2.4.11	
Abnormal Operating Conditions	16.5.2 16.6.2	DO-185B, §2.3.13.2	Paragraph 2.4.11	
Voltage Spike	17.0			Section Heading
Category A	17.1	DO-185B, §2.3.14.1	Paragraph 2.4.11	If Applicable
Category B	17.2	DO-185B, §2.3.14.2	Paragraph 2.4.11	If Applicable
Audio Frequency Conducted Susceptibility	18.0	DO-185B, §2.3.15	Paragraph 2.4.11	
Induced Signal Susceptibility	19.0	DO-185B, §2.3.16	Paragraph 2.4.11	
RF Susceptibility	20.0	DO-185B, §2.3.17	Paragraph 2.4.11	
Emission of RF Energy	21.0			Section Heading
Conducted	21.4	DO-185B, §2.3.18	Subparagraph2.4.8.1*+	(3)
Radiated	21.5	DO-185B, §2.3.18	Subparagraph 2.4.8.1*+	(3)
Radiated (Alternate Procedure)	21.6	DO-185B, §2.3.18	Subparagraph 2.4.8.1*+	(3)
Lightning Induced Transient Susceptibility	22.0		Paragraph 2.4.11	
Pin Injection Tests	22.5.1	(4)	Paragraph 2.4.11	
Cable Bundle Tests	22.5.2	(4)	Paragraph 2.4.11	
Lightning Direct Effects	23.0			(5) If Applicable
Icing	24.0			If Applicable
Electrostatic Discharge	25.0		Subparagraph 2.4.8.2*	
Fire/Flammability	26.0			(2) (6)

Note:

1. *In-flight loss of cooling testing is only applicable if the airborne equipment requires cooling air to be provided.*
2. *The application of this test may result in damage to the equipment. It may, therefore, be conducted after the other tests. Furthermore, Paragraph 2.1.7 of this document -"Effects of Test" – does not apply following crash safety shocks and fire/flammability. For crash safety and fire/flammability, there are no performance functional tests required.*
3. *Equipment performance requirements for this function of the equipment under test are defined within RTCA DO-160G.*
4. *Use RTCA DO-185B, §2.3.13.1 for the test requirement.*
5. *Lightning direct effects applies to the externally mounted equipment.*
6. *The fire/ flammability test is to ensure the equipment doesn't support flame propagation. There are no performance requirements.*

** Only normal operation checks required (no fault insertion)*

+ Ensure the monitor function completes at least one pass of all background health checks

2.3.3 DAA Ground-Based Equipment Required Performance – Environmental Conditions

Since no ground equipment environmental specification exists today, the environmental conditions and test procedures identified in one or more of the following documents may be used to demonstrate equipment compliance: RTCA DO-160G, Environmental Conditions and Test Procedures for Airborne Equipment, Environmental Conditions specified in Appendix J of this document, MIL-STD-810G, Department of Defense Test Method Standard Environmental Engineering Considerations and Laboratory Tests or MIL-STD-704F, Department of Defense Interface Standard Aircraft Electric Power.

RTCA DO-160G contains equipment categories for each environmental condition with different environmental test limits for each category. Some environmental conditions in RTCA DO-160G may not be appropriate for ground equipment qualification. Appendix J of this document, MIL-STD-810G and MIL-STD-704 contain additional equipment categories and environmental test limits that apply to the ground equipment. The equipment manufacturer is allowed to choose to which environmental category the article is to be qualified. The manufacturer's certification **shall (476)** specifically state the equipment categories and standards used (i.e., Category A/RTCA DO-160G, Category A1/ MOPS for Detect and Avoid (DAA) Systems, (RTCA Paper No. 261-15/PMC 1400)/Appendix J, or Method 516.6/MIL-STD-810G), and for which environment the article is qualified. Equipment components designed to be located in parts of the CS that may be exposed to different environmental conditions may be tested separately using the appropriate categories for each component. The combination test procedures and conditions are listed in Table 2-28.

Table 2-28 Environmental Procedures and Conditions

Environmental Test Procedure	Environmental Test Condition
RTCA DO-160G	Categories found in RTCA DO-160G
Appendix J of this document	Categories found in Appendix J of this document
MIL-STD-810G	Categories found in MIL-STD-810G
MIL-STD-704F	Categories found in MIL-STD-704F

Table 2-29 describes the locations of ground-based UAS equipment for testing and associated categories (CAT). It includes fourteen (14) locations.

Table 2-29 Locations of Equipment and Correlating Categories for RTCA DO-160G, MIL-STD-810G or MIL-STD 704 Tests

Stationary Use			Mobile Use		Portable and Non-stationary Use
Weather-Protected Locations	**Non-weather-Protected Locations**	**Underground Locations**	**Ground Vehicle Installations**	**Ship Environment**	
CAT A1 Temperature-controlled locations	**CAT B1** Non-weather-protected locations - extended	**CAT C1** Partly weather-protected underground locations	**CAT D1** Protected installation	**CAT E1** Totally weather-protected locations	**CAT F1** Temperature controlled locations
CAT A2 Control room locations	**CAT B2** Non-weather-protected locations – extremely cold		**CAT D2** Partly protected installation	**CAT E2** Non-weather-protected locations	**CAT F2** Partly temperature-controlled locations
	CAT B3 Non-weather-protected locations – extremely warm dry				**CAT F3** Partly weather-protected and non-weather-protected locations
					CAT F4 Partly weather-protected and non-weather-protected locations – extended

Table 2-30 lists all of the environmental conditions and test procedures documented in RTCA DO-160G, Appendix J of these MOPS, MIL-STD-810G, and MIL-STD-704F. These procedures are cross-referenced with the ground-based environments/locations. If an entry is blank or hatched, then performance testing is not required in conjunction with that environmental test.

The environmental tests and performance requirements described in Table 2-31 provide a laboratory means of testing the equipment using simulated environmental operating conditions.

Table 2-31 identifies the sets of performance tests that are specified in detail in this paragraph and intended to be conducted subject to the various environmental procedures in RTCA DO-160G, Appendix J of these MOPS, MIL-STD-810G, and MIL-STD-704F. The environmental conditions are cross-referenced to the performance requirements of Subsection 2.2 and performance test procedures of Subsection 2.4.

To use these tables, first determine the possible locations for the ground equipment using Table 2-29, then use Table 2-30 to determine the environmental conditions the equipment would be tested under, then cross reference using Table 2-31. Test the ground equipment using the performance tests specified in Table 2-31 for each article. If an entry is blank, then performance testing is left to the manufacturer to determine applicable performance criteria in conjunction with that environmental test.

Tests identified by the phrase, “when required,” apply when the manufacturer wishes to qualify the equipment to additional environmental conditions such as may be required by contractual obligations or environments applicable only to specific aircraft. Tests identified by the phrase “if applicable,” apply to equipment expected to be exposed to that environment during its service life. For example, Lightning Direct Effects testing is only applicable to externally mounted equipment.

While this document does specify which environments are required, it is the applicant’s responsibility to specify the category and/or range within that environment (e.g., High and Low Temperature, Category A from RTCA DO-160G, Humidity, Category A1 from Appendix J of these MOPS, or Shock, Method 516.6 from MIL-STD-810G). Lastly, there are environments not addressed in this document, such as hail, volcanic ash etc. These environments are not required, but the applicant may wish to consider them when qualifying the equipment.

Table 2-30 **Ground-Based Environmental Test Conditions and Locations Matrix**

Environment	Environmental Test Conditions	A1	A2	B1	B2	B3	C1	D1	D2	E1	E2	F1	F2	F3	F4	Remarks
High Temperature and Low Temperature	DO-160G, §4.0 or Subsection J.1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	(1)
Altitude	DO-160G, §4.0 or Subsection J.1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	(1)
Temperature Variation	DO-160G, §5.0 or Subsection J.2	X	X	X	X	X	X	X	X	X	X	X	X	X	X	(1)
Humidity	DO-160G, §6.0 or Subsection J.3	X	X	X	X	X	X	X	X	X	X	X	X	X	X	(1)
Shock	DO-160G, §7.0, Subsection J.4 or MIL-STD-810G, Method 516.6	X	X	X	X	X	X	X	X	X	X	X	X	X	X	(2)
Sinusoidal & Random Vibration (Pre-Delivery/Earthquake)	DO-160G, §8.0, Subsection J.5, or MIL-STD-810G, Method 514.6	X	X	X	X	X	X	X	X	X	X	X	X	X	X	(2)/(3)
Explosion	DO-160G. §9.0															Not Required
Waterproofness	DO-160G, §10.0			X	X	X	X		X		X			X	X	
Fluids Susceptibility	DO-160G, §11.0 or Appendix J.6			X	X	X	X	X	X		X		X	X	X	
Sand and Dust	DO-160G, §12.0 or Appendix J.7			X	X	X	X	X	X			X	X	X	X	
Fungus Resistance	DO-160G, §13.0			X	X	X	X	X	X		X		X	X	X	
Salt Fog	DO-160G, §14.0	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Solar Radiation	MIL-STD-810G, Method 505.5	(4)	(4)	X	X	X	(5)	(4)	(5)	(4)	X	(4)	(5)	X	X	
Magnetic Effect	DO-160G, §15.0			X	X	X	X	X	X		X		X	X	X	
Power Input	DO-160G, §16.0 or MIL-STD-704F	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Voltage Spike	DO-160G, §17.0	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Audio Frequency Conducted Susceptibility	DO-160G, §18.0	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Induced Signal Susceptibility	DO-160G, §19.0	X	X	X	X	X	X	X	X	X	X	X	X	X	X	

Environment	Environmental Test Conditions	A1	A2	B1	B2	B3	C1	D1	D2	E1	E2	F1	F2	F3	F4	Remarks
RF Susceptibility	DO-160G, §20.0	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Emission of RF Energy	DO-160G, §21.0	X	X	X	X	X	X	X	X	X	X	X	X	X	X	(6)
Lightning Induced Transient Susceptibility	DO-160G, §22.0	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Lightning Direct Effects	DO-160G, §23.0	X	X	X	X	X	X	X	X	X	X	X	X	X	X	(7) If Applicable
Icing	DO-160G, §24.0			X	X	X					X			X	X	If Applicable
Electrostatic Discharge	DO-160G, §25.0	X	X				X	X	X	X		X	X			
Fire/Flammability	DO-160G, §26.0	X	X	X	X	X	X	X	X	X	X	X	X	X	X	(8)

Note:

1. *Environmental test categories (test conditions) can be chosen from the categories found in RTCA DO-160G or Appendix J of these MOPS, where appropriate.*
2. *Only required to functionally check the article after exposure (e.g., transportation, drop article, etc.) for stationary locations.*
3. *This particular vibration is region specific and requires manufacturers to select the appropriate profile from MIL-STD-810G, if used*
4. *Limited to equipment exposed to solar radiation.*
5. *Not required if the alternate test procedure per Subsection J.1 and Table J-1 is performed.*
6. *This test is performed to determine the potential effects of the tested equipment, while operating, on external equipment that may be susceptible to Electro-Magnetic Interference (EMI).*
7. *Lightning direct effects applies to the externally mounted equipment.*
8. *The fire/flammability test is to ensure the equipment doesn't support flame propagation. There are no performance requirements.*

Table 2-31 **CS Equipment Environmental Test Conditions and Performance Matrix**

Function		CS DAA Processor	CS DAA Control Panel	DAA Traffic Display	Remarks
Environment	**Environmental Test Conditions**	**2.2.2.3 and 2.2.2.4 CS DAA Processor I/O**	**2.2.2.5 and 2.2.2.6 CS DAA Control Panel I/O**	**2.2.2.7 DAA Traffic Display I/O**	
Temperature/Altitude	RTCA DO-160G,§4.0 or Subsection J.1				Section Heading
Ground Survival Low Temperature Test and Short-Time Operating Low Temperature Test	RTCA DO-160G, §4.5.1 or Subsection J.1	Paragraph 2.4.12 Env Qual for CS DAA Processor Test Procedures	Paragraph 2.4.13 Env Qual for CS DAA Control Panel Test Procedures	Paragraph 2.4.14 Env Qual for DAA Traffic Display Test Procedures	
Operating Low Temperature Test	RTCA DO-160G, §4.5.2 or Subsection J.1	Paragraph 2.4.12	Paragraph 2.4.13	Paragraph 2.4.14	
Ground Survival High Temperature Test and Short-Time Operating High Temperature Test	RTCA DO-160G, §4.5.3 or Subsection J.1	Paragraph 2.4.12	Paragraph 2.4.13	Paragraph 2.4.14	
Operating High Temperature Test	RTCA DO-160G, §4.5.4 or Subsection J.1	Paragraph 2.4.12	Paragraph 2.4.13	Paragraph 2.4.14	
In-Flight Loss of Cooling Test	RTCA DO-160G, §4.5.5				Not Required
Altitude Test	RTCA DO-160G, §4.6.1 or Subsection J.1	Paragraph 2.4.12	Paragraph 2.4.13	Paragraph 2.4.14	
Decompression Test	RTCA DO-160G, §4.6.2				Not Required
Overpressure	RTCA DO-160G, §4.6.3				Not Required
Temperature Variation	RTCA DO-160G, §5.0 or Subsection J.2	Paragraph 2.4.12	Paragraph 2.4.13	Paragraph 2.4.14	
Humidity	RTCA DO-160G, §6.0 or Subsection J.3	Subparagraph 2.4.8.2*	Paragraph 2.4.13	Subparagraph 2.4.8.2*	

Function		CS DAA Processor	CS DAA Control Panel	DAA Traffic Display	Remarks
Environment	**Environmental Test Conditions**	**2.2.2.3 and 2.2.2.4 CS DAA Processor I/O**	**2.2.2.5 and 2.2.2.6 CS DAA Control Panel I/O**	**2.2.2.7 DAA Traffic Display I/O**	
Shock	RTCA DO-160G, §7.0				Section Heading
Operational Shock	RTCA DO-160G,§7.0, Subsection J.4 or MIL-STD-810G, Method 516.6	Subparagraph 2.4.8.1*+		Subparagraph 2.4.8.1 *+	
Crash Safety Shocks	RTCA DO-160G, §7.3 or Subsection J.4				Not Required
Vibration	RTCA DO-160G, §8.0, Subsection J.5 or MIL-STD-810G, Meth 514.6	Paragraph 2.4.12	Paragraph 2.4.13	Paragraph 2.4.14	(1) If Applicable
Explosion	RTCA DO-160G, §9.0				Not Required
Waterproofness	RTCA DO-160G, §10.0				Section Heading
Condensing Water Drip Proof Test	RTCA DO-160G, §10.3.1	Subparagraph 2.4.8.2*		Subparagraph 2.4.8.2*	If Applicable
Drip Proof Test	RTCA DO-160G, §10.3.2	Subparagraph 2.4.8.2*		Subparagraph 2.4.8.2*	If Applicable
Spray Proof Test	RTCA DO-160G, §10.3.3	Subparagraph 2.4.8.2*		Subparagraph 2.4.8.2*	If Applicable
Continuous Stream Proof Test	RTCA DO-160G, §10.3.4	Subparagraph 2.4.8.2*		Subparagraph 2.4.8.2*	If Applicable
Fluids Susceptibility	RTCA DO-160G, §11.0				Section Heading
Spray Test	RTCA DO-160G, §11.4.1	Subparagraph 2.4.8.2*		Subparagraph 2.4.8.2*	If Applicable
Immersion Test	RTCA DO-160G, §11.4.2 or Appendix J.6	Subparagraph 2.4.8.2*		Subparagraph 2.4.8.2*	If Applicable
Sand and Dust	RTCA DO-160G, §12.0 or Appendix J.7	Subparagraph 2.4.8.2*		Subparagraph 2.4.8.2*	When Required
Fungus Resistance	RTCA DO-160G, §13.0	Subparagraph 2.4.8.2*		Subparagraph 2.4.8.2*	When Required
Salt Fog	RTCA DO-160G, §14.0	Subparagraph 2.4.8.2*		Subparagraph 2.4.8.2*	When Required
Solar Radiation	Subsection J.2 or MIL-STD-810G, Method 505.5	Subparagraph 2.4.8.1*+	Paragraph 2.4.13	Paragraph 2.4.14	If Applicable
Magnetic Effect	RTCA DO-160G, §15.0	Subparagraph 2.4.8.1*+		Subparagraph 2.4.8.1*+	If Applicable

Function		CS DAA Processor	CS DAA Control Panel	DAA Traffic Display	Remarks
Environment	**Environmental Test Conditions**	**2.2.2.3 and 2.2.2.4 CS DAA Processor I/O**	**2.2.2.5 and 2.2.2.6 CS DAA Control Panel I/O**	**2.2.2.7 DAA Traffic Display I/O**	
Power Input	RTCA DO-160G, §16.0 or MIL-STD-704F				Section Heading
Normal Operating Conditions	RTCA DO-160G, §16.5.1 RTCA DO-160G, §16.6.1 or MIL-STD-704F	Paragraph 2.4.12	Paragraph 2.4.13	Paragraph 2.4.14	
Abnormal Operating Conditions	RTCA DO-160G, §16.5.2 RTCA DO-160G, §16.6.2 or MIL-STD-704F	Paragraph 2.4.12	Paragraph 2.4.13	Paragraph 2.4.14	
Voltage Spike	RTCA DO-160G, §17.0	Paragraph 2.4.12	Paragraph 2.4.13	Paragraph 2.4.14	
Audio Frequency Conducted Susceptibility	RTCA DO-160G, §18.0	Paragraph 2.4.12	Paragraph 2.4.13	Paragraph 2.4.14	
Induced Signal Susceptibility	RTCA DO-160G, §19.0	Paragraph 2.4.12	Paragraph 2.4.13	Paragraph 2.4.14	
RF Susceptibility	RTCA DO-160G, §20.0	Paragraph 2.4.12	Paragraph 2.4.13	Paragraph 2.4.14	
Emission of RF Energy	RTCA DO-160G, §21.0	Subparagraph 2.4.8.1*+		Subparagraph 2.4.8.1*+	(2)
Lightning Induced Transient Susceptibility	RTCA DO-160G, §22.0	Paragraph 2.4.12	Paragraph 2.4.13	Paragraph 2.4.14	
Lightning Direct Effects	RTCA DO-160G, §23.0				(3) If Applicable
Icing	RTCA DO-160G, §24.0				If Applicable
Electrostatic Discharge	RTCA DO-160G, §25.0	Subparagraph 2.4.8.2*		Subparagraph 2.4.8.2*	
Fire/Flammability	RTCA DO-160G, §26.0				(4)

Note:

1. *This particular vibration is region-specific and would require custom tailoring of MIL-STD-810G.*
2. *Equipment performance requirements for this function of the equipment under test are defined within RTCA DO-160G.*
3. *Lightning direct effects applies to externally mounted equipment.*
4. *The fire, flammability test is to ensure the equipment doesn't support flame propagation. There are no performance requirements.*

** Only normal operation checks are required (no fault insertion).*

+ Ensure the monitor function completes at least one pass of all background health checks.

2.4 Equipment Test Procedures

The test procedures described in this subsection are intended to provide a laboratory means of determining the overall performance characteristics of the equipment.

2.4.1 Definitions of Terms and Condition of Test

The following are definitions of terms and the conditions are applicable to the equipment tests specified herein:

1. Power Input Voltage – Unless otherwise specified, all tests must be conducted with calibrated equipment capable of measuring the voltage to design requirements. The input voltage must be measured at the input terminals of the equipment under test.
2. Power Input Frequency
    a. In the case of equipment designed for operation from an Alternating Current (AC) source of essentially constant frequency (e.g., 400 Hertz (Hz)); the input frequency must be adjusted to design frequency.
    b. In the case of equipment designed for operation from an AC source of variable frequency (e.g., 300 to 1000 Hz), unless otherwise specified, tests must be conducted with the input frequency adjusted to a selected frequency and within the range for which the equipment is designed.
3. Adjustment of Equipment – The circuits of the equipment under test must be properly aligned and otherwise adjusted in accordance with the manufacturer's recommended practices prior to application of the specified tests. No adjustments must be made once the test procedures have started.
4. Test Equipment – All equipment used in the performance of the tests should be identified by make, model and serial number where appropriate, and include its latest calibration date. When appropriate, all test equipment calibration standards should be traceable to national and/or international standards.
5. Test Instrument Precautions – Adequate precautions must be taken during the test to prevent the introduction of errors resulting from the connection of voltmeters, oscilloscopes and other test instruments across the input and output impedances of the equipment under test.
6. Ambient Conditions – Unless otherwise specified, all tests must be made within the following ambient conditions:
    a. Temperature: +15 to +35 degrees Celsius (C) (+59 to +95 degrees F)
    b. Relative Humidity: Not greater than 85%
    c. Ambient Pressure: 84 to 107 Kilopascals (kPa) (equivalent to +5,000 to –1,500') (+1,525 to –460 m).
7. Connected Loads – Unless otherwise specified, all tests must be performed with the equipment connected to loads having the impedance values for which it is designed.

2.4.1.1 Test Equipment

The equipment list required to perform the Subsection 2.4 tests are specified within the individual test subdivisions. Off-the-shelf test equipment is identified by commercial model or equivalent. Essential characteristics are provided to determine when the manufacturer is required to use actual DAA subsystem equipment articles during that testing or when non-standard test equipment is required.

In some cases, the test procedures use reports generated from test vectors to verify compliance. For those procedures, unless otherwise noted, a simulation environment capable of receiving simulated sensor output (i.e., ADS-B data, active surveillance data or radar data) and generating aural alerts and visual guidance on a display will be necessary. This will involve at least the UA DAA processor, the CS DAA processor, the CS DAA traffic display, the CS DAA Control panel, and real or simulated CNPC Datalink equipment

A detailed discussion of the test vectors can be found in Appendix P.

2.4.1.2 Detailed Test Procedures

The test procedures set forth below constitute a satisfactory method of determining required performance is achieved by the system. Although specific test procedures are cited, it is recognized that other methods may be preferred. Such alternate methods may be used if the manufacturer can show that they provide at least equivalent information and verification of the required performance.

2.4.2 Equipment Performance Requirements – Standard Conditions (§2.2)

Subsection 2.2 does not contain any requirements. No test procedures are required to verify Subsection 2.2.

2.4.2.1 General Equipment Characteristics (§2.2.1)

Paragraph 2.2.1 does not contain any requirements. No test procedures are required to verify Paragraph 2.2.1.

2.4.2.1.1 Latency (§2.2.1.1)

This subparagraph's test procedure requires the actual DAA equipment be included as part of the test setup. A simulated data link can be used during the testing as long as a qualified simulation is used to represent the time delay between the aircraft and ground station.

Step 1: Set up the DAA system in a normal operational status.

Step 2: Apply the degraded ADS-B, Mode C, Mode S and radar tracks of test vectors H1, C10 and M20 while measuring the latency between the DAA subsystem interfaces specified in Table 2-32. Appendix E provides more detail on latency considerations.

Step 3: Verify that the data latencies do not exceed the values shown in Table 2-32.

Table 2-32 Maximum Allowed Data Latencies

Subsystem	Interface (see Appendix E)	Total Latency (seconds)	Latency Compensation Error (ms)	Source of Requirement
ADS-B (1090ES/UAT)	B	2.5	-200/+400	DO-260/282
ADS-B (ADS-R)	B	3.5	-170/+420	DO-260/282
ATAR	B	1.0	0	DO-TBD (MOPS for Air-

Subsystem	Interface (see Appendix E)	Total Latency (seconds)	Latency Compensation Error (ms)	Source of Requirement
				to-Air Radar for Traffic Surveillance (RTCA Paper No. 170-16/ SC228 034))
Active Surveillance (Mode C/S)	B	1.0	0	DO-185
DAA Tracker	B1	1.0	900	§2.2.3.2.3
DAA Alerting Algorithm	D	1.0	0	§2.2.4.3.4.1
CNPC Data Link	F	2.0	0	Appendix K
DAA Guidance Processing	G	1.0	0	§2.2.4.4
DAA Display	G	0.5	0	DO-317B
Command-To-Execute	D/F	2.0	0	§2.2.4.4

2.4.2.1.2 UA DAA Surveillance Equipment (§2.2.1.2)

Subparagraph 2.2.1.2 does not contain any requirements. No test procedures are required to verify Subparagraph 2.2.1.2.

2.4.2.1.3 ATAR (§2.2.1.3)

Step 1: Verify that the ATAR meets the requirements defined in RTCA DO-TBD (MOPS for Air-to-Air Radar for Traffic Surveillance (RTCA Paper No. 170-16/ SC228 034))by either analysis of the results from test procedures required by that MOPS or through a TSO certification.

2.4.2.1.4 Airborne Active Surveillance (§2.2.1.4)

The airborne active surveillance equipment is verified as part of the test procedures in Subparagraph 2.4.3.1 and its subparagraphs.

2.4.2.1.5 ADS-B System (§2.2.1.5)

Step 1: Verify that the ADS-B receiver meets the requirements defined in RTCA DO-260B, equipage Class A1 or higher by either analysis of the results from test procedures in RTCA DO-260B or through a TSO certification.

If using an optional UAT receiver, verify that it meets the requirements defined in RTCA DO-282 by either analysis of the results from test procedures in RTCA DO-282B or through a TSO certification.

2.4.2.1.6 TCAS II System (Class 2) (§2.2.1.6)

The TCAS II subsystem equipment is verified as part of the test procedures in Subparagraph 2.4.3.1 and its subparagraphs.

2.4.2.2 DAA Input/Output Requirements (§2.2.2)

Paragraph 2.2.2 does not contain any requirements. No test procedures are required to verify Paragraph 2.2.2.

The following test procedures verify Input/Output requirements specific to data quality. Requirements related to the correct data being received, transmitted and processed are verified as part of the display test procedures in Subparagraph 2.4.5.5.

Note: *The display test procedures in Subparagraph 2.4.5.5 use an end-to-end testing environment where the full data flow is tested; i.e., the data displayed on the screen starts out as a simulated measurement from either an ADS-B receiver, active surveillance, or the radar system and is processed through the entire DAA system. For an ownship or an intruder to be displayed correctly, the input and output of the various states would need to be implemented correctly. Thus, requirements in Paragraph 2.2.2 specific to which states are transmitted are implicitly verified during execution of the display test procedures.*

2.4.2.2.1 UA DAA Processor Input Data Requirements (§2.2.2.1)

Subparagraph 2.2.2.1 does not contain any requirements. No test procedures are required to verify Subparagraph 2.2.2.1.

2.4.2.2.1.1 Ownship State Data (§2.2.2.1.1)

The following tests verify requirements related to the quality of ownship data. Requirements specific to the correct input format, reception, processing and display of data are verified as part of the test procedures in Subparagraph 2.4.5.5.

Step 1: Verify, by demonstration or analysis, that the UA DAA processor uses the same position source for all of the states listed in Subparagraph 2.2.2.1.1-2.

Step 2: Verify, by demonstration or analysis, that the UA DAA processor does not accept any data if the position source has detected a non-isolated signal-in-space fault.

Step 3: Verify, by demonstration or analysis, that the UA DAA processor does not accept pressure altitude data when the pressure altitude source has failed.

Step 4: Verify, by demonstration or analysis, that the UA DAA processor receives the SIL if it is dynamically sent.

Step 5: Apply the degraded ownship track from Test Vector D1 as simulated input to the UA DAA processor. Verify that:

- From t = 20 sec to 30 sec, ownship position source is flagged as invalid for DAA due to the received position data not having been updated more than 2.6 seconds
- From t = 40 sec to 50 sec, ownship data is not accepted due to invalid horizontal position information
- From t = 60 sec to 70 sec, ownship horizontal position data is not accepted due to 95% horizontal position uncertainty exceeding 0.1 NM
- From t = 80 sec to 90 sec, ownship horizontal position data is not accepted due to the horizontal position integrity bound exceeding 0.3 NM
- From t = 100 sec to 110 sec the source integrity level is larger than 1E-07

- From t = 120 sec to 130 sec, ownship horizontal position data is not accepted due to the horizontal velocity uncertainty exceeding 10 m/s

Note: *Test vector is encoded using a velocity uncertainty in excess of 10 m/s; for systems designed to meet Note 4 in Subparagraph 2.2.2.1.1, using this test vector is sufficient to show compliance.*

- From t = 140 sec to 150 sec, ownship pressure altitude data is not accepted due to altitude data being flagged invalid.

Note: *The procedure only requires the manufacturer to show that an update is not accepted, not that the ownship track is dropped or disappears. If the disappearance of the track is used as verification of this requirement, the test vector may need modification to include longer periods of the various data issues.*

2.4.2.2.1.1.1 Flight Intent Data (§2.2.2.1.1.1) (Optional)

If ownship intent data is incorporated in the alerting logic, the manufacturer should generate test vectors that demonstrate that this functionality is implemented correctly. The verification should ensure that intent data is used when it will be automatically executed by the UA, and not used when intent data will not be automatically executed or is unavailable.

2.4.2.2.1.2 ATAR Intruder Data (§2.2.2.1.2)

Subparagraph 2.2.2.1.2 does not include requirements related to the quality of ATAR data. Requirements specific to the correct input format, reception, processing and display of data are verified as part of the test procedures in Subparagraph 2.4.5.5.

Step 1: Apply degraded ATAR track from Test Vector D1 as input to the UA DAA processor.

Step 2: Verify that: From t = 20 sec to 30 sec, ATAR data is flagged as invalid for DAA due to data age exceeding 0.5 seconds.

2.4.2.2.1.3 Active Surveillance Intruder Data (§2.2.2.1.3)

Subparagraph 2.2.2.1.3 does not include requirements related to the quality of active surveillance intruder data. Requirements specific to the correct input format, reception, processing and display of data are verified as part of the test procedures in Subparagraph 2.4.5.5.

2.4.2.2.1.4 ADS-B In Intruder Data (§2.2.2.1.4)

This procedure verifies the requirement to not accept TIS-B data. Requirements specific to the correct input format, reception, processing and display of data are verified as part of the test procedures in Subparagraph 2.4.5.5.

Step 1: Verify, by demonstration or analysis, that the DAA UA Processor does not accept any TIS-B data from the ADS-B In source.

2.4.2.2.1.4.1 Intruder ADS-B Traffic State Vector Report Input Requirements (§2.2.2.1.4.1)

Step 1: Apply degraded ADS-B intruder track from Test Vector D1 as input to the UA DAA processor.

Step 2: Verify that:

- From t = 20 sec to 30 sec, no ADS-B intruder data is accepted due to the horizontal position uncertainty exceeding 0.1 NM (95%)
- From t = 40 sec to 50 sec, no ADS-B intruder data is accepted due to the horizontal position integrity bound exceeding 0.3 NM
- From t = 60 sec to 70 sec no ADS-B intruder data is accepted due to the source integrity level being larger than 1E-07
- From t = 80 sec to 90 sec, no ADS-B intruder data is accepted due to the horizontal velocity uncertainty exceeding 10 meters per second (m/s) (NACv < 1)

Note: *The test vector is encoded using a velocity uncertainty in excess of 10 m/s; for systems designed to meet Note 4 in Subparagraph 2.2.2.1.1, using this test vector is sufficient to show compliance.*

- From t = 100 sec to 110 sec, no ADS-B data is accepted due to the system design assurance being greater than 1E-05 (SDA < 2).

Note: *The procedure only requires the manufacturer to show that an update is not accepted, not that the ownship track is dropped or disappears. If the disappearance of the track is used as verification of this requirement, the test vector may need modification to include longer periods of the various data issues.*

2.4.2.2.1.4.2 ADS-B Intruder Mode Status Data Input Requirements (§2.2.2.1.4.2)

Subparagraph 2.2.2.1.4.2 does not include requirements related to the quality of ADS-B intruder data. Requirements specific to the correct input format, reception, processing and display of data are verified as part of the test procedures in Subparagraph 2.4.5.5.

2.4.2.2.1.4.3 TIS-B/ADS-R Service Status Data – Optional (§2.2.2.1.4.3)

If the use of TIS-B/ADS-R service status is incorporated in the alerting logic, the manufacturer should generate test vectors that demonstrate that this functionality is implemented correctly.

2.4.2.2.1.4.4 TCAS II RA Report (§2.2.2.1.4.4)

The reception of TCAS RA data is verified as part of the test procedures in Subparagraph 2.4.5.5.

2.4.2.2.1.4.4.1 Operational Coordination Message (§2.2.2.1.4.4)

The reception of OCM data is verified as part of the test procedures in Subparagraph 2.4.5.5.

2.4.2.2.1.5 TCAS II RA and Coordination Data (§2.2.2.1.5)

The reception of TCAS RA data is verified as part of the test procedures in Subparagraph 2.4.5.7.

2.4.2.2.1.6 Surveillance Equipment Operating Status and Health Data (§2.2.2.1.6)

The reception of the operating status and health data from surveillance subsystems is verified as part of the test procedures in Subparagraph 2.4.5.8 and Paragraph 2.4.6.

2.4.2.2.1.7 Flight Control System (FCS) (§2.2.2.1.7)

Subparagraph 2.2.2.1.7 does not contain any requirements. No test procedures are required to verify Subparagraph 2.2.2.1.7.

2.4.2.2.1.8 CNPC Data Link (§2.2.2.1.8)

The correct reception and processing of status and data are verified in Subparagraph 2.4.5.8 and Paragraph 2.4.6.

2.4.2.2.2 UA DAA Processor Output Data Requirements (§2.2.2.2)

Subparagraph 2.2.2.2 does not contain any requirements. No test procedures are required to verify Subparagraph 2.2.2.2.

2.4.2.2.2.1 Prioritized Track Data (§2.2.2.2.1)

The correct output format, prioritization, processing and display of traffic data is verified as part of the test procedures in Subparagraphs 2.4.3.2.3 and 2.4.4.3.4.1

Step 1: Verify, as part of the test procedure in Subparagraph 2.4.3.2.3, that tracks that do not meet the DAA data quality thresholds are not forwarded to the CS DAA processor.

Step 2: Verify, by analysis or demonstration, that the range resolution for horizontal position is 50 ft or better.

2.4.2.2.2.2 DAA System Modes of Operation and Health Status (§2.2.2.2.2)

The reception of the operating status and health data from surveillance equipment is verified as part of the test procedures in Subparagraph 2.4.5.8 and Paragraph 2.4.6.

2.4.2.2.2.3 TCAS II RA – Equipment Class 2 (§2.2.2.2.3)

The reception of TCAS RA data is verified as part of the test procedures in Subparagraph 2.4.5.6.

2.4.2.2.2.3.1 Flight Control System Commands from the UA DAA Processor (§2.2.2.2.3.1)

Subparagraph 2.2.2.2.3.1 does not contain any requirements. No test procedures are required to verify Subparagraph 2.2.2.2.3.1.

2.4.2.2.2.4 Onboard Data Recording Capability (§2.2.2.2.4)

This test procedure verifies that the UA DAA processor records the required data onboard the UA.

Step 1: Apply Test Vector D9 four times, sequentially, to generate sufficient reports.

Step 2: Verify, by demonstration or analysis, that the data recording system stores the information as required by Subparagraph 2.2.2.5.

Step 3: Verify, by inspection, that the recording capability uses non-volatile memory.

2.4.2.2.3 CS DAA Processor Input Requirements (§2.2.2.3)

The correct reception, processing and display of DAA data by the CS DAA processor is verified as part of the test procedures in Subparagraph 2.4.5.5.

2.4.2.2.4 CS DAA Processor Output Data Requirements (§2.2.2.4)

The correct reception, processing and display of DAA data by the CS DAA processor is verified as part of the test procedures in Subparagraph 2.4.5.5.

2.4.2.2.4.1 CS DAA Processor Operating Status and Health Data (§2.2.2.4.1)

The output of the operating status and health data of surveillance equipment is verified as part of the test procedures in Subparagraph 2.4.5.8 and Paragraph 2.4.6.

2.4.2.2.5 DAA Control Panel Input Requirements (§2.2.2.5)

The reception of pilot selected modes is verified as part of the test procedures in Subparagraph 2.4.5.8 and Paragraph 2.4.6.

2.4.2.2.6 DAA Control Panel Output Requirements (§2.2.2.6)

The output of pilot selected modes is verified as part of the test procedures in Subparagraph 2.4.5.8 and Paragraph 2.4.6.

2.4.2.2.7 CS DAA Traffic Display Input Data Requirements (§2.2.2.7)

The correct reception, processing and display of DAA data by the CS DAA processor is verified as part of the test procedures in Subparagraph 2.4.5.5.

The following subparagraphs verify requirements in Subparagraph 2.2.2.7 that are not related to the reception and processing of DAA data by the CS DAA processor.

2.4.2.2.7.1 Ownship Pressure Altitude (§2.2.2.7.1)

If ownship pressure altitude is used by the DAA traffic display to determine traffic actual altitude, the manufacturer should generate test vectors that verify that the DAA traffic display function receives the ownship pressure altitude from the ownship position source.

Similarly, the manufacturer should generate test vectors that verify that the DAA traffic display function receives the ownship barometric correction or corrected altitude from the ownship position sources.

2.4.2.2.7.2 Ownship Length and Width Code (§2.2.2.7.2)

If the ownship's physical extent is displayed, the manufacturer should generate test vectors that verify that the DAA traffic display function receives the aircraft's length and width code from ownship sources.

2.4.3 Active Surveillance, Equipment Class 2 RA Function and Tracker Performance Requirements

Paragraph 2.2.3 does not contain any requirements. No test procedures are required to verify Paragraph 2.2.3.

2.4.3.1 DAA Active Surveillance and DAA Equipment Class 2 RA Function Requirements

Subparagraph 2.2.3.1 does not contain any requirements. No test procedures are required to verify Subparagraph 2.2.3.1

2.4.3.1.1 DAA Active Surveillance (§2.2.3.1.1)

Table 2-33 provides a cross reference between the requirement sections of RTCA DO-185B listed in Paragraph 2.2.3 and their associated test procedures, also in RTCA DO-185B.

Step 1: Verify that the DAA active surveillance system passes the tests outlined in the relevant test procedure subdivisions listed in Table 2-33.

Step 2: In addition, verify that the DAA active surveillance system passes the tests outlined in the relevant test procedure subdivisions listed in RTCA DO-300A, Hybrid Surveillance. Where specific Sub-tests are identified, only those need to be applied.

Table 2-33 **Cross-Reference of DAA Surveillance Reqs to RTCA DO-185B Test Procedures**

TCAS II MOPS Requirements		Associated Required Test		DAA Notes (in §2.2.3.1.1)
2.2.3.1	Radiated Output Power	2.4.2.1.1.2	Radiated Output Power	
2.2.3.2	Unwanted Output Power	2.4.2.1.1.6	Unwanted Output Power	
2.2.3.3	Interrogation Spectrum	2.4.2.1.1.5	Interrogation Spectrum	
2.2.3.4	Interrogation Jitter	2.4.2.1.1.8	Interrogation Repetition Interval and Jitter	
2.2.3.5	Transmit Frequency and Tolerance	2.4.2.1.1.1	Transmit Frequency	
2.2.3.6	Interference Limiting	2.4.2.1.7.4	Interference Limiting	1
2.2.3.6.2	Interference Limiting Procedures	2.4.2.1.7.4.1	Interrogation Control of Airborne TCAS	1
2.2.3.6.3	Interrogations from TCAS On The Ground	2.4.2.1.7.4.2	Interrogation Control of TCAS On The Ground	1
2.2.3.8	Transmit Pulse Characteristics	2.4.2.1.1.4	TCAS Transmit Pulse Characteristics	
2.2.3.8.1	Mode C Transmissions	2.4.2.1.1.4	TCAS Transmit Pulse Characteristics	
2.2.3.8.2	Mode S Transmissions	2.4.2.1.1.4	TCAS Transmit Pulse Characteristics	
2.2.3.10.2.1	Detection	2.4.2.1.5.3	Mode S Extended Squitter Reception (opt.)	
2.2.3.10.2.4	TCAS Broadcast Interrogations	2.4.2.1.10.2	Use of Directional Antenna for TCAS Broadcast Interrogations	
2.2.3.10.2.4 2.2.3.10.6	TCAS Broadcast Interrogations Mode S Crosslink Capability	2.4.2.1.7.4.3	Correct Content of Transmitted TCAS Broadcast Interrogation Messages	
		2.4.2.1.7.2.1	Mode S Acquisition of Transponder Comm-B Register Information (opt.)	
2.2.3.10.7	Extended Squitter with Aircraft ID Message	2.4.2.1.5.3	Mode S Extended Squitter Reception (opt.)	
2.2.3.11	Compatibility with Own Mode S Transponder	2.4.2.1.7.5	Surveillance Target Capacity and Overload, Mode S	
2.2.3.12	Aircraft Suppression Bus	2.4.2.1.1.7	Aircraft Suppression Bus	
2.2.4	Surveillance Requirements		See Below	3, 9
2.2.4.1	Surveillance Update Rate	2.4.2.1.1.8	Interrogation Repetition Interval and Jitter	
2.2.4.2	System Delay	2.4.2.1.7.2	Mode S Range Acquisition	
2.2.4.4.1	Receiver Sensitivity and Bandwidth	2.4.2.1.2	Receiver Characteristics	
2.2.4.4.1.1	In-Band Acceptance	2.4.2.1.2.1	In-Band Acceptance	

TCAS II MOPS Requirements		Associated Required Test		DAA Notes (in §2.2.3.1.1)
2.2.4.4.1.2	Out-of-Band Rejection	2.4.2.1.2.2	Out-of-Band Rejection	
2.2.4.4.2.1	Mode C Reply Reception	2.4.2.1.4	Mode C Reply Reception	
2.2.4.4.2.1 2.2.4.4.2.1b	Mode C Reply Reception Criteria for Mode C Pulse Detection	2.4.2.1.3.1	Mode C Reply Reception	
		2.4.2.1.4.1	Bracket Detection and Reply Decoding	
		2.4.2.1.4.2	Wide Pulse Detection and Pulse Position Discrimination	
		2.4.2.1.4.3	Narrow Pulse Rejection	
2.2.4.4.2.1c	Criteria for Acceptance of Garbled Mode C Replies	2.4.2.1.4.2	Wide Pulse Detection and Pulse Position Discrimination	
2.2.4.4.2.1c 2.2.4.4.2.1d	Criteria for Acceptance of Garbled Mode C Replies Phantom Rejection	2.4.2.1.4.4	Detection of Garbled Replies	
		2.4.2.1.4.5	Detection of Interleaved Replies	
		2.4.2.1.4.6	Phantom Rejection	
2.2.4.4.2.2	Mode S Squitter and Reply Reception	2.4.2.1.5	Mode S Squitter and Reply Reception	
2.2.4.4.2.2 2.2.4.4.2.2b	Mode S Squitter and Reply Reception Criteria for Preamble Acceptance	2.4.2.1.4.7	Tactical Air Navigation (TACAN) and DME Rejection	
		2.4.2.1.3.2	Mode S Squitter and Reply Reception	
		2.4.2.1.5.1	Mode S Preamble Acceptance	
2.2.4.4.2.2c	Criteria for Data Block Acceptance in Squitter and Asynchronous Transmissions	2.4.2.1.5.2	Mode S Squitter and Fruit Reply Reception	
2.2.4.4.2.2c 2.2.4.4.2.2d	Criteria for Data Block Acceptance in Squitter and Asynchronous Transmissions Additional Criterion for Data Block Acceptance in Discrete Transmissions	2.4.2.1.5.3	Mode S Extended Squitter Reception (opt.)	
		2.4.2.1.5.4	Mode S Error Correction	
2.2.4.5	Interference Rejection and Control	2.4.2.1.6.1	Mode C Surveillance Initiation	
2.2.4.5.1.2	Reply Link Interference	2.4.2.1.3	Reply Link Interference	
2.2.4.5.1.2.1	Narrow Pulse Discrimination	2.4.2.1.3.1	Mode C Reply Reception	
2.2.4.5.1.2.1 2.2.4.5.1.2.2	Narrow Pulse Discrimination TACAN and DME Discrimination	2.4.2.1.3.2	Mode S Squitter and Reply Reception	
		2.4.2.1.3.1	Mode C Reply Reception	
2.2.4.5.1.2.2 2.2.4.5.3	TACAN and DME Discrimination TACAN and DME Signal Rejection	2.4.2.1.3.2	Mode S Squitter and Reply Reception	
		2.4.2.1.4.7	TACAN and DME Rejection	
		2.4.2.1.4.7	TACAN and DME Rejection	

TCAS II MOPS Requirements		Associated Required Test		DAA Notes (in §2.2.3.1.1)
2.2.4.5.4.1	Control of Synchronous Garble by Transmitter Power	2.4.2.1.1.3	Control of Synchronous Garble by Transmitter Power	
2.2.4.5.4.1.1	Minimum Basic Whisper-Shout Sequence	2.4.2.1.1.3.1	Whisper-Shout Sequence Relative Amplitude and Timing	
2.2.4.5.4.1.2	Higher Capability Whisper-Shout Sequences	2.4.2.1.1.3.1	Whisper-Shout Sequence Relative Amplitude and Timing	
2.2.4.5.4.1.3	Determination of Whisper-Shout Based on Synchronous Garble	2.4.2.1.1.3.2	Determination of Whisper-Shout Sequence	
2.2.4.6	Surveillance Tracking Requirements	2.4.2.1.6.1	Mode C Surveillance Initiation	
2.2.4.6 2.2.4.6.1	Surveillance Tracking Requirements Surveillance Target Track Capacity	2.4.2.1.8.2	Altitude and Range Tracking of Mode C and Mode S	
		2.4.2.1.6.4	Surveillance Target Track Capacity, Mode C	
2.2.4.6.1 2.2.4.6.1.1	Surveillance Target Track Capacity Surveillance Overload	2.4.2.1.7.5	Surveillance Target Capacity and Overload, Mode S	
		2.4.2.1.8.1	Surveillance Target Capacity	
		2.4.2.1.6.5	Surveillance Overload	
2.2.4.6.1.1 2.2.4.6.2	Surveillance Overload Range and Altitude Estimation	2.4.2.1.7.5	Surveillance Target Capacity and Overload, Mode S	
		2.4.2.1.6	Mode C Target Surveillance Performance	
2.2.4.6.2.1.2	Track Initiation	2.4.2.1.6.1	Mode C Surveillance Initiation	
2.2.4.6.2.1.2 2.2.4.6.2.1.3	Track Initiation Maintenance of Established Tracks	2.4.2.1.9.5	Mode C Azimuth Filtering	
		2.4.2.1.6.2	Mode C Surveillance Extension	
2.2.4.6.2.1.3 2.2.4.6.2.1.4	Maintenance of Established Tracks Multipath False Targets	2.4.2.1.6.3	Missing Mode C Replies	
		2.4.2.1.6.2	Mode C Surveillance Extension	
2.2.4.6.2.2	Mode S Targets	2.4.2.1.5.3	Mode S Extended Squitter Reception (opt.)	
2.2.4.6.2.2 2.2.4.6.2.2.1	Mode S Targets Squitter Processing	2.4.2.1.7	Mode S Target Surveillance Performance	
		2.4.2.1.7.1	Mode S Surveillance Initiation	
2.2.4.6.2.2.2	Acquisition	2.4.2.1.7.2	Mode S Range Acquisition	
2.2.4.6.2.2.3	Maintenance of Established Tracks	2.4.2.1.7.3	Maintenance of Established Mode S Tracks	
2.2.4.6.2.2.4	Power Programming	2.4.2.1.7.6	Mode S Power Programming	

TCAS II MOPS Requirements		Associated Required Test		DAA Notes (in §2.2.3.1.1)
2.2.4.6.4.2	Bearing Acquisition with Standard Ground Plane	2.4.2.1.9.1	Bearing Accuracy with Standard Ground Plane	
2.2.4.6.4.3	Bearing Accuracy in the Presence of Interference	2.4.2.1.9.2	Reply Processing	
2.2.4.6.4.3.1	Mode C Interleaved Replies	2.4.2.1.9.2.1	Mode C Interleaved Replies	
2.2.4.6.4.3.2	Mode C Overlapped Replies	2.4.2.1.9.2.2	Mode C Overlapped Replies	
2.2.4.6.4.3.3	Mode S Overlapped Replies	2.4.2.1.9.2.3	Mode S Overlapped Replies	
2.2.4.6.4.4	Bearing Filter Performance	2.4.2.1.9.3	Bearing Filter Performance	
2.2.4.6.4.4.1	Bearing Filter	2.4.2.1.9.3.1	Bearing Track and Coast	
2.2.4.6.4.4.1 2.2.4.7	Bearing Filter Antenna System	2.4.2.1.9.3.2	Filter Lag	
		2.4.2.1.7.2	Mode S Range Acquisition	
2.2.4.7 2.2.4.7.2	Antenna System Radiation Pattern	2.4.2.1.7.3	Maintenance of Established Mode S Tracks	
		2.4.2.1.9.4	Radiation Pattern	
2.2.4.7.2.1	Transmit Radiation Pattern	2.4.2.1.10.1	Use of Directional Interrogations for Mode C Surveillance and Bearing Receive Radiation Pattern	
2.2.4.7.2.2	Receive Radiation Pattern	2.4.2.1.10.1	Use of Directional Interrogations for Mode C Surveillance and Bearing Receive Radiation Pattern	
2.2.4.7.3	Use of a Directional Antenna for Mode S Interrogations	2.4.2.1.10.2	Use of a Directional Antenna for TCAS Broadcast Interrogations	
2.2.4.7.4.1	Squitter Listening	2.4.2.1.7.2	Mode S Range Acquisition	
2.2.6.5.1	TCAS II/Mode S Controls	2.4.2.3.3.1	TCAS/Mode S Controls	4
2.2.7.1.1	Failure Response	2.4.2.4.1	Automatic Performance Monitoring	5
2.2.7.1.2	Noninterference with Normal Operations	2.4.2.4.1	Automatic Performance Monitoring	6
2.2.7.1.3	Self Test	2.4.2.4.2	Self Test	5

Table 2-34 **Cross-Reference of DAA Surveillance Reqs to RTCA DO-300A Test Procedures**

DO-300A Requirement	Test	Sub Test
2.2.1 General	2.4.2.9 Surveillance Overload and Capacity Tests	
2.2.2 Shared Use of 1090 MHz Receiver with an ADS-B Receiving Subsystem	2.4.2.2 Verification of Shared Use of 1090 MHz Receiver with an ADS-B Receiving Subsystem	
2.2.3 Initial Detection of Mode S Targets and Determination of Their Address	2.4.2.3 Verification of Initial Detection of Mode S Targets and Determination of their Addresses	
2.2.4 Use of Extended Squitter Altitude for Determining Target Validity	2.4.2.4 Verification of Use of Extended Squitter Altitude for Determining Target Validity	
2.2.5.1 Acquisition of Standard Mode S Targets	2.4.2.5 Verification of Acquisition and Maintenance of Established Tracks using Active Surveillance	Test 1 – Intruders 1, 2, 3, 4, 5, 6, 7, 8
2.2.5.2 Acquisition of Extended Hybrid Surveillance Targets	2.4.2.5 Verification of Acquisition and Maintenance of Established Tracks using Active Surveillance	Test 4a, 4b
	2.4.2.6 Verification of Maintenance of Established Tracks using Passive Surveillance	Tests 5, 6, 7, 8, 9, 10
2.2.5.2.1 Extended Hybrid Surveillance Traffic Quality Requirements	2.4.2.5 Verification of Acquisition and Maintenance of Established Tracks using Active Surveillance	Test 3a, 3b, 4a, 4b,
	2.4.2.6 Verification of Maintenance of Established Tracks using Passive Surveillance	Tests 5, 6, 7, 8, 9
	2.4.2.7 Verification of Requirements Related to Transitions between Passive and Active Surveillance	Test 4, 3A
2.2.5.2.2 Establishing an Extended Hybrid Surveillance Track	2.4.2.6 Verification of Maintenance of Established Tracks using Passive Surveillance	Test 4
2.2.5.2.3 Extended Hybrid Surveillance Minimum Triggering Level (MTL)	2.4.2.6 Verification of Maintenance of Established Tracks using Passive Surveillance	Test 8, 9
2.2.5.2.4 Determination of Estimated Signal Strength	2.4.2.6 Verification of Maintenance of Established Tracks using Passive Surveillance	Test 12
2.2.6.1.1 Persistence of Active Surveillance	2.4.2.5 Verification of Acquisition and Maintenance of Established Tracks using Active Surveillance	Test 1 – Intruders 1, 2, 3, 7, 8, 9
2.2.6.1.2 Active to Hybrid Surveillance Transition	2.4.2.5 Verification of Acquisition and Maintenance of Established Tracks using Active Surveillance	Test 1 – Intruders 4, 5, 6, 7, 8, 9
	2.4.2.7 Verification of Requirements Related to Transitions between Passive and Active Surveillance	Test 2 – Intruder 3

DO-300A Requirement	Test	Sub Test
2.2.6.1.3 Active to Extended Hybrid Surveillance Transition	See tests for 2.2.7.2.2.1	
2.2.6.1.4 Active Surveillance Region	2.4.2.5 Verification of Acquisition and Maintenance of Established Tracks using Active Surveillance	Test 1 – Intruders 1-7
	2.4.2.6 Verification of Maintenance of Established Tracks using Passive Surveillance	Test 1 – Intruders 1, 2 Test 3 Test 5
	2.4.2.7 Verification of Requirements Related to Transitions between Passive and Active Surveillance	Test 1 – Intruders 1-4 Test 2 – All intruders Test 3 – Intruder 7 Test 4 Test 5
	2.4.2.7 Verification of Requirements Related to Transitions between Passive and Active Surveillance	Test 1 – Intruder 1 Test 2 – Intruder 3
2.2.6.2 Active Surveillance Requirements	2.4.2.5 Verification of Acquisition and Maintenance of Established Tracks using Active Surveillance	Test 1 – Intruders 4-9
	2.4.2.6 Verification of Maintenance of Established Tracks Using Passive Surveillance	Test 1 – Intruder 3 Test 13
	2.4.2.7 Verification of Requirements Related to Transitions between Passive and Active Surveillance	Test 1, Intruder 1 Test 2, Intruder 2
2.2.7.1.1 Persistence of Hybrid Surveillance	2.4.2.7 Verification of Requirements Related to Transitions between Passive and Active Surveillance	Test 1 – All intruders Test 2 – Intruders 1, 2
	2.4.2.6 Verification of Maintenance of Established Tracks Using Passive Surveillance	Test 10
2.2.7.1.2 Hybrid Surveillance Region	2.4.2.7 Verification of Requirements Related to Transitions between Passive and Active Surveillance	Test 2 – Intruders 1, 2 Test 4 Test 5
2.2.7.1.3 Extended Hybrid to Hybrid Surveillance Transitions	2.4.2.7 Verification of Requirements Related to Transitions between Passive and Active Surveillance	Test 4, Intruders 5, 6, 7
2.2.7.2.1 Persistence of Extended Hybrid Surveillance	2.4.2.6 Verification of Maintenance of Established Tracks Using Passive Surveillance	Test 5 Test 10

DO-300A Requirement	Test	Sub Test
2.2.7.2.2.1 Active to Extended Hybrid Surveillance Transition	2.4.2.5 Verification of Acquisition and Maintenance of Established Tracks Using Active Surveillance	Test 2 Test 3a Test 3b Test 4a Test 4b
2.2.7.2.2.2 Hybrid to Extended Hybrid Surveillance Transition	2.4.2.7 Verification of Requirements Related to Transitions between Passive and Active Surveillance	Test 4, Intruder 8
2.2.7.3 Track Updates Using Airborne Position Messages	2.4.2.6 Verification of Maintenance of Established Tracks Using Passive Surveillance	Test 2 – All intruders Test 6 Test 7 Test 15
2.2.7.4 Tracking in the absence of Airborne Position Messages	2.4.2.6 Verification of Maintenance of Established Tracks using Passive Surveillance	Test 2 – Intruders 3, 4 Test 15
	2.4.2.7 Verification of Requirements Related to Transitions between Passive and Active Surveillance	Test 3 – Intruders 1, 5, 6
2.2.7.5 Revalidation	2.4.2.6 Verification of Maintenance of Established Tracks using Passive Surveillance	Test 1 – All intruders Test 11 Test 14
	2.4.2.7 Verification of Requirements Related to Transitions between Passive and Active Surveillance	Test 2 – Intruder 3 Test 3 – Intruders 2-6 Test 3A – Intruders 2, 3 Test 4 – Intruders 6, 7
2.2.7.6 Error Budget Allocated to TCAS for Calculating Slant Range from Positions and Comparing it to TCAS Range	2.4.2.8 Verification of Error Budget in Computing Slant Range from Passive Data	Test 1
	2.4.2.6 Verification of Maintenance of Established Tracks Using Passive Surveillance	Test 10
2.2.8 Determining Whether Own Operating on Surface or Taking Off/Airborne	2.4.2.7 Verification of Requirements Related to Transitions between Passive and Active Surveillance	Test 5
	2.4.2.6 Verification of Maintenance of Established Tracks Using Passive Surveillance	Test 10
2.2.9.1 TYPE Subfield of the ME Field	2.4.2.4	
	2.4.2.6 Verification of Maintenance of Established Tracks using Passive Surveillance	
	2.4.2.7 Verification of Requirements Related to Transitions between Passive and Active Surveillance	

DO-300A Requirement	Test	Sub Test
	2.4.2.10 Verification of DF17 Decoding	
2.2.9.2 Altitude from Airborne Position Message	2.4.2.5 Verification of Acquisition and Maintenance of Established Tracks using Active Surveillance	
	2.4.2.6 Verification of Maintenance of Established Tracks using Passive Surveillance	
	2.4.2.7 Verification of Requirements Related to Transitions between Passive and Active Surveillance	Test 3, Intruder 1 Test 3A, Intruder 1
2.2.9.3 Compact Precision Report (CPR) Format from Airborne Position Message 2.2.9.4 Encoded Latitude from Airborne Position Message 2.2.9.5 Encoded Longitude from Airborne Position Message	2.4.2.6 Verification of Maintenance of Established Tracks using Passive Surveillance 2.4.2.7 Verification of Requirements Related to Transitions between Passive and Active Surveillance 2.4.2.10 Verification of DF17 Decoding	Test 1
2.2.9.6 ADS-B Version Number from Aircraft Operational Status Message 2.2.9.7 Navigation Integrity Code (NIC) from Airborne Position Message 2.2.9.8 Navigation Accuracy Category for Position (NACp) 2.2.9.8.1 NACp from Aircraft Operational Status Message 2.2.9.8.2 NACp from Target State and Status Message 2.2.9.9 Source Integrity Level (SIL) 2.2.9.9.1 SIL from Aircraft Operational Status Message 2.2.9.9.2 SIL from Target State and Status Message 2.2.9.10 System Design Assurance (SDA)	2.4.2.6 Verification of Maintenance of Established Tracks using Passive Surveillance 2.4.2.7 Verification of Requirements Related to Transitions between Passive and Active Surveillance	
2.2.10 Monitoring Requirements		Test 5
2.2.11 Interface to CAS Logic	2.4.2.6 Verification of Maintenance of Established Tracks using Passive Surveillance	Test 10
2.2.13 ADS-B Number of TCAS-equipped Aircraft (NTA)-3/NTA-6 Range Determination of On-ground TCAS Intruders	2.4.2.12 Verification of On-ground TCAS Range Determination Using ADS-B	

2.4.3.1.2 DAA with TCAS II Resolution Advisory Functionality (Equipment Class 2) (§2.2.3.1.2)

Step 1: Verify that the TCAS II system meets the requirements defined in RTCA DO-185B by either analysis of the results from test procedures required by RTCA DO-185B or through a TSO certification.

The reception of TCAS RA data internally to the DAA system is verified as part of the test procedures in Subparagraph 2.4.5.6.

2.4.3.2 DAA Track Processing – Surveillance Data Processing and Tracking Requirements

The verification of some tracker requirements requires the use of specific test vectors, as called out in the respective test procedure. Others, however, will reference the results from simulating the full set of 176 dynamic test vectors (marked with an "LL" in Appendix P). Manufacturers can simulate and score the system's performance for those test vectors once and use the results to verify multiple requirements. Where this is the case, the test procedure refers to the "dynamic set."

The test procedure assumes a tracker implementation similar to the one included as the sample tracker with these MOPS. Since the reference implementation assumes a best-source selection tracker, all 176 test vectors should be run for each sensor type individually (i.e., ADS-B, Mode C, Mode S and radar). Manufacturers using a fusion-type tracker will need to propose changes to the test procedures where the assumption of a single-source tracker limits the procedure's applicability.

Subparagraph 2.2.3.2 does not contain any requirements. No test procedures are required to verify Subparagraph 2.2.3.2.

2.4.3.2.1 Track Management (§2.2.3.2.1)

Step 1: Apply ADS-B track from Test Vector D7, where an intruder with closing speeds of 1200 knots and relative altitude rate of 10,000 fpm converges with the ownship.

Step 2: Verify that the DAA system generated and maintained a track as required by Subparagraph 2.2.3.2.1.

Step 3: Repeat Steps 1 and 2 with the Mode S active surveillance track of Test Vector D7.

Step 4: Repeat Steps 1 and 2 with the Mode C active surveillance track of Test Vector D7.

Step 5: Apply radar track from Test Vector D8, where a non-cooperative target converges on the ownship with a closing speed of 500 kts and an altitude rate of 5,000 fpm converges with the ownship.

Step 6: Verify that the DAA system generated and maintained a track as required by Subparagraph 2.2.3.2.1.

2.4.3.2.1.1 Track Initiation (§2.2.3.2.1.1)

Step 1: Verify, by demonstration or analysis of the results from simulating the 176 dynamic tracks, that the DAA system initiated tracks for ADS-B, ADS-R, Mode S, Mode C, and radar intruders.

Step 2: Verify, by analysis using the 176 dynamic test vectors, that tracks are initiated when the track accuracy is less than 125% of the required track performance (as defined in Table 2-20). Repeat for each sensor type (i.e., ADS-B, Mode C, Mode S and radar).

If track initiation via one of the alerting special cases (i.e., non-altitude or no-bearing) is incorporated, the manufacturer should generate test vectors that demonstrate that this functionality is implemented correctly.

2.4.3.2.1.2 Track Capacity (§2.2.3.2.1.2)

Step 1: Follow the test procedure for Subparagraph 2.4.2.2.2.4.

Step 2: Verify that the tracker maintains 36 tracks.

2.4.3.2.1.3 ADS-B Report Processing and Track Maintenance (§2.2.3.2.1.3)

Test Procedures in Subparagraph 2.4.3.2.1.3.1 through Subparagraph verify this requirement.

2.4.3.2.1.3.1 ADS-B and ADS-R Report Validity Checks (§2.2.3.2.1.3.1)

Subparagraph 3.2.3.1.3.1 of RTCA DO-317B contains an acceptable test procedure for verifying the ADS-B and ADS-R report validity check requirements.

Step 1: Verify, by following the test procedure described in Subparagraph 3.2.3.1.3.1 of RTCA DO-317B, that the DAA system correctly performs report validity checks.

2.4.3.2.1.3.2 Additional ADS-B Velocity Quality Monitoring (§2.2.3.2.1.3.2)

Subparagraph 2.2.3.2.1.3.2 does not contain any requirements. No test procedures are required to verify Subparagraph 2.2.3.2.1.3.2.

2.4.3.2.1.3.3 Duplicate Address Processing (§2.2.3.2.1.3.3)

Subparagraph 2.2.3.2.1.3.3 does not contain any requirements. No test procedures are required to verify Subparagraph 2.2.3.2.1.3.3.

2.4.3.2.1.3.3.1 Duplicate Address Processing for 1090 MHz Systems (§2.2.3.2.1.3.3.1)

Subparagraph 3.2.3.1.3.4 of RTCA DO-317B contains an acceptable test procedure for verifying requirements related to duplicate address processing of 1090MHz ADS-B systems.

Step 1: Verify, by following the test procedure described in Subparagraph 3.2.3.1.3.4 of RTCA DO-317B, that the DAA system correctly processes duplicate addresses for 1090MHz ADS-B systems. Exclude steps related to VDL4.

2.4.3.2.1.3.3.2 Duplicate Address Processing for Optional UAT Systems (§2.2.3.2.1.3.3.2)

Subparagraph 3.2.3.1.3.3 of RTCA DO-317B contains an acceptable test procedure for verifying requirements related to duplicate address processing of UAT ADS-B systems.

Step 1: Verify, by following the test procedure described in Subparagraph 3.2.3.1.3.3 of RTCA DO-317B, that the DAA system correctly processes duplicate addresses for UAT ADS-B systems. Exclude steps related to VDL4.

2.4.3.2.1.3.4 Additional Validation of ADS-B Traffic Position with Active Surveillance or Radar

Step 1: Verify, by demonstration or analysis, that ADS-B data that has been validated by a hybrid surveillance system is considered validated for DAA purposes (note that this does not include validation via extended hybrid surveillance).

Step 2: Verify, by demonstration or analysis, that the DAA system validates ADS-B if a radar or active surveillance track is available. The 176 dynamic tracks can be used as a basis, but in order to verify that the system is designed to always do this, the manufacturer may need to propose additional verification steps specific to the implementation.

Step 3: Verify, by demonstration, that the DAA system marks validated tracks as such.

2.4.3.2.1.3.4.1 Validation of Traffic Position with Active Surveillance (§2.2.3.2.1.3.4.1)

Step 1: Apply the active surveillance and 1090ES ADS-B track of Test Vector D3. Verify that:

- Validation fails between t=20 and t=40. During that time, validation fails due to violation of the slant range condition.
- Validation fails between t=60 and t=80. During that time, validation fails due to violation of the bearing condition while at a range greater than 1 NM
- Validation fails between t=100 and t=120. During that time, validation fails due to violation of the altitude condition.
- Validation fails between t=140 and t=160. During that time, validation fails because the difference in time between the ADS-B surveillance data and the active surveillance data is more than 250 ms.

Subparagraph 2.2.3.2.1.3.4.1 recommends that single validation failures do not result in disqualifying traffic. Test vector D3 is designed such that validation should fail for at least two consecutive validation attempts, assuming a minimum re-validation of every 10 seconds.

Step 2: Verify by, by analysis or demonstration, that validation occurs at least once every 10 seconds.

2.4.3.2.1.3.4.2 Validation of Traffic Position with Radar Data (§2.2.3.2.1.3.4.2)

Repeat the test procedure in Subparagraph 2.4.3.2.1.3.4.1 using the radar and 1090ES ADS-B tracks of Test Vector D3.

2.4.3.2.1.4 Track Termination (§2.2.3.2.1.4)

Step 1: Verify, by analysis using the 176 dynamic test vectors, that tracks are terminated when the track accuracy is exceeds 125% of the required track performance (as defined in Table 2-20) for longer than 8 seconds. Repeat for each sensor type (i.e., ADS-B, Mode C, Mode S and radar).

If track termination via one of the alerting special cases (i.e., non-altitude or no-bearing) is incorporated, the manufacturer should generate test vectors that demonstrate that this functionality is implemented correctly.

2.4.3.2.2 Data Association (§2.2.3.2.2)

Step 1: Verify, by demonstration or analysis, that ADS-B or ADS-R reports are only used for data association once they have passed the report validation checks defined in Sub2.2.3.2.1.3.2.

Step 2: Verify by demonstration or analysis, that data association obtained with an address match takes precedence over other methods of correlation.

Step 3: Verify, by demonstration or analysis, that the DAA system does not associate multiple radar tracks.

Step 4: Verify, by analysis, for the sensor combinations and data association method identified with an "X" in Table 2-35, that the DAA system performance meets the requirements in Subparagraph 2.2.3.2.2. An acceptable means to do this is to use the tracks in Test Vector D5 and degrade the intruder and ownship tracks using the sensor models described in Appendix Q. In order to generate representative performance estimates for data association, the simulation of a given sensor combination needs to be repeated multiple times until the performance metrics converge on a stable number. Each time the test vector is simulated, the error models would be re-sampled to ensure the system's displays robustness against different levels of state errors. Depending on the manufacturer's implementation the test vectors may need to modified in order to force whether the data association occurs based on address or special correlation.

Table 2-35 List of Sensor Combinations

Test Case	Sensor 1	Sensor 2	Sensor 3	Address Matching	Spatial Correlation
1	ADS-B/R	Act. Surv. – Mode S	N/A	X	X
2	ADS-B/R	Act. Surv. – Mode C	N/A	X	X
3	ADS-B/R	Radar	N/A		X
4	Radar	Act. Surv. – Mode S	N/A		X
5	Radar	Act. Surv. – Mode C	N/A		X
6	ADS-B/R	Radar	N/A		X
7	ADS-B/R	Act. Surv. – Mode S	Radar	X	X

2.4.3.2.3 State Estimation (§2.2.3.2.3)

Step 1: Verify, by demonstration or analysis, that the DAA system estimates the track state data.

If the alert state for intruders is determined onboard the UA, the downlink prioritization for intruders is defined in Subparagraph 2.4.4.3.4.1 (prioritization according to display priority). If this is the case, prioritization is verified as part of the test procedure in Subparagraph 2.4.4.3.4.1.

If the alert status is not determined onboard the aircraft, verify, using the truth track of Test Vector D4, that intruder tracks are prioritized according to the prioritization requirements defined in Subparagraph 2.2.3.2.3. Test vector D4 is designed such that this requirement is verified if the intruders are ordered in increasing order; i.e., Intruder 1 should be prioritized highest.

(Verification of altitude I/O requirements is performed as part of the test procedure in Subparagraph 2.4.5.5.)

Step 2: Verify, by analysis using the 176 dynamic test vectors, that the track accuracy output meets the requirements of Table 2-20 95% of the time. Repeat for all sensor types (i.e., ADS-B, Mode C, Mode S and radar), and, if applicable, for all sensor combinations.

Step 3: Verify, by demonstration or analysis, that the DAA tracker provides updates at a rate of at least 1 Hz.

2.4.3.2.3.1 Individual Time of Track Extrapolation and Traffic State File Generation (§2.2.3.2.3.1)

Step 1: Verify, by analysis, that the uncompensated latency introduced by the tracker does not exceed 100 ms. An acceptable methods of demonstrating compliance with this requirement is to compare the tracker output during the simulation of the 176 dynamic encounters. Refer to Appendix E for additional discussion on latency.

2.4.4 DAA Alerting and Guidance Processing Requirements (§2.2.4)

Paragraph 2.2.4 does not contain any requirements. No test procedures are required to verify Paragraph 2.2.4.

2.4.4.1 DAA Alert and Guidance Suppression Requirements (§2.2.4.1)

This test procedure uses Test Vector H1 to trigger an alert. If the signal indicating that the UA is taking off or landing is dependent on specific ownship or intruder states that differ from those provided in Test Vector H1, the manufacturer should provide a suitable test vector.

Step 1: Apply truth track Test Vector H1. Verify that a DAA alert is issued and that guidance information is displayed for the intruder.

Step 2: Restart simulation of H1. At t=10, send a signal (per manufacturer design) to the DAA system that indicates that the ownship is taking off. Maintain the signal for the duration of the test vector.

Step 3: Verify that the DAA alerts are automatically inhibited.

Step 4: Verify that the DAA guidance information is automatically inhibited.

Step 5 Verify that an indication is provided to the display processor that alerts and guidance information are inhibited.

Step 6: Restart simulation of H1. At t=10, send a signal (per manufacturer design) to the DAA system that indicates that the ownship is landing. Maintain the signal for the duration of the test vector.

Step 7: Verify that the DAA alerts are automatically inhibited.

Step 8: Verify that the DAA guidance information is automatically inhibited.

Step 9: Verify that an indication is provided to the display processor that alerts and guidance information are inhibited.

Step 10: Restart simulation of H1. At t=10, send a signal (per manufacturer design) to the DAA system that indicates that the ownship is On-ground.

Step 11: Verify that the DAA alerts are automatically inhibited.

Step 12: Verify that the DAA guidance information is automatically inhibited.

Step 13: Verify that an indication is provided to the display processor that alerts and guidance information are inhibited.

Step 14: Restart simulation of H1. At t=10, send a signal (per manufacturer design) to the DAA system that indicates that the ownship is taking off. Maintain the signal for the duration of the test vector.

Step 15: Manually enable alerts and guidance information.

Step 16: Verify that the DAA alerts are provided.

Step 17: Verify that the DAA guidance information is provided.

Step 18: Restart simulation of H1. At t=10, manually disable alerts.

Step 19: Verify that no DAA alerts are provided.

Step 20: Verify that no DAA guidance information is provided.

2.4.4.1.1 Intruder-Specific Alerting and Guidance Suppression (§2.2.4.1.1)

This procedure verifies that alerts on intruders with an On-ground status are suppressed.

Step 1: Apply the ADS-B track of Test Vector H1. Verify that a DAA alert is issued and that guidance information is displayed for the intruder.

Step 2: Restart simulation of H1. At t=10, mark the intruder's air/ground status to On-ground. Maintain On-ground status for the duration of the test vector.

Step 3: Verify that no DAA alerts are issued for the intruder.

Step 4: Verify that no DAA guidance information is issued for the intruder.

2.4.4.2 Ownship Intent Information Requirements (§2.2.4.2)

If the use of ownship intent is incorporated in the alerting logic, the manufacturer should generate test vectors that demonstrate that this functionality is implemented correctly. The verification should ensure that intent data is used when it will be automatically executed by the UA, and not used when intent data will not be automatically executed or is unavailable.

2.4.4.3 DAA Alerting Requirements (§2.2.4.3)

The verification of some requirements requires the use of specific test vectors, as called out in the respective test procedure. Others, however, will reference the results from simulating the larger set of test vectors; specifically, this set includes the Head-On, Converging, High-Speed, Maneuver, Overtaking and the 176 dynamic test vectors. Manufacturers can simulate and score the system's performance for those test vectors once and use the results to verify multiple requirements. Where this is the case, the test procedure refers to the "batch simulation."

Unless otherwise specified, the tracker output track for a given test vector should be used. The tracker output tracks were generated using the tracker implementation included as the sample tracker with these MOPS. Since the reference implementation assumes a best-source selection tracker, all 176 test vectors must be run for each sensor type individually (i.e., ADS-B, Mode C, Mode S; alerting performance on radar-only intruders is tested separately). Manufacturers using a fusion-type tracker will need to propose changes to the test procedures in cases where the assumption of a single-source tracker limits the procedure's applicability.

For requirements that are statistical in nature (e.g., average alert time), only the set of 176 dynamic encounters will be referenced (referred to as the "dynamic set").

Requirements related to the system's robustness to surveillance errors are verified if the provided test vectors are used to demonstrate compliance as they have been degraded with errors representative of those listed in Table 2-20. If a manufacturer chooses to use test vectors other than those provided with these MOPS, a procedure to verify the system's robustness to surveillance errors must be proposed.

Subparagraph 2.2.4.3 does not contain any requirements. No test procedures are required to verify Subparagraph 2.2.4.3.

2.4.4.3.1 DAA Well Clear (DWC) Definition (§2.2.4.3.1)

Subparagraph 2.2.4.3.1 does not contain any requirements. No test procedures are required to verify Subparagraph 2.2.4.3.1.

2.4.4.3.2 Hazard Zone Definition (§2.2.4.3.2)

Subparagraph 2.2.4.3.2 does not contain any requirements. No test procedures are required to verify Subparagraph 2.2.4.3.2.

2.4.4.3.3 Non-Hazard Zone Definition (§2.2.4.3.3)

Subparagraph 2.2.4.3.3 does not contain any requirements. No test procedures are required to verify Subparagraph 2.2.4.3.3.

2.4.4.3.4 Alert Types and Prioritization (§2.2.4.3.4)

Subparagraph 2.2.4.3.4 does not contain any requirements. No test procedures are required to verify Subparagraph 2.2.4.3.4.

2.4.4.3.4.1 Prioritization of Alert Types (§2.2.4.3.4.1)

Step 1: Verify, by analysis of the results from the batch simulation, that any alerted intruder only had one alert status at any point in time.

Step 2: Verify, by analysis of the results from the batch simulation, that for any alerted intruder that met the criteria of multiple alert levels, that the intruders' alert status was the highest of those alert levels, as listed in Subparagraph 2.2.4.3.4.1.

The following procedure verifies that intruder tracks are correctly prioritized for use by the display:

Step 1: Apply the truth track of Test Vector D9.

Step 2: Verify that intruder tracks are prioritized in the following order:

1. Intruders with an active TCAS II RA
2. Intruders with an active Warning Alert
3. Intruders with an active Corrective Alert

4. Intruders with an active Preventive Alert
5. Intruders with active Guidance Information
6. All Remaining traffic

Step 3: For Class 2 systems, using Test Vector D9, verify that the intruder tracks with TCAS RA status are ordered in the track priority assigned by the TCAS II system.

Step 4: For both Class 1 and Class 2 systems, using Test Vector D9, verify that intruder tracks with the same alert level, that have not been ordered by the TCAS II system, are ordered by increasing horizontal range between the ownship and the intruder.

Step 5: If the prioritization for transmission via the data link uses the display prioritization order, verify, using Test Vector D9, that the tracks are prioritized according to the order defined in Step 1.

Step 6 Verify, by analysis of the results from the batch simulation, that the intruder alert status is updated at a minimum rate of 1 Hz.

2.4.4.3.4.2 Preventive Alert (§2.2.4.3.4.2)

This test procedure verifies the required performance related to preventive alerts in non-special cases. As mentioned in Subparagraph 2.4.4.3, this test procedure (Steps 2-6) should be performed for each sensor type individually.

Step 1 Apply the ADS-B track of Test Vector D17. Verify that no preventive alert precedes a corrective alert. This requirement is verified if the test vector was scored using the encounter characterization files and the system demonstrated passing performance.

Step 2 Using the results from the batch simulation, verify that all preventive alerts are issued according to the late alert requirement outlined in Subparagraph 2.2.4.3.4.2. Appendix P contains a list of which test vectors are to be scored against the 20-second threshold, and which use the alternate threshold. If encounters are scored using the encounter characterization files with passing performance, this requirement is verified.

Step 3: Using all dynamic test vectors, verify that, on average, preventive alerts are issued 55 seconds prior to the intruder violating the hazard zone. If encounters are scored using the encounter characterization files with passing performance, this requirement is verified.

Step 4: For the alerts issued in Step 2, verify that preventive alerts persist for at least 4 seconds, unless the alert level increases within 4 seconds of the alert being first issued.

Step 5 Verify, using the results from the batch simulation, that all alerts are issued according to the early alert requirement outlined in Subparagraph 2.2.4.3.4.2. Appendix P contains a list of which test vectors are to be scored against the 75-second threshold, and which use the alternate threshold. If encounters are scored using the encounter characterization files with passing performance, this requirement is verified.

Step 6: For all non-alerted test vectors in Step 2, verify that no preventive alerts are issued. If encounters are scored using the encounter characterization files with passing performance, this requirement is verified.

2.4.4.3.4.3 Corrective Alert (§2.2.4.3.4.3)

This test procedure verifies the required performance related to corrective alerts in non-special cases. As mentioned in Subparagraph 2.4.4.3, this test procedure should be performed for each sensor type individually.

Step 1 Verify, using the results from the batch simulation, that all corrective alerts are issued according to the late alert requirement outlined in Subparagraph 2.2.4.3.4.3. Appendix P contains a list of which test vectors are to be scored against the 20-second threshold, and which use the alternate threshold. If encounters are scored using the encounter characterization files with passing performance, this requirement is verified.

Step 2: Using all dynamic test vectors, verify that, on average, corrective alerts are issued 55 seconds prior to the intruder violating the hazard zone. If encounters are scored using the encounter characterization files with passing performance, this requirement is verified.

Step 3: For test vectors used in Step 1 and Step 2, verify that corrective alerts persist for at least 4 seconds, unless the alert level increases within 4 seconds of the alert being first issued.

Step 4 Verify, using the results from the batch simulation, that all corrective alerts are issued according to the early alert requirement outlined in Subparagraph 2.2.4.3.4.3. Appendix P contains a list of which test vectors are to be scored against the 75-second threshold, and which use the alternate threshold. If encounters are scored using the encounter characterization files with passing performance, this requirement is verified.

Step 5: For all non-alerted test vectors in Step 1, verify that no corrective alerts are issued. If encounters are scored using the encounter characterization files with passing performance, this requirement is verified.

2.4.4.3.4.4 Warning Alert (§2.2.4.3.4.4)

This test procedure verifies the required performance related to warning alerts in non-special cases. As mentioned in Subparagraph 2.4.4.3, this test procedure should be performed for each sensor type individually.

Step 1 Verify, using the results from the batch simulation, that all warning alerts are issued according to the late alert requirement outlined in Subparagraph 2.2.4.3.4.4. Appendix P contains a list of which test vectors are to be scored against the 15-second threshold, and which use the alternate threshold. If encounters are scored using the encounter characterization files with passing performance, this requirement is verified.

Step 2: Using all dynamic test vectors, verify that, on average, warning alerts are issued 25 seconds prior to the intruder violating the hazard zone. If encounters are scored using the encounter characterization files with passing performance, this requirement is verified.

Step 3: For test vectors used in Step 1 and Step 2, verify that warning alerts persist for at least 4 seconds, unless the alert level increases within 4 seconds of the alert being first issued.

Step 4 Verify, using the results from the batch simulation, that all warning alerts are issued according to the early alert requirement outlined in Subparagraph 2.2.4.3.4.4. Appendix P contains a list of which test vectors are to be scored against the 55-second threshold, and which use the alternate threshold. If encounters are scored using the encounter characterization files with passing performance, this requirement is verified.

Step 5: For all non-alerted test vectors in Step 1, verify that no warning alerts are issued. If encounters are scored using the encounter characterization files with passing performance, this requirement is verified.

2.4.4.3.5 Alerting Special Cases (§2.2.4.3.5)

Subparagraph 2.2.4.3.5 does not contain any requirements. No test procedures are required to verify Subparagraph 2.2.4.3.5.

2.4.4.3.5.1 Alerting Special Cases – Radar Only (§2.2.4.3.5.1)

Subparagraph 2.2.4.3.5.1 does not contain any requirements. No test procedures are required to verify Subparagraph 2.2.4.3.5.1.

2.4.4.3.5.1.1 Radar Only – Preventive (§2.2.4.3.5.1.1)

Step 1: Verify, using the radar track of Test Vector H5, that no preventive alert is issued on the intruder.

2.4.4.3.5.1.2 Radar Only – Corrective (§2.2.4.3.5.1.2)

Step 1: Repeat the test procedure in Subparagraph 2.2.4.3.4.3 but using the radar tracker output tracks for intruders.

Step 2: Verify, using the radar track of Test Vector D6, that no corrective alert is issued on the intruder.

2.4.4.3.5.1.3 Radar Only – Warning (§2.2.4.3.5.1.3)

Step 1: Repeat the test procedure in Subparagraph 2.2.4.3.4.4 but using the radar tracker output tracks for intruders.

Step 2: Verify, using the radar track of Test Vector D6, that no warning alert is issued on the intruder.

2.4.4.3.5.2 No Bearing (§2.2.4.3.5.2)

Subparagraph 2.2.4.3.5.2 does not contain any requirements. No test procedures are required to verify Subparagraph 2.2.4.3.5.2.

2.4.4.3.5.2.1 No Bearing – Preventive (§2.2.4.3.5.2.1)

Step 1 Modify the bearing column of the tracker output of the Mode S active surveillance track of Test Vector H5 to remove all bearing information.

Step 2 Verify, using the modified track from Step 1, that no preventive alert is issued on the intruder.

2.4.4.3.5.2.2 No Bearing – Corrective (§2.2.4.3.5.2.2)

Step 1: Modify the bearing column of the Mode S tracker output of Test Vector H1 to contain no bearing information.

Step 2 Verify, using the track generated in Step 1, that a corrective alert is issued on the intruder as required by the encounter characterization file.

Step 3: Modify the bearing column of the Mode S tracker output of test vectors H9 and C24 to contain no bearing information.

Step 4: Verify, using the tracks generated in Step 3, that no corrective alerts are issued on any intruder.

2.4.4.3.5.2.3 No Bearing – Warning (§2.2.4.3.5.2.3)

Step 1: Modify the bearing column of the Mode S tracker output of Test Vector H1 to contain no bearing information.

Step 2 Verify, using the track generated in Step 1, that a warning alert is issued on the intruder as required by the encounter characterization file.

Step 3: Modify the bearing column of the Mode S tracker output of test vectors H9 and C24 to contain no bearing information.

Step 4: Verify, using the tracks generated in Step 3, that no warning alerts are issued on any intruder.

2.4.4.3.5.3 No Altitude (§2.2.4.3.5.3)

Subparagraph 2.2.4.3.5.3 does not contain any requirements. No test procedures are required to verify Subparagraph 2.2.4.3.5.3.

2.4.4.3.5.3.1 No Altitude – Preventive (§2.2.4.3.5.3.1)

Step 1 Modify the altitude column of the ADS-B tracker output track of Test Vector H5 to remove all altitude information.

Step 2 Verify, using the modified track from Step 1, that no preventive alert is issued on the intruder.

2.4.4.3.5.3.2 No Altitude – Corrective (§2.2.4.3.5.3.2)

Step 1: Modify the altitude column of the ADS-B tracker output track of Test Vector H1 to contain no altitude information.

Step 2 Verify, using the track generated in Step 1, that a corrective alert is issued on the intruder as required by the encounter characterization file.

Step 3 Modify the altitude column of the ADS-B tracker output track of test vectors H9 and C24 to remove all altitude information.

Step 4: Verify, using the tracks generated in Step 3, that no corrective alerts are issued on any intruder.

2.4.4.3.5.3.3 No Altitude – Warning (§2.2.4.3.5.3.3)

Step 1: Modify the altitude column of the ADS-B tracker output track of Test Vector H1 to contain no altitude information.

Step 2 Verify, using the track generated in Step 3, that a warning alert is issued on the intruder as required by the encounter characterization file.

Step 3 Modify the altitude column of the ADS-B tracker output track of test vectors H9 and C24 to remove all altitude information.

Step 4: Verify, using the tracks generated in Step 1, that no warning alerts are issued on any intruder.

2.4.4.4 Guidance Processing Requirements (§2.2.4.4)

Step 1: Verify, by demonstration or analysis, that the guidance processing subfunction provides horizontal guidance information as track or heading angles.

Step 2: Verify, by demonstration or analysis, that the guidance processing subfunction provides vertical guidance information as altitude and, if implemented, vertical rate bands.

Note: *The encounter characterization files provides as part of the test vectors assume a climb rate of 500' for the encoding of the minimum required and maximum allowed guidance information. If the manufacturer uses a different climb or descend rate assumption in the design of the vertical guidance processing subfunction, the altitude data in the encounter characterization files will need to be adjusted accordingly.*

Step 3: Verify, by analysis or by using the results from the batch simulation, that the Guidance Processing subfunction updates its output at no less than 1 Hz.

Step 4: Verify, by analysis or by using the results from the batch simulation, that the Guidance Processing subfunction provides positive guidance information until or unless there is an NMAC.

Step 5: Verify, by demonstration using an existing test vector (chosen by the manufacturer), that guidance information is correctly adjusted when a simulated wind component is introduced to the simulation. An acceptable way of doing this would be to compare the guidance information output of the selected test vector with and without the presence of wind.

Step 6: Verify, by demonstration or analysis, that the guidance processing subfunction accounts for sensor uncertainties.

2.4.4.4.1 DAA Guidance to Maintain DWC (§2.2.4.4.1)

Subparagraph 2.2.4.4.1 does not contain any requirements. No test procedures are required to verify Subparagraph 2.2.4.4.1.

Note*: The term "look-ahead time" used in the following subparagraphs refers to the* tau^{*}_{mod} *values found in Table 2-21.*

2.4.4.4.1.1 Preventive Maneuver Guidance (§2.2.4.4.1.1)

Follow this test procedure only if preventive maneuver guidance is implemented. As mentioned in Subparagraph 2.4.4.3, this test procedure should be performed for each sensor type individually unless instructed otherwise.

Step 1: Verify, by analysis of the results of the batch simulation, that preventive guidance information is issued for maneuvers that would result in the intruder entering the preventive hazard zone prior to the preventive late threshold. If encounters are scored using the encounter characterization files with passing performance, this requirement is verified.

Step 2 Verify, by analysis of the results of the batch simulation, that preventive guidance information is provided at the time a preventive alert is issued for any alerted intruder.

Step 3: Verify, by analysis of the results of the batch simulation, that preventive guidance information is not issued for trajectories that, if captured, would result in the intruder remaining in the preventive non-hazard zone within the look-ahead time. If encounters are scored using the encounter characterization files with passing performance, this requirement is verified.

Step 4: Verify, by analysis of the results of the batch simulation, that preventive guidance information is not issued prior to the preventive hazard zone look-ahead time for trajectories that, if captured, would result in the intruder entering the preventive hazard zone. If encounters are scored using the encounter characterization files with passing performance, this requirement is verified.

2.4.4.4.1.2 Corrective Maneuver Guidance (§2.2.4.4.1.2)

As mentioned in Subparagraph 2.4.4.3, this test procedure should be performed for each sensor type individually unless instructed otherwise.

Step 1: Verify, by analysis of the results of the batch simulation, that corrective guidance information is issued for maneuvers that would result in the intruder entering the corrective hazard zone prior to the corrective late threshold. If encounters are scored using the encounter characterization files with passing performance, this requirement is verified.

Step 2 Verify, by analysis of the results of the batch simulation, that corrective guidance information is provided at the time a corrective alert is issued for any alerted intruder.

Step 3: Verify, by analysis of the results of the batch simulation, that corrective guidance information is not issued for trajectories that, if captured, would result in the intruder remaining in the corrective non-hazard zone within the look-ahead time. If encounters are scored using the encounter characterization files with passing performance, this requirement is verified.

Step 4 If the option to provide preventive guidance information is implemented, verify, by analysis of the results of the batch simulation, that corrective guidance information is prioritized higher than preventive guidance information.

Step 5: Verify, by analysis of the results of the batch simulation, that corrective guidance information is not issued prior to the preventive hazard zone look-ahead time for trajectories that, if captured, would result in the intruder entering the corrective hazard zone. If encounters are scored using the encounter characterization files with passing performance, this requirement is verified.

2.4.4.4.1.3 Warning Maneuver Guidance (§2.2.4.4.1.3)

As mentioned in Subparagraph 2.4.4.3, this test procedure should be performed for each sensor type individually unless instructed otherwise

Step 1: Verify, by analysis of the results of the batch simulation, that warning guidance information is issued for maneuvers that would result in the intruder entering the warning hazard zone prior to the warning late threshold. If encounters are scored using the encounter characterization files with passing performance, this requirement is verified.

Step 2 Verify, by analysis of the results of the batch simulation, that warning guidance information is provided at the time a warning alert is issued for any alerted intruder.

Step 3: Verify, by analysis of the results of the batch simulation, that warning guidance information is not issued for trajectories that, if captured, would result in the intruder remaining in the warning non-hazard zone within the look-ahead time. If encounters are scored using the encounter characterization files with passing performance, this requirement is verified.

Step 4 If the option to provide preventive guidance information is implemented, verify, by analysis of the results of the batch simulation, that warning guidance information is prioritized higher than corrective guidance information.

Step 5: Verify, by analysis of the results of the batch simulation, that warning guidance information is not issued prior to the warning hazard zone look-ahead time for trajectories that, if captured, would result in the intruder entering the warning hazard zone. If encounters are scored using the encounter characterization files with passing performance, this requirement is verified.

Step 6: Modify the validation flag of the ADS-B tracker output track of Test Vector H1, implying that it is an unvalidated ADS-B track.

Step 7 Verify, using the modified track from Step 6, that no warning-level alerts or guidance information are issued on the intruder.

2.4.4.4.2 DAA Guidance to Regain DWC (§2.2.4.4.2)

As mentioned in Subparagraph 2.4.4.3, this test procedure should be performed for each sensor type individually unless instructed otherwise.

Step 1: Verify, by analysis of the results of the batch simulation, that for encounters where well clear is lost, that guidance to regain well clear is provided no later than when the loss of well clear first occurs, and no earlier than when a warning alert is first required.

Step 2: Verify, by analysis of the results of the batch simulation, that for encounters where providing guidance to regain well clear is required, that the guidance is provided continuously until well clear is regained.

Step 3: Repeat Steps 6 and 7 of the test procedure in Subparagraph 2.4.4.4.1.3. For Step 7, verify that no guidance to regain well clear is displayed.

Step 4: Verify, by analysis of the results of the batch simulation, that for encounters where providing guidance to regain well clear is required, that the provided horizontal guidance increases predicted horizontal separation at the CPA. If encounters are scored using the encounter characterization files with passing performance, this requirement is verified.

Step 5: Verify, by using the results of applying the ADS-B tracker output track of Test Vector D11, that horizontal DAA guidance to regain well clear is modified such that a secondary intruders will enter the hazard zone within 15 seconds. If encounters are scored using the encounter characterization files with passing performance, this requirement is verified.

Step 6: Verify, by using the results of applying the ADS-B tracker output track of Test Vector D12, that horizontal DAA guidance to regain well clear is modified such that the predicted separation for all intruder is greater than 4,000’ at the CPA If encounters are scored using the encounter characterization files with passing performance, this requirement is verified.

Step 7: Verify, by analysis of the results of the batch simulation, that for encounters where providing horizontal guidance to regain well clear is required, that once guidance is displayed, it does not reverse to the other side of the ownship’s heading.

Step 8: Verify, by analysis of the results of the batch simulation, that for encounters where providing horizontal guidance to regain well clear is required, that the width of the provided guidance is no less than 10 degrees.

Step 9: Verify, by analysis of the results of the batch simulation, that for encounters where providing horizontal guidance to regain well clear is required, that the width of the provided guidance information is no more than 90 degrees. If encounters are scored using the encounter characterization files with passing performance, this requirement is verified.

Step 10: Verify, by analysis of the results of the batch simulation, that for encounters where providing guidance to regain well clear is required, that the provided vertical guidance increases predicted horizontal separation at the CPA. If encounters are scored using the encounter characterization files with passing performance, this requirement is verified.

Step 11: Verify, by using the results of applying the ADS-B tracker output track of Test Vector D13, that vertical DAA guidance to regain well clear is modified such that a secondary intruders will enter the hazard zone within 15 seconds. If encounters are scored using the encounter characterization files with passing performance, this requirement is verified.

Step 12: Verify, by using the results of applying the ADS-B tracker output track of Test Vector D14, that vertical DAA guidance to regain well clear is modified such that the predicted separation for all intruder is greater than 450’ at the CPA If encounters are scored using the encounter characterization files with passing performance, this requirement is verified.

Step 13: Verify, by analysis of the results of the batch simulation, that for encounters where providing vertical guidance to regain well clear is required, that once guidance information is displayed, it does not reverse to the other side of the ownship’s heading.

Step 14: Verify, by analysis of the results of the batch simulation, that for encounters where providing altitude guidance to regain well clear is required, that the width of the provided guidance is at least 300’.

Step 15: Verify, by analysis of the results of the batch simulation, that for encounters where providing vertical rate guidance to regain well clear is required, that the width of the provided guidance is at least 500 fpm.

2.4.4.4.3 Guidance Processing for an MTE with a Corrective RA and DAA Warning Alert – Class 2

Step 1: Apply the ADS-B tracker output tracks of Test Vector D15 for both intruders. Note the alert state for the two intruders; Intruder 1 is causing a corrective RA and Intruder 2 is causing warning guidance and alerting.

Step 2 Verify, by using the results of Test Vector D15, that the provided horizontal DAA guidance to maintain well clear increases the predicted separation at the CPA for intruders causing corrective RAs. If encounters are scored using the encounter characterization files with passing performance, this requirement is verified.

Step 3 Verify, by using the results of Test Vector D15, that the provided horizontal DAA guidance does not cause intruders that are not causing corrective RAs to enter into the warning non-hazard zone within the next 15 seconds. If encounters are scored using the encounter characterization files with passing performance, this requirement is verified.

Step 4: Apply the ADS-B tracker output tracks of Test Vector D16 for both intruders. Note the alert state for the two intruders; Intruder 1 is causing a corrective RA and Intruder 2 is causing well clear recovery guidance.

Step 5 Verify, by using the results of Test Vector D16, that the provided horizontal DAA guidance to regain well clear increases the predicted separation at the CPA for intruders causing corrective RAs. If encounters are scored using the encounter characterization files with passing performance, this requirement is verified.

Step 6 Verify, by using the results of Test Vector D16, that the provided horizontal DAA guidance to regain well clear does not cause intruders that are not causing corrective RAs to enter into the warning non-hazard zone within the next 15 seconds. If encounters are scored using the encounter characterization files with passing performance, this requirement is verified.

2.4.4.4.4 Guidance Processing – Special Cases (§2.2.4.4.4)

Subparagraph 2.2.4.4.4 does not contain any requirements. No test procedures are required to verify Subparagraph 2.2.4.4.4.

2.4.4.4.4.1 Special Cases – Maintain DAA Well Clear (§2.2.4.4.4.1)

Subparagraph 2.2.4.4.4.1 does not contain any requirements. No test procedures are required to verify Subparagraph 2.2.4.4.4.1.

2.4.4.4.4.1.1 Radar Only Special Case (§2.2.4.4.4.1.1)

Subparagraph 2.2.4.4.4.1.1 does not contain any requirements. No test procedures are required to verify Subparagraph 2.2.4.4.4.1.1.

2.4.4.4.4.1.1.1 Preventive Maneuver Guidance – Radar Only (§2.2.4.4.4.1.1.1)

Step 1: Verify, using the tracker output file for the radar track of Test Vector H5, that no preventive guidance information is issued on the intruder.

2.4.4.4.4.1.1.2 Corrective Maneuver Guidance – Radar Only (§2.2.4.4.4.1.1.2)

Step 1: Verify, using the tracker output file for the radar track of Test Vector D6, that no corrective guidance information is issued on the intruder.

Step 2: Verify, using the tracker output file for the radar track of Test Vector H1, that corrective guidance information is provided for all vertical maneuvers.

Note *An alternate way of meeting this requirement is to calculate the vertical guidance information using a VMOD of 4000' for the Non-Hazard Zone. If this method is used, the manufacturer should generate a test that demonstrates that this functionality is implemented correctly.*

2.4.4.4.4.1.1.3 Warning Maneuver Guidance – Radar Only (§2.2.4.4.4.1.1.3)

Step 1: Verify, using the tracker output file for the radar track of Test Vector D6, that no warning guidance information is issued on the intruder.

Step 2: Verify, using the tracker output file for the radar track of Test Vector H1, that warning guidance information is provided for all vertical maneuvers.

2.4.4.4.4.1.2 No Bearing Special Case (§2.2.4.4.4.1.2)

Subparagraph 2.2.4.4.4.1.2 does not contain any requirements. No test procedures are required to verify Subparagraph 2.2.4.4.4.1.2

2.4.4.4.4.1.2.1 Preventive Maneuver Guidance – No Bearing (§2.2.4.4.4.1.2.1)

Step 1 Modify the bearing column of the tracker output file for the active surveillance track of Test Vector H5 to remove all bearing information.

Step 2 Verify, using the modified track from Step 1, that no preventive guidance information is issued on the intruder.

2.4.4.4.4.1.2.2 Corrective Maneuver Guidance – No Bearing (§2.2.4.4.4.1.2.2)

Step 1 Modify the bearing column of the tracker output file for the active surveillance track of Test Vector H1 to remove all bearing information.

Step 2 Verify, using the modified track from Step 1, that the DAA system produces corrective guidance information for all ranges of horizontal maneuvers.

Step 3: Verify that the vertical corrective guidance information is provided as required by the characterization file for the non-modified version of Test Vector H1.

2.4.4.4.4.1.2.3 Warning Maneuver Guidance – No Bearing (§2.2.4.4.4.1.2.3)

Step 1 Modify the bearing column of the tracker output file for the active surveillance track of Test Vector H1 to remove all bearing information.

Step 2 Verify, using the modified track from Step 1, that the DAA system produces warning guidance information for all ranges of horizontal maneuvers.

Step 3: Verify that the vertical warning guidance information is provided as required by the characterization file for the non-modified version of Test Vector H1.

2.4.4.4.4.1.3 No Altitude Special Case (§2.2.4.4.4.1.3)

Subparagraph 2.2.4.4.4.1.3 does not contain any requirements. No test procedures are required to verify Subparagraph 2.2.4.4.4.1.3.

2.4.4.4.4.1.3.1 Preventive Maneuver Guidance – No Altitude (§2.2.4.4.4.1.3.1)

Step 1 Modify the altitude column of the tracker output file for the 1090ES ADS-B track of Test Vector H5 to remove all altitude information.

Step 2 Verify, using the modified track from Step 1, that no preventive guidance information is issued on the intruder.

2.4.4.4.4.1.3.2 Corrective Maneuver Guidance – No Altitude (§2.2.4.4.4.1.3.2)

Step 1 Modify the altitude column of the tracker output file for the active surveillance track of Test Vector H1 to remove all altitude information.

Step 2 Verify, using the modified track from Step 1, that the DAA system produces corrective guidance information for all ranges of vertical maneuvers.

Step 3: Verify that the horizontal corrective guidance information is provided as required by the characterization file for the non-modified version of Test Vector H1.

2.4.4.4.4.1.3.3 Warning Maneuver Guidance – No Altitude (§2.2.4.4.4.1.3.3)

Step 1 Modify the altitude column of the tracker output file for the active surveillance track of Test Vector H1 to remove all altitude information.

Step 2 Verify, using the modified track from Step 1, that the DAA system produces warning guidance information for all ranges of vertical maneuvers.

Step 3: Verify that the horizontal warning guidance information is provided as required by the characterization file for the non-modified version of Test Vector H1.

2.4.4.4.4.2 Special Cases – Regain DAA Well Clear (§2.2.4.4.4.2)

Subparagraph 2.2.4.4.4.2 does not contain any requirements. No test procedures are required to verify Subparagraph 2.2.4.4.4.2.

2.4.4.4.4.2.1 Radar Only Special Case (§2.2.4.4.4.2.1)

Step 1: Verify, using the radar track of Test Vector D10, that guidance to regain well clear is not provided before t = 100 s. After t = 100 s, only horizontal DAA guidance information should be provided. From t = 100 s to the end of the test vector the envelope of projected uncertainty exceeds the expected separation at the CPA.

2.4.4.4.4.2.2 No Bearing Special Case (§2.2.4.4.4.2.2)

Step 1 Modify the bearing column of the tracker output file for the active surveillance track of Test Vector H1 to remove all bearing information.

Step 2 Verify, using the modified track from Step 1, that the DAA system only produces vertical guidance information to regain well clear.

2.4.4.4.4.2.3 No Altitude Special Case (§2.2.4.4.4.2.3)

Step 1 Modify the altitude column of the tracker output file for the active surveillance track of Test Vector H1 to remove all altitude information.

Step 2 Verify, using the modified track from Step 1, that the DAA system only produces horizontal guidance information to regain well clear.

2.4.4.5 Guidance Collision Avoidance Interoperability Requirements (§2.2.4.5)

Subparagraph 2.2.4.5 does not contain any requirements. No test procedures are required to verify Subparagraph 2.2.4.5.

2.4.4.5.1 Class 2 CA RA Guidance (§2.2.4.5.1)

The following test procedure only applies to Class 2 systems.

Step 1: Apply the ADS-B tracker output file of Test Vector H1.

Step 2: At t = 175, simulate the arrival of a "Do Not Descend" RA.

Step 3: Verify that vertical DAA guidance information is consistent with active Preventive RA information.

Step 4: Repeat Steps 1-3 for all eight preventive RA types

Step 5: Re-apply the ADS-B tracker output file of Test Vector H1.

Step 6: At t = 175, simulate the arrival of a "Climb" RA.

Step 7: Verify that DAA altitude guidance information is inhibited for the duration of the Corrective RA.

Step 8: Verify that horizontal DAA guidance information is provided consistently throughout the Preventive RA.

Step 9: Repeat Steps 5-8 for all sixteen corrective RA types.

Note: *If vertical velocity guidance information is provided as part of the DAA guidance information, the manufacturer should generate test vectors that demonstrate that the vertical velocity guidance information is consistent with active Corrective RA.*

2.4.4.5.2 Vertical DAA Guidance (§2.2.4.5.2)

Subparagraph 2.2.4.5.2 does not contain any requirements. No test procedures are required to verify Subparagraph 2.2.4.5.2.

2.4.4.5.2.1 Determining Intruders' Vertical RA Capability (§2.2.4.5.2.1)

Step 1: Apply the Mode S tracker output file of Test Vector H1.

Step 2: Compel, either by simulation or by actual manipulation, the intruder to send DF=0 and DF=16 replies with the RI field equal to 3.

Step 3: Verify that the DAA system registers that the intruder is capable of vertical RAs.

Step 4: Compel, either by simulation or by actual manipulation, the intruder to send DF=0 and DF=16 replies with the RI field equal to 4.

Step 5: Verify that the DAA system registers that the intruder is capable of vertical RAs.

2.4.4.5.2.2 Determining Intruders' VRC Information (§2.2.4.5.2.2)

Step 1: For a Class 2 DAA system with TCAS II in RA mode, compel, either by simulation or by actual manipulation, the intruder to send through an RA-capable CA system, a UF=16 interrogation, with the VRC=1 within the MU field, addressed to the ownship Mode S address.

Step 2: Verify that the DAA system registers the intruder VRC of "Do not pass below."

Step 3: For a Class 2 DAA system with TCAS II in RA mode, compel, either by simulation or by actual manipulation, the intruder to send through an RA-capable CA system, a UF=16 interrogation, with the VRC=2 within the MU field, addressed to the ownship Mode S address.

Step 4: Verify that the DAA system registers the intruder VRC of "Do not pass above."

Step 5: For a Class 2 DAA system with TCAS II in RA mode, compel, either by simulation or by actual manipulation, the intruder to send through an RA-capable CA system, a UF=16 interrogation, VRC=0 within the MU field, addressed to the ownship Mode S address.

Step 6: Verify that the DAA system registers the intruder VRC of "None."

Step 7: For a Class 1 DAA system or a Class 2 DAA system with TCAS II not in RA mode, compel, either by simulation or by actual manipulation, the intruder to send through active surveillance, a UF=16 interrogation, VRC=1 within the MU field, addressed to the ownship Mode S address.

Step 8: Verify that the DAA system registers the intruder VRC of "Do not pass below."

Step 9: For a Class 1 DAA system or a Class 2 DAA system with TCAS II not in RA mode, compel, either by simulation or by actual manipulation, the intruder to send through active surveillance, a UF=16 interrogation, VRC=2 within the MU field, addressed to the ownship Mode S address.

Step 10: Verify that the DAA system registers the intruder VRC of "Do not pass above."

Step 11: Compel, either by simulation or by actual manipulation, the intruder to send ADS-B operational coordination message (DF=17, Type Code 28, Subtype 3) equal to 1, with the traffic Mode S address equal to the ownship Mode S address.

Step 12: Verify that the DAA system registers the intruder VRC of "Do not pass below."

Step 13: Compel, either by simulation or by actual manipulation, the intruder to send an ADS-B operational coordination message (DF=17, Type Code 28, Subtype 3) equal to 2, with the traffic Mode S address equal to the ownship Mode S address.

Step 14: Verify that the DAA system registers the intruder VRC of "Do not pass above."

Step 15: For an intruder broadcasting in compliance with RTCA DO-260B ADS-B Out, compel, either by simulation or by actual manipulation, the intruder to send a 1090ES TCAS II RA broadcast message (DF=17, Type Code 28, Subtype 002) with TID equal to the ownship Mode S address, MTE=0, and TTI = 1, with Bit 43 equal to 0.

Step 16: Verify that the DAA system registers the intruder VRC of "Do not pass above."

Step 17: For an intruder broadcasting in compliance with RTCA DO-260B ADS-B Out, compel, either by simulation or by actual manipulation, the intruder to send a 1090ES TCAS II RA broadcast message (DF=17, Type Code 28, Subtype 002) with TID equal to the ownship Mode S address, MTE=0, and TTI = 1, with Bit 43 equal to 1.

Step 18: Verify that the DAA system registers the intruder VRC of "Do not pass below."

Step 19: For an intruder broadcasting in compliance with RTCA DO-260B ADS-B Out, compel, either by simulation or by actual manipulation, ADS-B messages to be sent, but without RA broadcast messages.

Step 20: Verify that the DAA system registers the intruder VRC of "None."

Step 21: Compel, either by simulation or by actual manipulation, an encounter with an RA-capable aircraft that is not broadcasting in compliance with the requirements of Subparagraph 2.4.4.5.2.

Step 22: Verify that the DAA system determines that the VRC remains unknown.

2.4.4.5.2.3 Vertical DAA Guidance Modification (§2.2.4.5.2.3)

Step 1: Compel, either by simulation or by actual manipulation, an encounter with a vertical RA-capable intruder broadcasting a VRC of "Do not pass above" that generates corrective guidance information.

Step 2: Verify that the DAA system provides corrective guidance information for vertical velocities greater than 0 fpm and altitudes above the current altitude.

Step 3: Compel, either by simulation or by actual manipulation, an encounter with a vertical RA-capable intruder broadcasting a VRC of "Do not pass above" that generates warning guidance information.

Step 4: Verify that the DAA system provides warning guidance information for vertical velocities greater than 0 fpm and altitudes above the current altitude.

Step 5: Compel, either by simulation or by actual manipulation, an encounter with a vertical RA-capable intruder broadcasting a VRC of "Do not pass below" that generates corrective guidance information.

Step 6: Verify that the DAA system provides corrective guidance information for vertical velocities less than 0 fpm and altitudes below the current altitude.

Step 7: Compel, either by simulation or by actual manipulation, an encounter with a vertical RA-capable intruder broadcasting a VRC of "Do not pass below" that generates warning guidance information.

Step 8: Verify that the DAA system provides warning guidance information for vertical velocities less than 0 fpm and altitudes below the current altitude.

Step 9: Compel, either by simulation or by actual manipulation, an encounter with a vertical RA-capable intruder broadcasting a VRC of "Unknown" that generates corrective guidance information.

Step 10: Verify that the DAA system provides corrective guidance information for all altitudes and vertical velocities outside of the current vertical velocity ±500 ft.

Step 11: Compel, either by simulation or by actual manipulation, an encounter with a vertical RA-capable intruder broadcasting a VRC of "Unknown" that generates warning guidance information.

Step 12: Verify that the DAA system provides warning guidance information for all altitudes and vertical velocities outside of the current vertical velocity ±500 ft.

Step 13: Verify, that during Step 10 and Step 12, the vertical velocity used to provide vertical velocity guidance is the vertical velocity when the VRC is first received.

Step 14: Compel, either by simulation or by actual manipulation, an encounter with a vertical RA-capable intruder within the CA region where the VRC is unknown.

Step 15: Verify that the DAA system removes all vertical guidance based on absolute or relative altitude.

2.4.4.5.3 Horizontal DAA Guidance (§2.2.4.5.3)

Step 1: For a horizontal RA-capable intruder being tracked by an RA-capable CA system, compel, either by simulation or by actual manipulation, the intruder to send a UF=16 interrogation, with the MU field equal to 1, addressed to the ownship Mode S address.

Step 2: Verify that the DAA system registers the horizontal complement of "Do not turn left."

Step 3: Repeat Step 1 with the MU field set to 5.

Step 4: Verify that the DAA system registers the horizontal complement of "Do not turn left."

Step 5: For a horizontal RA-capable intruder being tracked by active surveillance, compel, either by simulation or by actual manipulation, the intruder to send a UF=16 interrogation, with the MU field equal to 2, addressed to the ownship Mode S address.

Step 6: Verify that the DAA system registers the horizontal complement of "Do not turn right."

Step 7: Repeat Step 5 with the MU field set to 6.

Step 8: Verify that the DAA system registers the horizontal complement of "Do not turn right."

Step 9: For a horizontal RA-capable intruder broadcasting in compliance with future versions of RTCA DO-260C, compel, either by simulation or by actual manipulation, the intruder to send an ADS-B Operational Coordination Message (DF=17, Type Code 28, Subtype 3), with the traffic Mode S address equal to the ownship Mode S address and the HRC field equal 1.

Step 10: Verify that the DAA system registers the horizontal complement of "Do not turn left."

Step 11 Compel, either by simulation or by actual manipulation, an encounter with a horizontal RA-capable intruder broadcasting an HRC of "Do not turn right" that generates corrective guidance.

Step 12: Verify that the DAA system provides corrective guidance information for relative headings of +1 to +180 degrees from the current heading.

Step 13 Compel, either by simulation or by actual manipulation, an encounter with a horizontal RA-capable intruder broadcasting an HRC of "Do not turn right" that generates warning guidance.

Step 14: Verify that the DAA system provides warning guidance information for relative headings of +1 to +180 degrees from the current heading.

Step 15 Compel, either by simulation or by actual manipulation, an encounter with a horizontal RA-capable intruder broadcasting an HRC of "Do not turn left" that generates corrective guidance.

Step 16: Verify that the DAA system provides corrective guidance information for relative headings of -1 to -180 degrees from the current heading.

Step 17 Compel, either by simulation or by actual manipulation, an encounter with a horizontal RA-capable intruder broadcasting an HRC of "Do not turn left" that generates warning guidance.

Step 18: Verify that the DAA system provides warning guidance information for relative headings of -1 to -180 degrees from the current heading.

2.4.5 DAA Traffic Display Subsystem Requirements (§2.2.5)

The tests described in this paragraph provide a means to verify whether the required functions of the DAA traffic display equipment are properly included in a manufacturer's implementation. The verification procedures are designed as bench tests to provide a laboratory means of demonstrating compliance with the requirements specified in Paragraph 2.2.5 of these MOPS.

With the exception of the seven subparagraphs listed immediately below, in order to conduct these bench tests, manufacturers must, at a minimum, have the ability to input simulated DAA messages regarding the ownship and traffic elements into the actual DAA traffic display being considered for the MOPS. The manufacturer must also be capable of setting the DAA messages to valid or invalid.

The following subparagraphs require additional, actual system components to satisfy the test conditions. (Refer to Figure 1-3 for a depiction of the DAA system components.)

1. **DAA Traffic Display Latency** (2.4.5.1.2.4) – requires that both the DAA traffic display and-the CS DAA processor be powered up and connected
2. **DAA Aural Alerts** (2.4.5.3.2) – requires the DAA aural alerting system be powered up and connected to the DAA traffic display
3. **System Status** (2.4.5.7) – requires that all DAA components be powered up and connected to the DAA traffic display
4. **Multifunction Display** (2.4.5.8) – requires DAA traffic display as well as the multifunction display of which the DAA traffic display is a part
5. **DAA Traffic Display Alert and Guidance Suppression** (2.4.5.11) – requires the DAA traffic display be configured to receive flight status messages
6. **DAA Guidance to Maintain and Regain DWC** (2.4.5.5) – Test 2 requires that intruder data is simulated as a measurement from all available surveillance sources (e.g., ADS-B receiver, active surveillance, radar system) and processed through all the required DAA subsystems as shown in Figure 2-2. This is to allow for I/O requirements from Paragraph 2.2.2 to be verified.
7. **TCAS II Resolution Advisory Guidance for Integrated Systems** (2.4.5.6) – Test 2 requires that, at a minimum, intruder data is simulated as a measurement from a TCAS II system and is processed through all the required DAA subsystems as shown in Figure 2-2. This is to allow for I/O requirements from Paragraph 2.2.2 to be verified.

2.4.5.1 General Characteristics

2.4.5.1.1 Ownship

2.4.5.1.1.1 Ownship Symbol – General

Requirements tested: 303, 309, 310, 311

Purpose

This test verifies that the traffic display information includes a distinct reference symbol to represent the location of the ownship when ownship position information is valid. When it is not valid, the DAA traffic display produces an indication that the DAA system is operating in a degraded mode.

Conditions

The test requires that the DAA traffic display be powered up and configured such that it can receive and display DAA system messages. If the display provides multiple, pilot-selectable modes, this test needs to be completed for each available display mode. During the test, at least one traffic element classified as nearby traffic needs to be displayed.

In the first part of the test, information regarding the location of the ownship and nearby traffic needs to be entered into the DAA traffic display. In the second part of the test, position information regarding the ownship will be removed from the DAA traffic display.

Verify

1. When ownship position is valid, the DAA display shows a symbol representing ownship location. (303, 309)
2. The ownship symbol is distinct from nearby traffic. (311)
3. When ownship position information is not available, the DAA traffic display indicates that it is in a degraded mode with a message such as “Ownship Data Quality Failure/Degraded DAA Mode” or “Ownship Nav Position Failure/Degraded DAA Mode.” (310)

2.4.5.1.1.2 Ownship Symbol – Directionality

Requirement tested: 312

Purpose

This test verifies that the ownship symbol is directional when the directionality information is valid and non-directional when directionality information is not valid.

Conditions

The test requires that the DAA traffic display be powered up and configured such that it can receive and display DAA system messages. The DAA traffic display also needs to be capable of receiving information regarding direction of the ownship and whether ownship directional information is valid.

To begin, enter ownship position and directional information into DAA display. Then modify directional information regarding the ownship. In the final part of the test, set the ownship directionality information to invalid. If the display provides multiple, pilot-selectable modes, this test needs to be completed for each available display mode.

Verify

1. The ownship symbol on DAA traffic display is directional (e.g., an arrowhead shape) when directionality information is valid. (312)
2. In case of North Up display orientation, the ownship symbol directionality accurately reflects updates to its direction information. (312)
3. The ownship symbol on the DAA traffic display is non-directional (e.g., a circle or square) when directionality information is invalid. (312)

2.4.5.1.1.3 Ownship Symbol – Display Orientation

Requirements tested: 402, 403, 404

Purpose

This test verifies that the DAA traffic display is capable of displaying the same orientations as other navigation displays in the CS and correctly indicates its current orientation to the pilot.

Conditions

The test requires that the DAA traffic display be powered up and configured such that it can receive and display DAA system messages. The DAA traffic display also needs to be capable of receiving information regarding the position and direction of the ownship and position and direction information of at least one nearby traffic element.

To begin, set display orientation to one of the available orientation modes (e.g., North-up, track-up, heading-up) and enter ownship position and direction information into the DAA traffic display. Then repeat for all available orientation modes.

Note: *In accomplishing this test, multiple heading inputs should be used to ensure the own aircraft symbol and the nearby traffic are properly oriented.*

Verify

1. If CS implements a north-up orientation mode, the front of the ownship symbol is oriented in the direction of the aircraft's track when the DAA traffic display is also in north-up orientation. (402)
2. If CS implements a heading-up orientation mode, the front of the ownship symbol is oriented toward the top of the display when the DAA traffic display is also in heading-up mode. (402)
3. If CS implements a track-up orientation mode, the front of the ownship symbol is oriented toward the top of the display when the DAA traffic display is also in a track-up orientation mode. (402)
4. The DAA traffic display indicates which orientation mode (e.g., North-up, track-up, heading-up) is currently being displayed. (403)
5. The symbols for nearby traffic elements are properly positioned and oriented in each available orientation mode relative to the ownship. (404)

2.4.5.1.2 Traffic Display Criteria

Requirements tested: 300, 301, 336

Purpose

This test verifies that the DAA traffic display correctly shows all traffic causing DAA alerts or TCAS II RAs, as well as all nearby intruders, subject to the maximum number of traffic elements that can be displayed.

Test 1a Conditions

The first test is intended to ensure that alerted aircraft are displayed on the DAA traffic display and that all nearby traffic is visible as well.

Note: *All tests in this subparagraph assume the display is meeting, but not surpassing, requirement 351, which states that the display must be capable of displaying the eight highest-priority traffic elements.)*

This test requires that the DAA traffic display be powered up and configured such that it can receive and display DAA system messages and, if the ownship is equipped with TCAS II, TCAS II system messages. The DAA traffic display needs to be capable of receiving information regarding position and direction of the ownship and position and direction information of nearby traffic elements. To begin the test, enter ownship position and direction into the system. Then provide the DAA traffic display with valid position and directional information for eight traffic elements. All eight traffic elements need to be within ±4000’ relative altitude and 6 NM of the ownship, covering all four quadrants (to the left, front, back, and right of the ownship). The traffic element closest to the ownship should be positioned such that it generates a DAA alert. After 30 seconds in an alert state, the traffic element should be positioned so that it no longer generates a DAA alert. Finally, for TCAS II equipped systems, change position of the next closest traffic element such that a TCAS II RA alert is generated in the DAA display. If the display provides multiple, pilot-selectable modes, this test needs to be completed for each available display mode.

Test 1a Verify

1. When DAA alert is generated, the traffic element causing the alert is displayed on the DAA traffic display. (300)
2. When TCAS II RA is generated, the traffic element causing the alert is displayed on the DAA traffic display. (300)
3. When the DAA or TCAS II alert is generated, all eight traffic elements within ±4000’ and 6 NM from the ownship are shown within the DAA traffic display. (301)

Test 1b Conditions

This test is intended to be a stressing condition, such that more than the maximum number of traffic elements (8) are within ±4000’ and 6 NM from the ownship. To begin this portion of the test, enter position and direction of the ownship. Then enter sixteen traffic elements within ±4000’ and 6 NM and at all four quadrants around the ownship. The traffic element closest to the ownship should be positioned such that it generates a DAA alert. After 30 seconds of alert status, reposition intruder such that it no longer generates a DAA alert. Then, for ownship systems equipped with TCAS II, change position of the next closest traffic element such that it generates a TCAS II RA alert on the ownship DAA display. If the display provides multiple, pilot-selectable modes, this test needs to be completed for each available display mode.

Test 1b Verify

1. When the DAA alert is generated, the eight highest-priority traffic elements within ±4000’ and 6 NM from the ownship are shown within the DAA traffic display. (301)
2. When the TCAS II alert is generated, the eight highest-priority traffic elements within ±4000’ and 6 NM from the ownship are shown within the DAA traffic display. (301)

Test 1c Conditions

This test is intended to be a further stressing condition to ensure that the nearby relevant traffic is displayed during a DAA alert or TCAS II RA, even when decluttering has been enabled by the pilot. To begin this portion of the test, enter position and direction of the ownship. Then enter position and direction of eight traffic elements not in alert status within ±4000’ and 6 NM and at all four directions around the ownship. Enable the decluttering function such that all traffic not currently in a DAA or TCAS II alert status are removed from the display (i.e., no alerted traffic is visible). Then the traffic element closest to the ownship should be positioned such that it generates a DAA alert. After 30 seconds of alert status, reposition the intruder such that it no longer generates a DAA alert. Then, for ownship systems equipped with TCAS II, change position of the next closest traffic element such that it generates a TCAS II RA alert on the ownship DAA display. If the display provides multiple, pilot-selectable modes, this test needs to be completed for each available display mode.

Test 1c Verify

1. When the decluttering function is on and there are no active DAA or TCAS II alerts, no aircraft are visible on the DAA traffic display. (301)
2. When the decluttering function is on and a DAA alert is generated, all eight aircraft are visible on the DAA traffic display. (301)
3. When the decluttering function is on and a TCAS II RA is generated, all eight aircraft are visible on the DAA traffic display. (301)

Test 1d Conditions

This test is intended to be a stressing condition, where multiple alerts are active simultaneously and are positioned outside the minimum TDC of ±4000' and 6 NM from the ownship. This test requires that the DAA traffic display be powered up and configured such that it can receive and display DAA system messages and, if the ownship is equipped with TCAS II, TCAS II system messages. The DAA traffic display receives information regarding position and direction of the ownship and position and direction information of nearby traffic elements. To begin the test, enter the ownship position and direction into the system. Set the TDC to maximum horizontal and vertical range.

Enter into the display four guidance traffic priority intruders outside ±4000' and 6 NM from the ownship, but within the maximum altitude and range that the DAA traffic display is capable of representing (i.e., Intruders 1-4, with Intruder 1 closest to the ownship). Enter into the display four additional guidance traffic priority intruders within ±4000' and 6 NM (i.e., Intruders 5-8). (Note: this is assuming an eight-element maximum display; this needs to be scaled appropriately for the display maximum of the system under test.) Then enter one additional remaining traffic priority intruder (lowest priority) within ±4000' and 6 NM (i.e., Intruder 9).

Once traffic is in place, for Step 1 set Intruder 1 to generate a DAA alert. After 30 seconds of alert status, reset Intruder 1 conditions so that it no longer generates a DAA alert. In Step 2, for ownship systems equipped with TCAS II, change Intruder 5 to generate a TCAS II RA alert. Finally, for Step 3, set Intruders 1-4 to DAA alerts.

If the display provides multiple, pilot-selectable modes, complete this test for each available display mode.

Test 1d Verify

Ensure the display is as expected from setup as the introduction of the alert is going to show a change in the display.

1. One to eight guidance traffic priority intruders are displayed on the DAA traffic display.
2. A DAA alert for Intruder 1 in Step 1 is generated on the DAA traffic display. (300)
3. Intruders 5-9 in Step 1 are shown on the DAA traffic display when Intruder 1 is an active DAA alert. (301)

Ensure the correct traffic elements outside 6 NM are displayed.

1. Intruders 2 & 3 traffic elements outside ±4000’ and 6 NM from the ownship are shown on the DAA traffic display in Step 1.
2. A TCAS II RA alert is generated for Intruder 5 in Step 2 and shown on the DAA traffic display (if applicable). (300)
3. Intruders 6-9 are shown on the DAA traffic display in Step 2 when Intruder 5 is an active TCAS II RA alert (if applicable). (301)

Ensure the correct traffic elements outside 6 NM are displayed.

1. Intruders 1-3 traffic elements outside ±4000’ and 6 NM from the ownship are shown on the DAA traffic display in Step 2.
2. DAA alerts for Intruders 1-4 in Step 3 are shown on the DAA traffic display. (300)
3. A TCAS II RA alert for Intruder 5 remains on DAA traffic display in Step 3 (if applicable). (300)
4. Intruders 6-8 in Step 3 are shown on the DAA traffic display (intruder 9 is no longer displayed). (301)

Test 2 Conditions

The test requires that the DAA traffic display be powered up and configured such that it can receive and display DAA system messages. The DAA traffic display is required to be capable of receiving DAA system messaging regarding position and direction of the ownship and position and direction information of nearby traffic elements. Enter ownship position and direction into DAA processor. Then provide the DAA display with valid position and directional information of one traffic element located more than 6 NM from the ownship so that it is outside of the horizontal display range but not generating a DAA alert. Once traffic is in place, change the horizontal and vertical position of the traffic element located outside the traffic display range so that it generates a DAA alert. If the display provides multiple, pilot-selectable modes, this test needs to be completed for each available display mode.

Test 2 Verify

When the DAA alert is generated, the traffic located outside the configured traffic display range is given a symbol shape that indicates the traffic is off-scale (such as a half-symbol) and at the correct bearing relative to the ownship. (336)

2.4.5.1.2.1 Alternative Traffic Display Criteria

Requirement tested: 302

Purpose

This test verifies that the DAA traffic display visually indicates whenever non-default traffic display criteria are being used.

Condition

The test requires that the DAA traffic display criteria be adjustable from the default values. To begin, power up the DAA traffic display. Then change the first non-default traffic display criterion. Repeat for all other non-default traffic display criteria that the DAA traffic display is capable of implementing. If the display provides multiple, pilot-selectable modes, this test needs to be completed for each available display mode.

Verify

The non-default traffic display criteria are visually annunciated on the DAA traffic display for each alternate criteria setting. (302)

2.4.5.1.2.2 Traffic Digital Range Resolution

Requirement tested: 379

Purpose

This test verifies that the DAA traffic display's numeric range indicator is able to represent traffic range with sufficient resolution.

Condition

The test requires that the DAA traffic display be powered up and configured such that it can receive and display DAA system messages. To begin the test, provide ownship position and direction information to the DAA display. Then enter the horizontal and vertical position of two traffic elements, one of which is less than 10 NM from the ownship, and one that is greater than 10 NM from the ownship. Activate the numeric range indicator for each of these traffic elements. Next, for the traffic element closest to the ownship, change the range by 0.1 NM. Then, for the traffic element farthest from the ownship, change the range by 1 NM. If the display provides multiple, pilot-selectable modes, this test needs to be completed for each available display mode.

Verify

1. The DAA traffic display range indication changes by 0.1 NM when the traffic element that is less than 10 NM from the ownship changes horizontal position by 0.1 NM. (379)
2. The DAA traffic display range indication changes by 1 NM when the traffic element that is greater than 10 NM from the ownship changes horizontal position by 1 NM. (379)

2.4.5.1.2.3 Number of Traffic Elements

Requirements tested: 319, 351

Purpose

This test verifies that the DAA traffic display is able to represent at least the eight highest priority traffic elements as output from the DAA processor when those traffic elements satisfy the traffic display criteria.

Condition

The test requires that the DAA traffic display be powered up and configured such that it can receive and display DAA system messages. The DAA traffic display is required to be capable of receiving location information for the ownship and nearby traffic elements.

Provide ownship position, altitude and direction to the DAA display. Then provide to the DAA display the position, altitude and directional information of one more than the maximum number of traffic elements allowed by the DAA traffic display, that are prioritized in compliance with the DAA processor's criteria and within 6 NM of the ownship. All intruders are required to have a relative altitude within the selected vertical display range. One intruder is required to generate a DAA alert (i.e., preventive alert, corrective alert, or warning alert). The remaining traffic elements are required to be classified as other traffic (i.e., no alert status). If the display provides multiple, pilot-selectable modes, this test needs to be completed for each available display mode.

Verify

1. The DAA traffic display represents one traffic symbol for each traffic report it received that meets the traffic display criteria for at least eight traffic elements. (319)
2. The DAA traffic display represents the maximum number of traffic elements that it is designed to display, and that at least eight of the intruders are represented. The traffic element generating the DAA alert is one of the intruders displayed. The nearby traffic that is not displayed has the lowest priority of the nearby target elements. (351)

2.4.5.1.2.4 DAA Traffic Display Latency

Requirements tested: 305, 306

Purpose

This test verifies by analysis that the DAA traffic display meets the required total latency between the CS DAA processor and the DAA traffic display. It also verifies that the traffic is updated at a minimum of once per second.

Conditions

The test requires the actual hardware and software interfaces between, and including, the traffic receiver and the DAA traffic display, as well as a detailed analysis of the worst case latency for nominal operation. The analyses do not need to account for data aging between traffic updates or hardware failure modes that can degrade latency.

The following analyses are required:

1. An analysis of the entire DAA system to verify that the maximum latency between the CS DAA processor and the DAA traffic display does not exceed 0.5 seconds. (305)
2. An analysis to verify that the DAA traffic display is updated at least once per second. (306)

2.4.5.1.3 Traffic Information

Requirements tested: 303, 304, 308, 313, 314, 315, 316, 320, 322, 324, 368, 369 370, 396, 397, 398, 399

Purpose

This test verifies that the DAA traffic display is able to represent symbols for nearby traffic elements relative to the ownship and that the required information for each element is displayed graphically.

Condition

The test requires that the DAA traffic display be powered up and configured such that it can receive and display DAA system messages. If the display provides multiple, pilot-selectable modes, this test needs to be completed for each available display mode. To begin the test, enter ownship position and directional information into DAA traffic display. Then enter the position and directional information of eight traffic elements flying at a constant altitude. At least one of the traffic elements should have a traffic ID made up of at least eight alphanumeric characters. Then alter the vertical velocity of at least one of the traffic elements such that it is 500 fpm or greater.

Verify

1. The DAA traffic display has a symbol indicating ownship position. (303)
2. The DAA traffic display indicates the range being displayed. (303, 396)
3. One or more range rings are placed at specified radii from the ownship. (397)
4. The inner range ring has discrete markings at each of the 12 clock positions. (398)
5. The range ring markings are the same color as the ownship. (399)
6. The DAA traffic display includes altitude bands so that currently-selected vertical range of traffic elements relative to the ownship is represented. (303)
7. The DAA traffic display represents each traffic symbol at a location that represents its relative horizontal and vertical position with respect to the ownship. (320)
8. Each traffic symbol is cyan or white. (322)
9. Each traffic symbol is a different color from the ownship symbol. (324)

10. Each traffic symbol can be distinguished from other traffic symbols. (308)
11. Each traffic element has a corresponding data tag (313)
12. Each data tag is associated with its corresponding traffic symbol on the traffic display (e.g., the data tag is located in close proximity to the symbol). (314)
13. Each data tag includes the altitude of the corresponding traffic element. (315)
14. Traffic elements with a vertical velocity rate of 500 fpm or greater have a vertical direction indicator in the data tag. (304, 315, 368)
15. The vertical direction indicator is a vertical arrow placed to the immediate right of the traffic symbol. (369)
16. The color of the altitude and vertical direction indicator is the same as the color of the associated traffic symbol. (316)
17. Traffic directionality is represented in the traffic symbol. (304)
18. Each traffic element has a horizontal velocity trend indicator (e.g., a predictor line or a history trail). (304)
19. For the traffic element with an ID, the traffic ID field displays at least eight alphanumeric characters. (370)

2.4.5.1.3.1 Traffic – Data Blocks

Requirements tested: 317, 318

Purpose

This test verifies that each traffic symbol can be readily associated with a unique data block.

Conditions

The test requires that the DAA traffic display be powered up and configured such that it can receive and display DAA system messages. To begin the test, provide to the DAA display the position and direction of the ownship. Next, enter the position and direction, ground speed, range, category, and traffic ID of eight nearby traffic elements. Select one of the nearby traffic elements. Repeat for each of the remaining traffic elements. If the display provides multiple, pilot-selectable modes, this test needs to be completed for each available display mode.

Verify

1. A means is provided to associate each traffic symbol with its corresponding data block. (317)
2. Selecting a nearby traffic element brings up the data block associated with the traffic symbol. (318)
3. The data block associated with the selected traffic displays all additional traffic information required by the installed applications. (318)

2.4.5.1.3.2 Traffic – Directionality

Requirements tested: 321, 323, 325, 326, 327, 328, 329, 330

Purpose

This test verifies that traffic symbols are directional when the directionality information is valid and non-directional when directionality information is not valid. It also verifies that directionality of traffic symbols shifts with the DAA traffic display's orientation and that it is displayed with a proper resolution. Finally, it also verifies that each direction of travel can be represented for traffic.

Conditions

The test requires that the DAA traffic display be powered up and configured such that it can receive and display DAA system messages. The DAA traffic display is also required to be capable of receiving information regarding horizontal direction of nearby traffic and whether nearby traffic directional information is valid.

To begin, provide to the DAA display ownship position and directional information. Then provide position and directional information of at least one nearby traffic element to the DAA display. Then change the heading of a nearby traffic symbol by 7.5º to the right and then 7.5º to the left. Next, have one traffic element do a 360° turn and then have ownship do a 360° turn. Then change the display orientation of the DAA traffic display, and repeat for each available display orientation mode. In the final part of the test, remove from the DAA display the directionality information of at least one traffic element so that it is no longer valid.

Verify

1. When traffic directionality information is valid, the traffic symbol is an unfilled arrowhead shape pointing in the direction of the traffic element's heading. (321)
2. When the traffic element is making a 360° turn the directionality of the traffic symbol is correct throughout the maneuver. (321)
3. When the direction of the traffic element is changed by 7.5º to the left or right, the traffic symbol direction can be seen to change accordingly. (330)
4. When traffic directionality information is valid, the direction of the traffic symbol is displayed relative to the DAA traffic display's orientation. (329)
5. When the ownship is making a 360° turn, the position of the nearby traffic symbols rotates accordingly while in track-up and heading up display orientations. (329)
6. When directionality information is invalid, the traffic symbol is an unfilled diamond shape. (325)
7. When directionality information is invalid, the traffic symbol is the same color as when the directionality information is valid. (323, 326, 327)
8. When directionality information is invalid, traffic is a different color from the ownship symbol. (328)

2.4.5.1.3.3 Traffic – Ground Speed

Requirements tested: 371, 372

Purpose

This test verifies, when implemented, that the DAA traffic display correctly represents the ground speed of nearby traffic.

Conditions

The test requires that the DAA traffic display be powered up and configured such that it is capable of receiving information regarding position, direction, altitude, and ground speed of the ownship, as well as relative position, direction, altitude, and ground speed of nearby traffic elements. If the display provides multiple, pilot-selectable modes, this test needs to be completed for each available display mode. To begin the test, enter ownship position, direction, altitude, and ground speed information into DAA traffic display. Then enter the position, direction, altitude and ground speed of one traffic element. Next, set the ground speed of the traffic element to 300 knots. Then increase the ground speed of the traffic element by 1 knot, and then after 30 seconds, decrease the ground speed by 1 knot. Finally, increase the ground speed of the traffic element to 999 knots.

Verify

1. The DAA traffic display correctly displays the intruder's changes in ground speed with a minimum resolution of 1 knot. (372)
2. The DAA traffic display represented the intruder's ground speed of 999 knots. (371)

2.4.5.1.3.4 Traffic – Horizontal Velocity Vector

Requirements tested: 374, 375, 376, 377, 378

Purpose

This test verifies that traffic horizontal velocity vectors are implemented appropriately.

Conditions

The test requires that the DAA display be powered up and configured such that it is capable of receiving information regarding position of the ownship as well as relative position of nearby traffic elements. To begin, set the display range to 5 NM. Then provide the DAA display with the ownship position. Next enter position and direction information of eight nearby traffic elements. Four of these should be 3 to 5 NM from the ownship position, two with speeds of 250 knots and two with speeds of 340 knots. In addition, four traffic elements should be 6 to 10 NM from the ownship, with two having speeds of 250 knots, and two with speeds of 340 knots. Once traffic is in place, change the scale of the predictor lines or history trails (if it is possible to do so), whichever is implemented in the DAA traffic display. Next, change display range to 10 NM. If the display provides multiple, pilot-selectable modes, this test needs to be completed for each available display mode.

Verify

1. The DAA traffic display graphically depicts traffic horizontal velocity as a predictor/leader line or history trail. (374)
2. The predictor lines or history trails are distinguishable from traffic vertical direction indicators. (378)
3. The same scale is used to display all predictor lines or history trails. (375)
4. When the display range is changed, the size of the predictor lines or history trails changes accordingly. (376)
5. If the scale of the predictor lines or history trails can be changed, the scaling value is indicated on the DAA traffic display. (377)

2.4.5.1.3.5 Traffic – Altitude

2.4.5.1.3.5.1 Traffic – Relative Altitude

Requirements tested: 355, 356, 357, 358, 359, 360

Purpose

This test verifies that traffic relative altitude is properly displayed in a data tag when relative altitude information is available, and when it is not available, relative altitude information is not displayed in the data tag.

Conditions

The test requires that the DAA display be powered up and configured such that it is capable of receiving information regarding the relative altitude of nearby traffic elements. If the display provides multiple, pilot-selectable modes, this test needs to be completed for each available display mode. To begin the test, enter the ownship position and actual altitude into DAA traffic display. Then enter the position of at least two traffic elements flying at the same altitude relative to the ownship. Next, change the relative altitude of one traffic element so that its altitude is higher than the ownship. Then change the relative altitude of another traffic element so that it has lower altitude relative to the ownship. Repeat the previous two steps by changing the relative altitude of the two traffic elements by values of ±100'. Finally, for one traffic element, remove the relative altitude information as an input to the DAA traffic display.

Verify

1. When relative altitude is available, the data tag for traffic at the same altitude as the ownship displays the relative altitude with the digits "00" positioned below the traffic symbol. (360)
2. When relative altitude information is available, the data tag for traffic above the ownship has the relative altitude preceded by a "+" sign and is placed above the traffic symbol. (357)
3. When relative altitude information is available, the data tag for traffic below the ownship has the relative altitude preceded by a "-" sign and is placed below the traffic symbol. (358)
4. When relative altitude information is available, relative altitude consists of at least two digits representing altitude difference in hundreds of feet. (359)
5. When relative altitude information is available, relative altitude is displayed with a resolution of 100'. (356)
6. When the traffic relative altitude information is not available, the traffic altitude is not displayed. (355)

2.4.5.1.3.5.2 Traffic – Multiple Altitude Types

Requirements tested: 353, 354, 361, 362, 363, 364, 365, 366, 367

Purpose

For DAA traffic displays capable of displaying different types of altitude in addition to relative altitude (i.e., traffic actual altitude, and traffic geometric altitude), this test verifies that the type of altitude being displayed is represented properly, and that relative altitude is the default altitude represented.

Conditions

The test requires that the DAA traffic display be powered up and configured such that it can receive and display DAA system messages. To begin the test, provide ownship position to the DAA display. Then provide to the DAA display the position information of at least one nearby traffic element. For the traffic element(s), valid actual altitude, geometric altitude, and pressure altitude information should be included. Once the traffic has been passed to the DAA display, switch the DAA display's altitude type from the default setting to actual altitude, followed by traffic geometric altitude. Finally, position the traffic below the transition altitude and select traffic pressure altitude. The traffic should be in traffic pressure altitude mode below the transition altitude for at least 45 seconds. Finish the test by climbing the traffic element above the transition altitude while traffic pressure altitude is still selected. The traffic should remain above the transition altitude and in traffic pressure altitude mode for at least 45 seconds. If the display provides multiple, pilot-selectable modes, this test needs to be completed for each available display mode.

Verify

1. The data tag of the nearby traffic element displays relative altitude as the default case. (353)
2. The DAA traffic display indicates which type of altitude is being displayed as the various altitude types are tested. (354)
3. When actual altitude is selected, the actual altitude tag is positioned above the traffic symbol when it is higher than the ownship, and below the traffic symbol when it is lower than the ownship. (361)
4. When actual altitude is selected, the actual altitude is represented with a three-digit number representing hundreds of feet above MSL. (362)
5. The traffic actual altitude is corrected for the local barometric pressure using same correction as the ownship. (363)
6. When traffic geometric altitude is selected, it is only displayed in the data block associated with its traffic element and not directly on the DAA traffic display (i.e., not in the data tag). (364)
7. When traffic geometric altitude is selected and displayed, there is a label to indicate that geometric altitude is the currently selected altitude type, such as "HAE" (3241' HAE). (365)
8. Once the intruder has descended below the transition altitude and traffic pressure altitude has been selected, pressure altitude is displayed for a maximum of 30 seconds in the data tag. (366)
9. Once the intruder has climbed above the transition altitude and traffic pressure altitude has been selected, pressure altitude can be shown in the data tag for more than 30 seconds. (366)
10. When traffic pressure altitude is displayed, it has a corresponding altitude reference label (e.g., "FL" or "Press Alt"). (367)

2.4.5.1.3.6 Traffic – Emitter Category

Requirements tested: 373

Purpose

This test verifies that, when implemented, the DAA traffic display is able to unambiguously display the category of traffic elements (i.e., the emitter category).

Conditions

The test requires that the DAA traffic display be powered up and configured such that it is capable of receiving information regarding position of the ownship as well as relative position of nearby traffic elements. To begin the test, provide to the DAA display the position and direction of the ownship, as well as the position and direction of four nearby traffic elements, each belonging to a different traffic category (e.g., "light," "heavy," "rotor craft," "emergency vehicle"). If the display provides multiple, pilot-selectable modes, this test needs to be completed for each available display mode.

Verify

The traffic category (emitter category) is correctly displayed in the data tag, the data block (or via some other means) for each of the tested traffic categories. (373)

2.4.5.2 Traffic Display Controls

Requirements tested: 394, 395, 414, 415, 416, 417, 418, 419, 420

Purpose

The test defined in this subparagraph verifies that the DAA traffic display controls perform the required functions.

Conditions

These tests are to be performed using the actual controls or control panels. The test requires that the DAA traffic display be powered up and configured such that it is capable of receiving information regarding position of the ownship as well as relative position of nearby traffic elements. To begin the test, enter the position and direction of the ownship and the position and direction of the maximum number of traffic elements able to be displayed by the DAA traffic display. If the display provides multiple, pilot-selectable modes, this test needs to be completed for each available display mode.

Verify

1. Range Selection. A control is provided to select the available display ranges between the minimum and maximum values. (414)
2. The DAA traffic display is adjustable to a minimum range of 6 NM in the direction of ownship travel. (394)
3. The DAA traffic display is adjustable to a maximum range of at least 40 NM in the direction of ownship travel, as measured from the direction of ownship position to the edge of the viewable screen. (395)
4. Altitude Band. A control is provided to select the available altitude bands between the minimum and maximum values. (415)

5. Traffic Altitude Selection. If the DAA traffic display is capable of representing different altitude types, a control is provided to adjust between the different altitude options. (416)
6. Traffic Selection. If traffic selection is implemented, there is a switch provided that allows the flight crew to select at least one traffic element. (417)
7. Display Brightness. A means is provided to adjust the display brightness between minimum and maximum levels. (420)
8. Display Decluttering. If DAA traffic display decluttering is implemented, a means is provided for the flight crew to turn on and off the decluttering function. Turning decluttering on correctly reduces the number of traffic elements displayed. (418)
9. The flight crew can perform the de-cluttering function by a Simple Action (e.g., toggling the declutter function on and off). (419)

2.4.5.2.1 Altitude Bands

Requirements tested: 400, 401

Purpose

This test verifies that the DAA traffic display is capable of showing the traffic elements appropriate for both the minimum and maximum vertical filtering ranges.

Conditions

The test requires that the DAA traffic display be capable of receiving information regarding position and direction of the ownship and position and direction information of nearby traffic elements. To begin the test, enter the ownship position and direction into the system. Once the ownship is represented within the traffic display, ensure the display is set to the minimum vertical filtering range of ±4000'. Then provide the DAA display with valid position and directional information for twelve traffic elements. Eight traffic elements are required to be within ±4000' relative altitude and 6 NM of the ownship, covering all four quadrants (to the left, front, back, and right of the ownship), and two traffic elements are required to be at ±9900' relative altitude of the ownship. The remaining two traffic elements are required to be 10000' relative altitude of the ownship. Next, select the maximum vertical filter range (which must be at least ±9900'). If the display provides multiple, pilot-selectable modes, this test needs to be completed for each available display mode.

Verify

1. When the minimum vertical filter range is selected, only the traffic within an altitude range of ±4000' relative to the ownship are visible. (400)
2. When the maximum vertical filter range is selected, the eight targets within ±4000', and two traffic elements at ±9900' relative to the ownship, at a minimum, are visible. (401)

2.4.5.3 DAA Alerting

2.4.5.3.1 DAA Alert Symbology

Requirements tested: 331, 332, 333, 334, 335, 337, 338, 339, 345, 346, and 531

Purpose

This test verifies that DAA traffic alerts with valid directionality information are shown with the proper symbols and in the proper color. It also tests that the preventive and corrective alert symbols are modified when their traffic status is unvalidated ADS-B.

Test 1 Conditions

The test requires that the DAA traffic display be powered up and configured such that it can receive and display DAA system messages. To begin the test, provide to the DAA display the position and direction of the ownship. Then, the display must show an intruder classified as a preventive alert, a corrective alert, and a warning alert. A different traffic element is required to be associated with each generated DAA alert. The alerts are required to be generated sequentially, with only one active DAA alert at a time. Next, a new traffic element is required to generate maneuver guidance without registering as an active DAA alert. All traffic elements are required to include valid directionality information. One of the alerted traffic elements is required to lack altitude information. Another of the alerted traffic elements is required to report an altitude of +200’ relative to the ownship but be associated with altitude uncertainty of at least ±300’. If the display provides multiple, pilot-selectable modes, this test needs to be completed for each available display mode.

Test 1 Verify

1. The traffic symbol is amber/yellow for caution level alerts (preventive and corrective alerts). (334)
2. The traffic symbol is red for the warning alert. (335)
3. Traffic classified as a preventive alert is displayed as a filled amber/yellow directional arrowhead with an amber/yellow circle around the symbol. (334, 337)
4. Traffic classified as a corrective alert is displayed as a filled amber/yellow circle containing a black outline of the directional symbol. (334, 338)
5. Traffic classified as a warning alert is displayed as a filled red directional arrowhead with a red square around the symbol. (335, 339)
6. The symbol of the traffic element generating maneuver guidance without registering an active DAA alert is displayed as filled. (331)
7. Traffic that has an alert condition is distinguishable from the same traffic symbol without an alert. (332)
8. Directionality is preserved for as long as traffic directionality is valid during an alert. (333)
9. The altitude and vertical trend fields are empty for the intruder not reporting any altitude information. (345)
10. The altitude and vertical trend fields are empty for the intruder with altitude uncertainty greater than its relative altitude (e.g., +02). (346)

Note: *Examples of the required alert symbology can be found in Figure 2-12 through Figure 2-14.*

Test 2 Conditions

The test requires that the DAA traffic display be powered up and configured such that it can receive and display DAA system messages. The display must also be capable of receiving messages designating intruders with an unvalidated ADS-B traffic status. To begin the test, provide to the DAA display the position and direction of the ownship. Then, send to the display two different intruders with a traffic status of unvalidated ADS-B. Position Intruder 1 so that it generates a preventive alert. After 20 seconds in alert status, reposition Intruder 1 so that it is no longer an active alert. Once Intruder 1 has been removed from alert status, position Intruder 2 so that it generates a corrective alert. After 20 seconds in alert status, reposition Intruder 2 so that it is no longer an active alert. If the display provides multiple, pilot-selectable modes, this test needs to be completed for each available display mode.

Test 2 Verify

The preventive and corrective traffic symbols for Intruders 1 and 2 are modified from the default traffic symbol (as seen in Test 1) to indicate an unvalidated ADS-B traffic status. (531)

2.4.5.3.1.1 DAA Alert Symbology for No-Bearing Targets

Requirements tested: 340, 341, 342, 343, 344, 345, 346

Purpose

This test verifies that DAA traffic without valid bearing information is shown with the proper symbols and in the proper color.

Conditions

The test requires that the DAA traffic display be powered up and configured such that it can receive and display DAA system messages. To begin the test, provide to the DAA display the position and direction of the ownship. Then provide to the display the range of two traffic elements without valid bearing information. One traffic element is required to have valid relative and actual altitude information, while the other is required to report no altitude information. Next, change the position of the traffic element with altitude information such that it generates a corrective alert (CORR) while level with the ownship. While the alert is active, change the intruder's vertical rate to a minimum of ±500 fpm. After 10 seconds, change the intruder's vertical rate to 0 fpm and simulate a level of altitude uncertainty greater than the intruder's current relative altitude level (e.g., greater than 200' uncertainty). Next, if alert is still active, change the position of this intruder so as to remove the alert. Next, change the position of the traffic element without altitude information such that it generates a warning alert (WARN). While intruder is still generating a warning alert, reposition the first intruder so that it generates a simultaneous corrective alert. If the display provides multiple, pilot-selectable modes, this test needs to be completed for each available display mode.

Verify

1. Alerts are issued on DAA traffic display for traffic generating a corrective alert and for traffic generating a warning alert, despite lack of valid bearing information. (340)
2. The no-bearing alert displays “No-Bearing” in text, range in NM, relative altitude (hundreds of feet), the intruder vertical velocity arrow, and threat level (e.g., “CORR” or “WARN”), in that order. (341)
3. Alphanumeric strings are red for warning alerts and amber or yellow for corrective alerts. (342)
4. The type of altitude information presented by the DAA display is consistent with the selected altitude mode (relative or actual altitude). (343)
5. The altitude and vertical trend fields are empty for the intruder with altitude uncertainty greater than its relative altitude (e.g., +02). (346)
6. The altitude and vertical trend fields in the no-bearing alert message are empty for the intruder not reporting any altitude information. (345)
7. When the Corrective DAA alert and DAA Warning Alert are active simultaneously, the DAA display shows two distinct no-bearing alerts. (344)

2.4.5.3.2 DAA Aural Alerts

Requirements tested: 425, 426, 427, 428, 429, 430, 431, 432, 433, 434

Purpose

The following test verifies that DAA aural alerts are appropriately implemented and that aural alerts are suppressed when an intruder is downgraded in threat status. It also verifies that simultaneous alerts are properly queued.

Test 1 Conditions

This test requires that the DAA display be powered up and configured such that DAA aural alerts can be presented. To begin the test, provide to the DAA display the position and direction of the ownship. Then the DAA traffic display must receive the following intruders: Intruder 1 should be positioned to generate a preventive alert. After 30 seconds the alert should be removed. Intruder 2 must then generate a corrective alert, which is then removed after 30 seconds. Intruder 3 must generate a warning alert, and then be removed after 30 seconds. Intruder 4 must generate a corrective and then be subsequently downgraded in threat status to a preventive alert. After 20 seconds in the preventive alert status, remove the alert from the display. Finally, Intruder 5 must generate a warning alert and then be subsequently downgraded in threat status to a corrective alert. After 15 seconds as a corrective alert, it should once again be downgraded, this time to a preventive alert. After 15 seconds as a preventive alert, remove the alert from the display. If the display provides multiple, pilot-selectable modes, this test needs to be completed for each available display mode

Test 1 Verify

1. "Traffic, monitor" is audibly annunciated for Intruder 1 when the preventive alert is registered by the DAA processor and its presentation is synchronized with the display of the alert. (425)
2. "Traffic, avoid" is audibly annunciated for Intruder 2 when the corrective alert is registered by the DAA processor and its presentation is synchronized with the display of the alert. (426)
3. "Traffic, maneuver now" is audibly annunciated twice for Intruder 3 when the warning alert is registered by the DAA processor and its presentation is synchronized with the display of the alert. (427)
4. For Intruders 4 and 5, the aural alert is suppressed every time the threat status is downgraded from a higher-level alert to a lower-level one. (432)

Test 2 Conditions

This test is intended to test the multiple requirements for handling the issuance of aural alerts when they are registered either simultaneously or within the alert duration window (four seconds). The test requires that the DAA display be powered up and configured such that DAA aural alerts can be presented. To begin the test, provide to the DAA traffic display the position and direction of the ownship. Then enter the position and direction of twenty intruders into the DAA traffic display. The test should be completed in the following stages. If the display provides multiple, pilot-selectable modes, this test needs to be completed for each available display mode.

In the first stage, set Intruder 1 to a preventive alert and Intruder 2 to a corrective alert simultaneously. After 30 seconds remove both alerts. Next, set Intruder 3 to a preventive alert and Intruder 4 to a warning alert simultaneously. After 30 seconds remove both alerts. Next, set Intruder 5 to a corrective alert and Intruder 6 to a warning alert simultaneously. After 30 seconds remove both alerts.

In the second stage, set Intruder 7 to a preventive alert and Intruder 8 to a corrective alert simultaneously. Then, within four seconds (the aural alert duration) change Intruder 7 from a preventive alert to a non-alert status. After 30 seconds, remove the remaining alert on Intruder 8.

In the third stage, set Intruder 9 to a preventive alert. Then, between one and four seconds after Intruder 9 registers as a preventive alert, set Intruder 10 to a corrective alert. After 30 seconds remove both alerts. Then set Intruder 11 to a preventive alert. Then, between one to four seconds after Intruder 11 registers as a preventive alert, set Intruder 12 to a warning alert. After 30 seconds remove both alerts. Next, set Intruder 13 to a corrective alert. As with the others, between one and four seconds after Intruder 13 registers as a corrective alert, set Intruder 14 to a warning alert. After 30 seconds remove both alerts.

In the fourth and final stage, set Intruder 15 to a corrective alert. Then, between one and four seconds after Intruder 15 registers as a corrective alert, set Intruder 16 to a preventive alert. After 30 seconds remove both alerts. Then set Intruder 17 to a warning alert. Then, between one and four seconds after Intruder 17 registers as a warning alert, set Intruder 18 to a preventive alert. After 30 seconds remove both alerts. Finally, set Intruder 19 to a warning alert. Then, between one and four seconds after Intruder 19 registers as a warning alert, set Intruder 20 to a corrective alert. After 30 seconds remove both alerts.

Test 2 Verify

1. For Intruders 1 to 6, the aural alert for the higher priority intruder is audibly annunciated when the alert is registered by the DAA traffic display and its presentation is synchronized with the display of the alert. (429)
2. For Intruders 1 to 6, the aural alert of the lower priority intruder is audibly annunciated following the issuance of the higher priority alert. (430)
3. The aural alert for Intruder 7 is not audibly annunciated following the issuance of the higher priority aural alert. (431)
4. For Intruders 9 to 14, the aural alert for the higher priority intruder is audibly annunciated when the alert is registered by the DAA traffic display and its presentation is synchronized with the display of the alert (i.e., interrupts ongoing annunciation of any lower priority alert). (432)
5. For Intruders 9 to 14, the aural alert for the lower priority intruder is not subsequently completed or repeated following the issuance of the higher priority aural alert. (432)
6. For Intruders 15 to 20, the aural alert for the higher priority intruder is audibly annunciated, in full (i.e., not interrupted), when the alert is registered by the DAA traffic display and its presentation is synchronized with the display of the alert. (433)
7. For Intruders 15 to 20, the aural alert for the lower priority intruder is audibly annunciated following the issuance of the higher priority aural alert. (433)

2.4.5.4 TCAS II Alert Symbology for Integrated Systems

Requirements tested: 347, 348, 349, 350

Purpose

This test verifies that, for DAA systems integrated with TCAS II, TCAS II Corrective Resolution Advisories, Preventive Resolution Advisories and Traffic Advisories are properly displayed.

Conditions

The test requires that the DAA traffic display be powered up and configured such that it can receive and display DAA and TCAS II system messages. To begin the test, provide to the DAA display the position and direction of the ownship. Then provide to DAA display the valid position and direction of nearby traffic elements capable of generating the following alert types. First, provide to the DAA traffic display an intruder that generates a TCAS II Corrective Resolution Advisory. Then, provide to the DAA traffic display an intruder that generates a TCAS II Preventive Resolution Advisory that had not previously been declared an alert by the DAA system. Next, provide to the DAA display an intruder that generates a corrective alert and then alter the position of the same intruder to generate a simultaneous TCAS II Preventive RA. Finally, provide to the DAA traffic display an intruder that generates a TCAS II Traffic Advisory. If the display provides multiple, pilot-selectable modes, this test needs to be completed for each available display mode.

Verify

1. The DAA traffic display shows alerts for TCAS II Corrective Resolution Advisories as defined in RTCA DO-185B (347)
2. A black outline of a directional arrowhead is visible when the direction information is valid. (348)
3. The DAA traffic display shows a DAA preventive alert for the traffic element that generated a TCAS II Preventive Resolution Advisory without having previously been declared a DAA alert. (349)
4. The DAA traffic display does not display a TCAS II Preventive Resolution Advisory for the traffic element that was already declared a corrective alert. (349)
5. The DAA traffic display suppresses TCAS II Traffic Advisory. (350)

2.4.5.5 DAA Guidance to Maintain and Regain DWC

Requirements tested: 380, 381, 382, 383, 384, 385, 386, 387, 388, 389, 390, 391, 392, Paragraph 2.2.2.

Purpose

This test verifies that the DAA guidance to maintain and regain DWC is provided and properly displayed. The test also ensures that the I/O requirements (as specified in Paragraph 2.2.2) are sufficiently met.

Test 1 Conditions

The test requires that the DAA traffic display be powered up and configured such that it can receive and display DAA system messages. To start the test, valid ownship information is provided to the DAA display. Intruders should then be systematically sent into the DAA display within 15 NM of the ownship and at all four quadrants around the ownship (to the left, front, right, and back). The intruders should also range from +2000 ft to -2000 ft, at 500-ft increments (including co-altitude) from the ownship's altitude. Several intruders should be close to enough to generate horizontal and vertical DAA maneuver guidance in the direction of the intruders without becoming active DAA alerts. At least one intruder should progress to a corrective alert and a second intruder should progress to a warning alert. If preventive maneuver guidance is implemented, one intruder should progress to a preventive alert. Finally, one intruder should progress to a loss of well clear or otherwise generate DAA guidance to regain DWC. If the display provides multiple, pilot-selectable modes, this test needs to be completed for each available display mode.

Test 1 Verify

1. Verify by inspection that DAA corrective and warning maneuver guidance bands are distinct from other DAA information and from each other. (380)
2. The DAA traffic display provides corrective maneuver guidance in the form of amber/yellow bands against the corrective alert. (381)
3. The DAA traffic display provides warning maneuver guidance in the form of red bands against the warning alert. (382)
4. Horizontal maneuver guidance bands are positioned relative to the ownship's position and heading on the DAA traffic display. (383)

5. The horizontal maneuver guidance bands cover a minimum of ±90 degrees left and right from the ownship's current heading regardless of location of intruder. (384)
6. If vertical maneuver guidance is implemented within an altitude tape, the vertical maneuver guidance bands cover a minimum of ±2000' from the ownship's current altitude if overlaying an altitude tape. (385)
7. If vertical maneuver guidance is implemented within vertical velocity tape, the vertical maneuver guidance bands range from -3000 to +3000 fpm if overlaying a vertical velocity indicator. (386)
8. When preventive maneuver guidance is provided by the DAA processor, the DAA traffic display provides maneuver guidance in the form of amber/yellow bands. (387)
9. If no bands are implemented as the indication of positive maneuver guidance, the DAA traffic display differentiates those trajectory options from trajectories that are not being assessed by the DAA system with a distinct pattern and/or color that is not red, amber/yellow, or green. (388)
10. Verify by inspection that guidance to regain DWC is distinct from other DAA information. (389)
11. The DAA traffic display depicts guidance to regain DWC in green. (390)
12. Guidance to regain DWC displays the range of trajectories provided by the DAA processor (391)
13. The horizontal guidance to regain DWC is depicted relative to the ownship's current position and heading. (392)

<u>Test 2 Conditions</u>

The test requires that the DAA traffic display be powered up and configured such that it can receive and display DAA system messages. Intruder data is to be simulated as a measurement from all available surveillance sources (e.g., ADS-B receiver, active surveillance, radar system) and processed through all the required DAA subsystems as shown in <u>Figure 2-2</u>. To start the test, valid ownship information is provided to the DAA display. Intruders should then be systematically sent into the DAA display within 15 NM of the ownship and at all four quadrants around the ownship (to the left, front, right, and back). The intruders should also range from +2000 ft to -2000 ft, at 500-ft increments (including co-altitude) from the ownship's altitude. Several intruders should be close to enough to generate horizontal and vertical DAA maneuver guidance in the direction of the intruders without becoming active DAA alerts. At least one intruder should progress to a corrective alert and a second intruder should progress to a warning alert. If preventive maneuver guidance is implemented, one intruder should progress to a preventive alert. Finally, one intruder should progress to a loss of well clear or otherwise generate DAA guidance to regain DWC. If the display provides multiple, pilot-selectable modes, this test needs to be completed for each available display mode

<u>Test 2 Verify</u>

No difference is observed in what is displayed on the screen as compared to Test 1. The absence of any difference in what is displayed on the screen verifies that the I/O requirements are implemented correctly. (Paragraph 2.2.2)

2.4.5.6 TCAS II Resolution Advisory Guidance for Integrated Systems

Requirements tested: 393, Paragraph 2.2.2

Purpose

To ensure that for Class 2 DAA systems, RA guidance for Corrective RAs is implemented in compliance with Subparagraph 2.2.6.2 of RTCA DO-185B and that I/O requirements (as specified in Paragraph 2.2.2) are sufficiently met.

Test 1 Conditions

The test requires that the DAA traffic display be powered up and configured such that it can receive and display DAA and TCAS II system messages. To begin the test, provide to the DAA display the position and direction of the ownship. Then provide to DAA display the valid position and direction of one nearby traffic element. Next, provide to the DAA traffic display a TCAS II Corrective Resolution Advisory. If the display provides multiple, pilot-selectable modes, this test needs to be completed for each available display mode.

Test 1 Verify

The DAA traffic display provides TCAS II Resolution Advisory guidance in compliance with Subparagraph 2.2.6.2 of RTCA DO-185B for the intruders generating TCAS II Corrective RAs. (393)

Test 2 Conditions

The test requires that the DAA traffic display be powered up and configured such that it can receive and display DAA and TCAS II system messages. At a minimum, intruder data is to be simulated as a measurement from a TCAS II system and processed through all the required DAA subsystems as shown in Figure 2-1Figure 2-. Other intruder data from other surveillance sources (e.g., ADS-B receiver or radar system) may also be used in addition to the TCAS II system. To begin the test, provide to the DAA display the position and direction of the ownship. Then provide to the DAA traffic display the valid position and direction of one nearby traffic element. Next, provide to the DAA traffic display a TCAS II Corrective Resolution Advisory. If the display provides multiple, pilot-selectable modes, this test needs to be completed for each available display mode.

Test 2 Verify

No difference is observed in what is displayed on the screen as compared to Test 1. The absence of any difference in what is displayed on the screen verifies that the I/O requirements are implemented correctly. (Paragraph 2.2.2)

2.4.5.7 System Status

Requirements tested: 405, 406, 407, 408, 409, 410, 412, 413

Purpose

The purpose of this test is to verify that the GDTI properly indicates the health of any of the DAA subsystems listed in Table 2-26 and any non-normal system status therein.

Conditions

The test may, at the manufacturer's discretion, be performed in an open box mode. The manufacturer needs to provide means of their own design (e.g., the manual disconnecting of cables or cutting of wires, a temporary test harness, a permanent test connector or any combination of these) for inducing the malfunctions for which status must be displayed.

In any instance where the relation between the malfunction and the means for inducing the malfunction is not physically obvious, the manufacturer needs to provide an engineering analysis that establishes this relation.

The test requires that all DAA subsystems listed in Table 2-26 (e.g., radar, ADS-B, and TCAS II) be powered up and configured such that they are capable of receiving information regarding position of the ownship as well as relative position of nearby traffic elements. The individual subsystem Health Monitoring Functions must also be running, along with the high-level DAA Operational Monitoring Function.

To begin the test, enter into the DAA processor the vertical and horizontal position of the ownship and its direction. Then enter the vertical and horizontal position and the direction of at least one nearby traffic element. Next, remove power to the DAA processor and DAA traffic display for 30 seconds. Then return power to the DAA processor and the DAA traffic display. For the next part of the test, create a non-normal status in one of the DAA subsystems. Repeat for the remaining DAA subsystems. Then generate a non-normal status in one of the DAA subsystems that can be detected by the high-level DAA operational monitoring function. Repeat for each possible DAA operational state. Next, generate a non-normal DAA traffic display status that can be detected by the high-level DAA operational monitoring function. For the final part of the test, remove each input to the DAA processor. If the display provides multiple, pilot-selectable modes, this test needs to be completed for each available display mode.

Verify

1. The GDTI indicates the health of the DAA system to the flight crew. (405)
2. When the electrical power to the DAA processor and the DAA traffic display is turned off, there is an indication of an electrical power failure on the GDTI (e.g., blank screen). (406)
3. The non-normal status of each DAA subsystem is indicated on the GDTI. (407)
4. When the high-level DAA operational monitoring function detects a non-normal DAA status in the DAA processor, it is indicated on the GDTI. (408)
5. The GDTI indicates non-normal DAA subsystem status from the operational monitoring function. (409)
6. The GDTI removes traffic from the display when the traffic display monitor indicates a DAA traffic display failure. (410)
7. The GDTI provides a visual indication that the radar is transmitting. (412)
8. The GDTI indicates the appropriate input failure message when inputs to the DAA processor are removed (e.g., DAA failure/ADS-B failure/TCAS II input failure/CNPC link failure/radar failure). (413)

2.4.5.8 Multifunction Displays

Requirements tested: 421, 422, 423, 424

Purpose

This test verifies that for DAA traffic displays that are part of a shared, or multifunction display (MFD), information is displayed consistently across the different display functions, and that the DAA traffic display is always available. It also verifies that DAA cautions and warnings are displayed regardless of the shared display format being employed.

Conditions

The test requires that the MFD of which the DAA traffic display is a part be powered up and configured to receive and display DAA system messages. All of the functions that the MFD is capable of performing (e.g., weather display, terrain display) must also be running.

To begin the test, ensure DAA traffic display is set to minimum display range (6 NM and ±4000') and then enter information regarding the location of the ownship and the location of at least two traffic elements within the minimum display range. Then for the DAA traffic display function, cycle through all available display orientation modes (e.g., heading-up, North-up, and track-up). Then change the display range to 40 NM. Next, activate one of the non-DAA traffic display functions that the MFD is capable of performing and change the horizontal and vertical position of one traffic element to generate a preventive alert. Then change the horizontal and vertical position of one traffic element to generate a corrective alert, and finally change the position of a traffic element to generate a warning alert. Repeat this process for each of the non-DAA traffic display functions the MFD is capable of performing. In the last part of the test, use some means to render the DAA traffic display inoperable.

Verify

1. The DAA traffic display is visible at all times, regardless of which other function is currently active. (421)
2. If the DAA traffic display orientation is heading-up, a heading-up orientation is displayed in the other MFD functions. (422)
3. If the DAA traffic display orientation is North-up, a North-up orientation is displayed in the other MFD functions. (422)
4. If the DAA traffic display orientation is track-up, a track-up orientation is displayed in the other MFD functions. (422)
5. When the DAA traffic display range is increased to 40 NM, the same range is displayed in the other MFD functions. (422)
6. The DAA traffic display shows caution and warning alerts regardless of which MFD function is active. (424)
7. Verify by inspection that when the DAA traffic display is inoperable it is obvious to the observer (i.e., the indication that the DAA traffic display is under normal operation is now absent). (423)

2.4.5.9 Display Visibility

Requirements tested: 420, 307

Purpose

The goal of this test is to verify that the brightness of the display can be adjusted and that the luminance and contrast of the display allows it to be readable through the full range of normally expected ambient illumination conditions in a manner consistent with the SAE ARP4256A.

Conditions

The test requires that the DAA traffic display be powered up and configured such that it can receive and display DAA system messages. It must also be configured to allow the adjustment of the display's brightness. To begin the test, enter the position and direction information of the ownship and at least eight traffic elements. Then vary the intensity of illumination through the full range of the normally expected ambient illumination conditions likely to be encountered in a control station, from complete darkness to unfiltered light on the face of the DAA traffic display. If the display provides multiple, pilot-selectable modes, this test needs to be completed for each available display mode.

Verify

1. A means is provided to adjust the brightness of the display. (420)
2. Verify by inspection that the DAA traffic display text is readable at a distance of 30 inches through the full range of the normally expected illumination conditions. (307)

2.4.5.10 Additional Applications and Designated Traffic

Requirement tested: 352

Purpose

This test verifies that if applications in addition to DAA are implemented in the DAA traffic display, there is a means to determine the traffic's application capability.

Conditions

The test requires that the DAA traffic display be powered up and configured such that it can receive and display DAA system messages. To begin the test, provide to the DAA display the position and direction of the ownship, and that of two traffic elements. Then manually enable one of the additional, non-DAA applications. For one of the traffic elements, enter information regarding the element that makes it valid with respect to that application. For the other traffic element, enter information that makes it invalid with respect to that application. Repeat for each additional application. If the display provides multiple, pilot-selectable modes, this test needs to be completed for each available display mode.

Verify

There is a means to determine the traffic's application capability with respect to each installed application, whether it is done graphically, by a simple action or another means. (352)

2.4.5.11 DAA Traffic Display Alert and Guidance Suppression

Requirement tested: 411

Purpose

This test verifies that the GDTI indicates when alerts and guidance are automatically being suppressed during the takeoff, landing, and/or airport VFR traffic pattern phases of flight.

Condition

The test requires that the DAA traffic display be powered up and configured such that it can receive and display DAA system messages as well as flight status messages. Any additional systems required to indicate that alerts/guidance are being suppressed are also required to be powered up and connected to the DAA display.

To begin the test, provide the DAA traffic display with the ownship position and direction. Once the ownship is represented within the traffic display, provide the DAA display valid position and directional information for three traffic elements that would generate each DAA threat level individually: preventive alert, corrective alert, and warning alert. Then provide the DAA traffic display with flight status messages stating that the ownship is in each of the following phases of flight: takeoff, landing, and airport. If the display provides multiple, pilot-selectable modes, this test needs to be completed for each available display mode.

Verify

1. When the simulated takeoff, landing and airport system messages are received by the DAA traffic display, the DAA traffic display provides an indication that alerts are being suppressed. (411)
2. When the simulated takeoff, landing and airport system messages are received by the DAA traffic display, the DAA traffic display provides an indication that guidance is being suppressed. (411)

2.4.6 DAA Pilot Selected Modes (§2.2.6)

This procedure tests the pilot selected modes for the DAA control panel, the radar subsystem control panel and Equipment Class 2 TCAS II subsystem pilot selected modes.

Setup: Compel, either by simulation or by actual manipulation, equipment for each DAA subsystem listed in Table 2-26 into normal operation.

1. Verify display of normal DAA system operational status and failed operational status for all subsystems listed in Table 2-26.
2. Initialize the aircraft with any set of intruders that display traffic, guidance, and if equipped with TCAS II, TCAS intruders with both TA and RA conditions.
3. Set the DAA pilot mode to Standby.
4. Verify that the UA DAA processor, active surveillance and CS DAA processor generate the Standby operational status report.
5. Verify that the UA DAA processor, active surveillance and CS DAA processor are continuously reporting current status (about every second).
6. Verify that the operational status display changes to the new mode within 1.5 seconds of the pilot mode change.
7. Verify that the high-level DAA operational monitoring function display updates to Standby within 1.5 seconds of the pilot mode change.
8. Verify that the traffic display removes traffic and guidance information.

9. Verify that the pilot selected mode of Standby is consistent with the UA DAA processor operational status, active surveillance operational status, the CS DAA processor operational status and the pilot displays.
10. Set the DAA pilot mode to DAA Traffic Only.
11. Verify that the UA and CS DAA processors generate the normal operational status report.
12. Verify that the UA and CS DAA processors are continuously reporting current status (about every second).
13. Verify that the operational status display changes to the Normal mode within 1.5 seconds of the pilot mode change.
14. Verify that the high-level DAA operational monitoring function displays the new mode within 1.5 seconds of the pilot mode change.
15. Verify that the traffic display only displays traffic information.
16. Verify that the pilot selected mode of Traffic Only is consistent with the UA DAA processor operational status, the CS DAA processor operational status and pilot displays.
17. Set the DAA pilot mode to DAA Guidance.
18. Verify that the UA and CS DAA processors generate normal operational status reports.
19. Verify that the UA and CS DAA processors are continuously reporting current status (about every second).
20. Verify that the operational status mode displays Normal mode within 1.5 seconds of the pilot mode change.
21. Verify that the high-level DAA operational monitoring function displays Normal mode within 1.5 seconds of the pilot mode change.
22. Verify that the traffic displays both traffic and guidance information.
23. Verify that the pilot selected mode of DAA guidance is consistent with the UA DAA processor operational status, the CS DAA processor operational status and pilot displays.
24. Set the DAA pilot mode to Self-Test.
25. Verify that the UA DAA processor, active surveillance and CS DAA processor generate the Standby operational status report.
26. Verify that the UA DAA processor, active surveillance and CS DAA processor are continuously reporting current status (about every second).
27. Verify that the operational status mode display changes to Standby mode within 1.5 seconds of the pilot mode change.
28. Verify that the high-level DAA operational monitoring function displays the new mode within 1.5 seconds of the pilot mode change.
29. Verify that the traffic display removes traffic and guidance information.
30. Verify that feedback is provided for the pilot selected mode of Self-Test, which reports the operational status of the UA DAA processor, active surveillance, and the

CS DAA processor in Standby mode during Self-Test. Ensure the feedback allows the pilot to recognize the difference between Self-Test display states, Display Failure, Normal operational status and pilot standby mode selection. (FAR, Part 25, 1302(b)(3) compliance)

31. Return the pilot selected mode to DAA Guidance.

Test 1: The following test steps are required for TCAS II pilot mode selections for Equipment Class 2 DAA systems.

1. Set the TCAS II subsystem RA pilot mode to RA Off.
2. Verify that the UA and CS DAA processors receive the TA Only operational status report for the TCAS II.
3. Verify that the UA and CS DAA processors are continuously reporting current status (about every second).
4. Verify that the operational status mode display changes to the Normal mode within 1.5 seconds of the pilot mode change.
5. Verify that the high-level DAA operational monitoring function displays the normal mode within 1.5 seconds of the pilot mode change.
6. Verify that the traffic display removes TCAS RA guidance information.
7. Verify that the pilot selected mode of RA Off is consistent with the UA DAA processor operational status, the CS DAA processor operational status (TA Only) and pilot displays.
8. Set the TCAS II subsystem RA pilot mode to RA Manual.
9. Verify that the UA and CS DAA processors receive the TA/RA operational status report for TCAS II.
10. Verify that the UA and CS DAA processors are continuously reporting current status (about every second).
11. Verify that the operational status mode changes to the Normal mode within 1.5 seconds of the pilot mode change.
12. Verify that the high-level DAA operational monitoring function displays Normal mode within 1.5 seconds of the pilot mode change.
13. Verify that the traffic display includes TCAS RA guidance information. Additional tests for Subsection 3.3 verify the auto-manual RA execution.
14. Verify that the pilot selected mode of RA Off is consistent with the UA DAA processor operational status, the CS DAA processor operational status (TA/RA) and pilot displays.
15. Set the TCAS II subsystem RA pilot mode to RA Auto.
16. Verify that the UA and CS DAA processors receive the TA/RA operational status report for TCAS II.
17. Verify that the UA and CS DAA processors are continuously reporting current status (about every second).
18. Verify that the operational status mode display changes to the normal mode within 1.5 seconds of the pilot mode change.

19. Verify that the high-level DAA operational monitoring function displays normal mode within 1.5 seconds of the pilot mode change.
20. Verify that the traffic display includes TCAS RA guidance information. Note, additional installed equipment testing in Subsection 3.3 verifies the auto-manual RA execution.
21. Verify that the pilot selected mode of RA Auto is consistent with the UA DAA processor operational status, the CS DAA processor operational status (TA/RA) and pilot displays.

Test 2: The following test steps are required for all DAA equipment systems to test the pilot mode selections for radar.

Setup: Compel, either by simulation or by actual manipulation, each DAA subsystem equipment article listed in Table 2-26, into normal operation.

1. Verify a normal DAA system operational status and operational status display for all subsystems listed in Table 2-26.
2. Initialize the aircraft with any set of intruders that display traffic, guidance, and if equipped with TCAS II, TCAS intruders with both TA and RA conditions.
3. Set the DAA pilot mode to Guidance.
4. Set the radar pilot mode to Off.
5. Verify that the UA and CS DAA processors receive the Failed operational status report for the radar.
6. Verify that the UA and CS DAA processors and the radar are continuously reporting current status (about every second).
7. Verify that the operational status mode displays Failed mode for the radar within 1.5 seconds of the pilot mode change.
8. Verify that the high-level DAA operational monitoring function displays Degraded mode within 1.5 seconds of the pilot mode change.
9. Verify that the traffic displays both traffic and guidance information and all radar traffic is removed.
10. Verify that the pilot selected mode of Radar Off is consistent with the radar operational status of the radar, the DAA subsystem and pilot displays.
11. Set the radar pilot mode to Standby.
12. Verify that the UA and CS DAA processors receive the standby operational status report for the radar.
13. Verify that the UA and CS DAA processors and the radar are continuously reporting current status (about every second).
14. Verify that the operational status mode displays Normal mode for the radar within 1.5 seconds of the pilot mode change.
15. Verify that the high-level DAA operational monitoring function displays Normal state within 1.5 seconds of the pilot mode change.
16. Verify the traffic display shows both traffic and guidance information and all radar traffic is unavailable.

17. Verify that the pilot selected mode of Radar Standby is consistent with the operational status of the radar, the DAA subsystem and pilot displays.
18. Compel, either by simulation or by actual manipulation, the UA DAA system to be on the ground.
19. Set the radar pilot mode to Transmit.
20. Verify that the UA and CS DAA processors receive the Standby operational status report for the radar.
21. Verify that the UA and CS DAA processors and the radar are continuously reporting current status (about every second).
22. Verify that the operational status mode displays Normal mode for the radar within 1.5 seconds of the pilot mode change.
23. Verify that the high-level DAA operational monitoring function displays Normal state within 1.5 seconds of the pilot mode change.
24. Verify that the traffic display shows both traffic and guidance information and all radar traffic is unavailable.
25. Verify that feedback is provided to the pilot that the pilot selected mode of Radar Transmit is consistent with the radar operational status (Standby), the DAA subsystem operational status, and pilot displays. Transmit is inhibited on the ground
26. Set the radar pilot mode to Standby.
27. Verify that the pilot selected mode of Radar Standby is consistent with the pilot display and the operational status of the radar and DAA subsystem.
28. Set the radar pilot mode to Ground Transmit.
29. Verify that the UA and CS DAA processors receive the Ground Transmit operational status report for the radar.
30. Verify that the UA and CS DAA processors and the radar are continuously reporting current status (about every second).
31. Verify that the operational status mode displays Normal mode for the radar within 1.5 seconds of the pilot mode change.
32. Verify that the high-level DAA operational monitoring function displays Normal state within 1.5 seconds of the pilot mode change.
33. Verify that the traffic displays traffic, guidance and radar information.
34. Verify that the pilot selected mode of Radar Ground Transmit is consistent with the pilot display and the operational status of the radar and DAA subsystem.
35. Set the radar pilot mode to Standby.
36. Verify that the pilot selected mode of Radar Standby is consistent with the pilot display and the operational status of the radar and DAA subsystem.
37. Compel, either by simulation or by actual manipulation, the DAA system to be airborne.
38. Set the radar pilot mode to Transmit.
39. Verify that the UA and CS DAA processors receive the transmit operational status report for the radar.

40. Verify that the UA and CS DAA processors and the radar are continuously reporting current status (about every second).
41. Verify that the operational status mode displays Normal mode for the radar within 1.5 seconds of the pilot mode change.
42. Verify that the high-level DAA operational monitoring function displays Normal state within 1.5 seconds of the pilot mode change.
43. Verify the traffic display shows traffic, guidance and radar information.
44. Verify that the pilot selected mode of Radar Transmit is consistent with the pilot display and the operational status of the radar and DAA subsystem.

Test 3: The following test steps are required for all DAA equipment to inform the pilot if one or more DAA pilot selected modes become unavailable.

Setup: Compel, either by simulation or by actual manipulation, each DAA subsystem equipment article listed in Table 2-26, into normal operation.

1. Verify a normal DAA system operational status and operational status display for all subsystems listed in Table 2-26.
2. Initialize the aircraft with any set of intruders that display Traffic, Guidance, and if equipped with TCAS II, TCAS intruders with both TA and RA conditions.
3. Set the DAA pilot mode to Guidance.
4. Verify that the UA and CS DAA processors generate the normal Operational Status report.
5. Verify that the UA and CS DAA processors are continuously reporting current status (about every second).
6. Verify that the operational status mode displays Normal mode within 1.5 seconds of the pilot mode change.
7. Verify that the high-level DAA operational monitoring function displays Normal mode within 1.5 seconds of the pilot mode change.
8. Verify that the traffic displays both traffic and guidance information.
9. Verify that the pilot selected mode of DAA Guidance is consistent with the UA DAA processor operational status, the CS DAA processor operational status and pilot displays.
10. Compel, either by simulation or by actual manipulation, ownship distance information to be failed for the DAA subsystem equipment article providing this ownship state data.
11. Verify neither the DAA Traffic Only nor the DAA Guidance modes selections are available and an information warning sent the pilot.
12. Verify that feedback for the pilot selected mode selection information is consistent with the UA DAA processor operational status, the CS DAA processor operational status and pilot displays.
13. Remove the ownship data failure.

14. Verify both the DAA Traffic Only and DAA Guidance modes selections are available and the system returns to the system defined recovery state (as specified by the manufacturer).
15. Verify that the pilot selected mode is consistent with the UA DAA processor operational status, the CS DAA processor operational status and pilot displays.
16. Set the DAA pilot mode to Traffic Only.
17. Verify that the UA and CS DAA processors generate the normal Operational Status report.
18. Verify that the UA and CS DAA processors are continuously reporting current status (about every second).
19. Verify that the operational status mode displays Normal mode within 1.5 seconds of the pilot mode change.
20. Verify that the high-level DAA operational monitoring function displays Normal mode within 1.5 seconds of the pilot mode change.
21. Verify that the traffic displays only traffic information.
22. Verify that the pilot selected mode of DAA Guidance is consistent with the UA DAA processor operational status, the CS DAA processor operational status and pilot displays.
23. Compel, either by simulation or by actual manipulation, the ownship speed information to be failed for the DAA subsystem equipment article providing this ownship state data.
24. Verify neither the DAA Traffic Only nor the DAA Guidance modes selections are available and an information warning sent the pilot.
25. Verify that feedback for the pilot selected mode selection information is consistent with the UA DAA processor operational status, the CS DAA processor operational status and pilot displays.
26. Remove the ownship data failure.
27. Verify both the DAA Traffic Only and DAA Guidance modes selections are available and the system returns to the system defined recovery state (as specified by the manufacturer).
28. Verify that the pilot selected mode is consistent with the UA DAA processor operational status, the CS DAA processor operational status and pilot displays.
29. Set the DAA pilot mode to Guidance.
30. Verify that the UA and CS DAA processors generate the normal Operational Status report.
31. Verify that the UA and CS DAA processors are continuously reporting current status (about every second).
32. Verify that the operational status mode displays Normal mode within 1.5 seconds of the pilot mode change.
33. Verify that the high-level DAA operational monitoring function displays Normal mode within 1.5 seconds of the pilot mode change.
34. Verify that the traffic displays both traffic and guidance information.

35. Verify that the pilot selected mode of DAA Guidance is consistent with the UA DAA processor operational status, the CS DAA processor operational status and pilot displays.
36. Compel, either by simulation or by actual manipulation, the ownship altitude information to be failed for the DAA subsystem equipment article providing this ownship state data.
37. Verify neither the DAA Traffic Only nor the DAA Guidance modes selections are available and an information warning sent the pilot.
38. Verify that the pilot selected mode is consistent with the UA DAA processor operational status, the CS DAA processor operational status and pilot displays.
39. Remove the ownship data failure.
40. Verify both the DAA Traffic Only and DAA Guidance modes selections are available and the system returns to the system defined recovery state (as specified by the manufacturer).
41. Verify that the pilot selected mode is consistent with the UA DAA processor operational status, the CS DAA processor operational status and pilot displays.
42. Set the DAA pilot mode to Traffic Only.
43. Verify that the UA and CS DAA processors generate the normal Operational Status report.
44. Verify that the UA and CS DAA processors are continuously reporting current status (about every second).
45. Verify that the operational status mode displays Normal mode within 1.5 seconds of the pilot mode change.
46. Verify that the high-level DAA operational monitoring function displays Normal mode within 1.5 seconds of the pilot mode change.
47. Verify that the traffic displays only traffic information.
48. Verify that the pilot selected mode of DAA Guidance is consistent with the UA DAA processor operational status, the CS DAA processor operational status and pilot displays.
49. Compel, either by simulation or by actual manipulation, the UA DAA processor to be failed for this DAA subsystem equipment article.
50. Verify neither the DAA Traffic Only nor the DAA Guidance modes selections are available and an information warning sent the pilot.
51. Verify that the pilot selected mode is consistent with the UA DAA processor operational status, the CS DAA processor operational status and pilot displays.
52. Remove the UA DAA processor failure.
53. Verify both the DAA Traffic Only and DAA Guidance modes selections are available and the system returns to the system defined recovery state (as specified by the manufacturer).
54. Verify that the pilot selected mode is consistent with the UA DAA processor operational status, the CS DAA processor operational status and pilot displays.
55. Set the DAA pilot mode to Guidance.

56. Verify that the UA and CS DAA processors generate the normal Operational Status report.
57. Verify that the UA and CS DAA processors are continuously reporting current status (about every second).
58. Verify that the operational status mode displays Normal mode within 1.5 seconds of the pilot mode change.
59. Verify that the high-level DAA operational monitoring function displays Normal mode within 1.5 seconds of the pilot mode change.
60. Verify that the traffic displays both traffic and guidance information.
61. Verify that the pilot selected mode of DAA Guidance is consistent with the UA DAA processor operational status, the CS DAA processor operational status and pilot displays.
62. Compel, either by simulation or by actual manipulation, the CS DAA processor to be failed for this DAA subsystem equipment article.
63. Verify neither the DAA Traffic Only nor the DAA Guidance modes selections are available and an information warning sent the pilot.
64. Verify that the pilot selected mode is consistent with the UA DAA processor operational status, the CS DAA processor operational status and pilot displays.
65. Remove the UA DAA processor failure.
66. Verify both the DAA Traffic Only and DAA Guidance modes selections are available and the system returns to the system defined recovery state (as specified by the manufacturer).
67. Verify that the pilot selected mode is consistent with the UA DAA processor operational status, the CS DAA processor operational status and pilot displays.
68. Set the DAA pilot mode to Traffic Only.
69. Verify that the UA and CS DAA processors generate the normal Operational Status report.
70. Verify that the UA and CS DAA processors are continuously reporting current status (about every second).
71. Verify that the operational status mode displays Normal mode within 1.5 seconds of the pilot mode change.
72. Verify that the high-level DAA operational monitoring function displays Normal mode within 1.5 seconds of the pilot mode change.
73. Verify that the traffic displays only traffic information.
74. Verify that the pilot selected mode of DAA Guidance is consistent with the UA DAA processor operational status, the CS DAA processor operational status and pilot displays.
75. Compel, either by simulation or by actual manipulation, the CS DAA traffic display to be failed for this DAA subsystem equipment article.
76. Verify neither the DAA Traffic Only nor the DAA Guidance modes selections are available and an information warning sent the pilot.

77. Verify that the pilot selected mode is consistent with the UA DAA processor operational status, the CS DAA processor operational status and pilot displays.
78. Remove the CS DAA traffic display failure.
79. Verify both the DAA Traffic Only and DAA Guidance modes selections are available and the system returns to the system defined recovery state (as specified by the manufacturer).
80. Verify that the pilot selected mode is consistent with the UA DAA processor operational status, the CS DAA processor operational status and pilot displays.
81. Set the DAA pilot mode to Guidance.
82. Verify that the UA and CS DAA processors generate the normal Operational Status report.
83. Verify that the UA and CS DAA processors are continuously reporting current status (about every second).
84. Verify that the operational status mode displays Normal mode within 1.5 seconds of the pilot mode change.
85. Verify that the high-level DAA operational monitoring function displays Normal mode within 1.5 seconds of the pilot mode change.
86. Verify that the traffic displays both traffic and guidance information.
87. Verify that the pilot selected mode of DAA Guidance is consistent with the UA DAA processor, the CS DAA processor operational status and displayed to the pilot.
88. Compel, either by simulation or by actual manipulation, the CS DAA Control Panel to be failed for this DAA subsystem equipment article.
89. Verify both the DAA Traffic Only and DAA Guidance modes selections are unavailable and an information warning sent the pilot.
90. Verify that the pilot selected mode is consistent with the UA DAA processor, the CS DAA processor operational status and displayed to the pilot.
91. Remove the CS DAA Control Panel failure.
92. Verify both the DAA Traffic Only and DAA Guidance modes selections are available and the system returns to the system defined pilot mode recovery state (as specified by the manufacturer).
93. Verify that the pilot selected mode is consistent with the UA DAA processor operational status, the CS DAA processor operational status and pilot displays.

Note:

1. *Pilot selected modes are commonly displayed on the control head/selector switch, but may be displayed on the same display showing traffic information, or on a utility page accessible to the flight crew, or a subsystem control box, but somewhere the current Pilot Selected Mode can be visibly detectable by the pilot.*
2. *Users may find it possible to include all or parts of the test procedures in Subparagraph 2.4.5.7 – System Status in this test paragraph.*

2.4.7 Pilot Entry Subsystem (§2.2.7)

Requirements related to pilot entry subsystems have been allocated to other subsystems, and Paragraph 2.2.7 contains no requirements. No specific test procedures are required to verify Paragraph 2.2.7.

2.4.8 DAA Subsystem Operational Status (§2.2.8)

This procedure tests the operational status modes for different DAA subsystem mode and equipment article failures.

These test procedures require the actual DAA equipment be included as part of the test setup. A simulated link can be used during the testing as long as a qualified simulation is used to represent the time delay between the aircraft and CS.

Setup: Compel, either by simulation or by actual manipulation, each DAA subsystem equipment article listed in Table 2-26into normal operation.

1. Verify a normal DAA system operational status display for all subsystems listed in Table 2-26.
2. Compel, either by simulation or by actual manipulation, each DAA subsystem into each Operational Status.
3. Verify that the UA and CS DAA processors are receiving the correct Operating Status report.
4. Verify that the UA and CS DAA processors are receiving continuous current reporting (about every second).
5. Verify that the operational status display changes to the new status within 1.5 seconds of status change.
6. Verify that the high-level DAA operational monitoring function display changes to the new status within 1.5 seconds of the operational status change.
7. Repeat for all DAA subsystems listed in Table 2-26.

2.4.8.1 DAA Subsystem Operational Status Reporting Requirement (§2.2.8.1)

This procedure tests the health monitoring function for each subsystem and the timely execution of that function.

Setup: Compel, either by simulation or by actual manipulation, each DAA subsystem equipment article listed in Table 2-26, into normal operation and check for normal DAA system operational status display for all subsystems listed in Table 2-26.

1. Verify that the UA and CS DAA processors receive the Normal Operational Status report.
2. For a subsystem equipment article, compel, either by simulation or by actual manipulation, a condition that causes a “Failed” Operational Status.
3. Verify that the DAA Subsystem Health Monitor generates a “Failed” operational status within 1 second ±0.5 seconds.
4. Clear the failure condition and return that subsystem to Normal operational status.

5. Verify that the DAA Subsystem Health Monitor generates a “Normal” operational status within 1 second ±0.5 seconds.
6. Repeat for all DAA subsystem equipment articles listed.

2.4.8.2 DAA Subsystem Initiation Test (§2.2.8.2)

This procedure tests that each DAA subsystem contains a comprehensive set of test to check the hardware, software and firmware for safe operations.

Verify – Demonstrate that each subsystem (and associated equipment articles) in Table 2-26 provides 100% failure detection for the subsystem functional elements that contribute to Hazardous and Misleading Information (HMI) via appropriate failure analysis, including failure modes and effects that properly account for detection interference. The user should reference SAE 4761 for appropriate failure analysis methods.

Setup: Compel, either by simulation or by actual transmission, a signal indicating to the subsystem the aircraft is on the ground.

1. Start up the DAA system from a power off state.
2. Compel, either by simulation or by actual manipulation, each DAA subsystem equipment article listed in Table 2-26, into normal operation and check a normal DAA system operational status display for all subsystems listed in Table 2-26.
3. Identify all subsystem tests that detect and isolate HMI failures.
4. Select 10% of the above subsystem HMI failure tests for each subsystem equipment article to create a subsystem 10% test list. In the subsystem 10% test list, ensure the test list includes tests that execute only On-ground, only Airborne, and execute during both On ground and Airborne phases.
5. For a test from the above subsystem 10% test list, compel, either by simulation or by actual manipulation, a condition that causes a “Failed” Operational Status and execute that test. Repeat this on ground and airborne when a test executes in both flight phases.
6. Verify that the DAA function stops processing the traffic display.
7. Clear the failure condition, perform a restart and ensure display processing resumes.
8. Repeat through each subsystem until the subsystem 10% test list completes.

2.4.8.3 DAA Subsystem Initiation Test Fail Report (§2.2.8.3)

This procedure tests that each DAA subsystem reports a failure of the initiation test to the UA DAA processor and CS DAA processors

Setup: Compel, either by simulation or by actual manipulation, each DAA subsystem article listed in Table 2-26, into normal operation and verify a nominal DAA system operational status display for all subsystems listed in Table 2-26.

1. For a given subsystem, perform the initiation test and compel, either by simulation or by actual manipulation, a condition that causes a Failed Operational Status during the initiation test.
2. Verify that the UA and CS DAA processors receive the "Failed" Operational Status report.
3. Clear the failure condition, perform a restart to return that subsystem to normal operating mode.
4. Verify that the UA and CS DAA processors receive the "normal" Operational Status report.
5. For that subsystem, perform the initiation test and compel, either by simulation or by actual manipulation, a condition that causes a Degraded Operational Status during the initiation test (if applicable).
6. Verify that the UA and CS DAA processors receive the "degraded" operational status report (as applicable).
7. Clear the failure condition, perform a restart to return to that subsystem to normal operational status.
8. Verify that the UA and CS DAA processors receive the "normal" Operational status report.
9. Repeat for all DAA subsystem articles listed in Table 2-26.

2.4.8.4 DAA Subsystem Operational Status Display (§2.2.8.4)

This procedure tests that each DAA subsystem reporting off-nominal operational status is displayed on the manufacturer's designated system health display. When normal operations status is reported for all subsystem, there is a blank display as the minimal requirement. This test procedure assumes a blank page display for all healthy situations. The manufacturer may need to adjust the test procedure response criteria if they use a non-blank display to represent a healthy system.

Setup: Compel, either by simulation or by actual manipulation, each DAA subsystem equipment article listed in Table 2-26, into normal operation and check for a normal DAA system operational status display for all subsystems listed in Table 2-26.

1. Set up each DAA subsystem equipment article to be operating in a "nominal" Operational Status.
2. For each DAA subsystem equipment article listed in Table 2-26, compel, either by simulation or by actual manipulation, that subsystem to generate a condition that causes a "Failed" Operational Status.
3. Verify that the DAA system operational status display indicates a "Failed" status for that DAA subsystem to the pilot within 2 seconds ±0.5 seconds.
4. Verify that the DAA system operational status display indicates the failed subsystem component to the pilot.
5. Clear the failure condition and return that subsystem to Normal operational Status.
6. Verify that the DAA system operational status display goes blanks within 2 seconds ±0.5 seconds.

7. For each DAA subsystem equipment article listed in Table 2-26, compel, either by simulation or by actual manipulation, that subsystem to generate a condition that causes a “Degraded” Operational Status.
8. Verify that the DAA system operational status display indicates a “Degraded” status for that DAA subsystem to the pilot within 2 seconds ±0.5 seconds.
9. Verify that the DAA system operational status display indicates the degraded subsystem component to the pilot.
10. Clear the failure condition and return that subsystem to Normal operational status.
11. Verify that the DAA system operational status display blanks within 2 seconds ±0.5 seconds.
12. For each DAA subsystem equipment article listed in Table 2-26, compel, either by simulation or by actual manipulation, that subsystem to generate a condition that causes a “Standby” Operational Status.
13. Verify that the DAA system operational status display indicates a “Standby” status, for that DAA subsystem to the pilot within 2 seconds ±0.5 seconds.
14. Clear the failure condition and return that subsystem to Normal operational status.
15. Verify that the DAA system operational status display blanks within 2 seconds ±0.5 seconds.

Note: *Failed, Degraded, or Standby status indications may be displayed on the same display showing traffic information, or on a fault page accessible to the flight crew, or somewhere else (i.e., a DAA subsystem control box in the Control Station) where it can be visibly detectable by the pilot.*

2.4.8.5 DAA Subsystem Lack of Operational Status Report (§2.2.8.5)

This procedure tests that each DAA subsystem reports operational status in a timely manner or the system is considered failed. When normal operations status is reported for all subsystem, there is a blank display as the minimal requirement. This test procedure assumes a blank page display for all healthy situations. The manufacturer may need to adjust the test procedure response criteria if they use a non-blank display to represent a healthy system.

Setup: Compel, either by simulation or by actual manipulation, each DAA subsystem equipment article listed in Table 2-26, into normal operation and check for a normal DAA system operational status display for all subsystems listed in Table 2-26.

1. For each DAA subsystem listed in Table 2-26, compel, either by simulation or by actual manipulation, that subsystem to stop generating operational status reports to the UA DAA processor (keeping the reports to the CS DAA processor valid).
2. Verify that the UA DAA processor registered the lack of a DAA subsystem operational status report as a Failed subsystem on the DAA system operational status display within 5-7 seconds of the last report (no sooner than 5, no later than 7).
3. Clear the failure condition and return that subsystem to Normal operational status .
4. Verify that the DAA system operational status display blanks within 2 seconds ±0.5 seconds.

5. For each DAA subsystem equipment article listed in Table 2-26, compel, either by simulation or by actual manipulation, that subsystem to stop generating an operational status reports to the CS DAA processor (keeping the reports to the UA DAA processor valid).
6. Verify that the CS DAA processor registered the lack of a DAA subsystem operational status report as a Failed subsystem on the DAA system operational status display within 5-7 seconds of the last report (no sooner than 5, no later than 7).
7. Clear the failure condition and return that subsystem to Normal operational status.
8. Verify that the DAA system operational status display blanks within 2 seconds ±0.5 seconds.
9. For each DAA subsystem equipment article listed in Table 2-26, compel, either by simulation or by actual manipulation, that subsystem to stop generating an operational status reports to both the UA DAA processor and the CS DAA processor.
10. Verify that the UA and CS DAA processors registered the lack of a DAA subsystem operational status report as a Failed subsystem on the DAA system operational status display within 5-7 seconds of the last report (no sooner than 5, no later than 7).
11. Clear the failure condition and return that subsystem to Normal operational status.
12. Verify that the DAA system operational status display blanks within 2 seconds ±0.5 second.

2.4.9 High-level DAA Operational Monitoring Function (§2.2.9)

This procedure tests that the DAA system monitoring function collectively reports on the health of all the individual subsystems and displays off-nominal operational state on the manufacturer's designated system health display. A blank display is the minimal requirement for a normal operational state. This test procedure assumes a blank page display for all healthy situations. The manufacturer may need to adjust the test procedure response criteria if a non-blank display is used to represent a healthy system.

Setup: Compel, either by simulation or by actual manipulation, each DAA subsystem equipment article listed in Table 2-26, into normal operation and check for normal display of DAA system operational status and high-level DAA operational monitoring function display.

1. For each subsystem, compel, either by simulation or by actual manipulation, that subsystem to generate a failed operational state.
2. Verify that the high-level DAA operational monitoring function display changes to Failed within 2 seconds ±0.5 seconds.
3. Verify that the Master Caution Warning Light/System illuminates within ±0.5 seconds of the high-level DAA operational monitoring function display change.
4. Clear the failure condition and return that subsystem to a normal operational state.
5. Verify that the high-level DAA operational monitoring function display blanks within 2 seconds ±0.5 seconds.
6. Verify that the Master Caution Warning Light/System is extinguished within ±0.5 seconds of the high-level DAA operational monitoring function display change.

7. For that subsystem, compel, either by simulation or by actual manipulation, that subsystem to generate a Standby operational state (if applicable).
8. Verify that the high-level DAA operational monitoring function display changes to Standby within 2 seconds ±0.5 seconds (only applicable to DAA subsystems that enter Standby via the Pilot Mode selection of Standby or from Pilot Mode selection of Self-Test).
9. Verify that the Master Caution Warning Light/System extinguishes within ±0.5 seconds of the high-level DAA operational monitoring function display change.
10. Clear the failure condition and return that subsystem to a normal operational state.
11. Verify that the high-level DAA operational monitoring function display blanks within 2 seconds ±0.5 seconds.
12. Verify that the Master Caution Warning Light/System remains extinguished within ±0.5 seconds of the high-level DAA operational monitoring function display change.
13. For that subsystem, compel, either by simulation or by actual manipulation, that subsystem to generate a degraded operating mode (if applicable).
14. Verify that the high-level DAA operational monitoring function display changes to Degraded within 2 seconds ±0.5 seconds (as applicable).
15. Verify that the Master Caution Warning Light/System illuminates within ±0.5 seconds of the high-level DAA operational monitoring function display change.
16. Clear the failure condition and return that subsystem to Normal operational state.
17. Verify that the high-level DAA operational monitoring function display blanks within 2 seconds ±0.5 seconds.
18. Verify that the Master Caution Warning Light/System extinguished within ±0.5 seconds of the high-level DAA operational monitoring function display change.
19. Repeat for all DAA subsystems listed in Table 2-26.

2.4.9.1 High-level DAA Operational Monitoring Function Display (§2.2.9.1)

Paragraph 2.4.9 test procedures contain the test cases for this subparagraph's requirements.

2.4.9.2 High-level DAA Operational Monitoring Function Master Caution Warning Light/System

Paragraph 2.4.9 test procedures contain the test cases for this subparagraph's requirements.

2.4.10 Restart after Power Interruption while in Flight (§2.2.10)

Paragraph 2.2.10 does not contain any requirements. No test procedures are required to verify Paragraph 2.2.10.

2.4.11 Environmental Qualification for UA DAA Processor Test Procedure -Airborne

This test verifies that input data is properly received by the UA DAA processor and output data is properly sent by the UA DAA processor for the purposes of verifying operational performance under the airborne environmental conditions. It is not necessary to use the traffic display setup and multiple display orientation/mode testing as referenced in Paragraph 2.4.5 for these tests. The manufacturer should record the data and verify the outputs from the recordings. In addition, simulated UA DAA processor traffic and guidance software can be used to generate data output from the input conditions.

2.4.11.1 Verification of Ownship Input Data

Requirements specific to the correct input format, reception, processing and display of ownship input data are verified under standard conditions as part of the test procedures in Subparagraph 2.4.5.5, as modified at the start of Paragraph 2.4.5. For this test procedure, repeat the test in Subparagraph 2.4.5.5, using Test 2 conditions under the conditions as specified in Table 2-27.

Verify that the appropriate ownship state data is output by the UA DAA processor.

Note: *Ensure that the navigation system is not providing the ownship state information to the display. If it is, then verify the intruder distance from the ownship position information.*

2.4.11.2 Verification of ATAR Input Data

Requirements specific to the correct input format, reception, processing and display of ATAR input data are verified under standard conditions as part of the test procedures in Subparagraph 2.4.5.5, as modified at the start of Paragraph 2.4.5. For this test procedure, repeat the test in Subparagraph 2.4.5.5 using Test 2 conditions, under the conditions as specified in Table 2-27. Use only an ATAR intruder input.

Verify that the ATAR intruder data is output by the UA DAA processor.

2.4.11.3 Verification of Active Surveillance Input Data

Requirements specific to the correct input format, reception, processing and display of active surveillance input data are verified under standard conditions as part of the test procedures in subparagraph 2.4.5.5, as modified at the start of Paragraph 2.4.5. For this test procedure, repeat the test in subparagraph 2.4.5.5 using Test 2 conditions, under the conditions as specified in Table 2-27. Use only an active surveillance intruder input.

Verify that the active surveillance intruder data is an output by the UA DAA processor.

2.4.11.4 Verification of ADS-B/ADS-R Input Data

Requirements specific to the correct input format, reception, processing and display of ADS-B/ADS-R input data are verified under standard conditions as part of the test procedures in subparagraph 2.4.5.5, as modified at the start of Paragraph 2.4.5. For this test procedure, repeat the test in subparagraph 2.4.5.5 using Test 2 conditions, under the conditions as specified in Table 2-27. Use ADS-B or ADS-R intruder input as a minimum.

1. Verify that no TIS-B data is received.
2. Verify that the ADS-B intruder data is output by the UA DAA processor.

2.4.11.5 Verification of TCAS II Input Data (Class 2)

Requirements specific to the correct input format, reception, processing and display of TCAS II input data are verified under standard conditions as part of the test procedures in Subparagraph 2.4.5.6. For this test procedure, repeat the test in subparagraph 2.4.5.6, using Test 2 conditions under the conditions as specified in Table 2-27. Use TCAS II intruder type data input as a minimum.

1. Verify that the TCAS II traffic is output by the UA DAA processor.
2. Verify that the TCAS II Corrective Resolution Advisory is output by the UA DAA processor.

2.4.11.6 Verification of All Surveillance Sources

Class 1 – Requirements specific to the correct input format, reception, processing and display of surveillance source input data are verified under standard conditions as part of the test procedures in Subparagraph 2.4.5.5, at the start of Paragraph 2.4.5. For this test procedure, repeat the test in Subparagraph 2.4.5.5, using Test 2 conditions under the conditions as specified in Table 2-27. Use radar, ADS-B and active surveillance type data input.

Verify that all traffic types are output by the UA DAA processor.

Class 2 – Requirements specific to the correct input format, reception, processing and display of surveillance source input data are verified under standard conditions as part of the test procedures in Subparagraph 2.4.5.6, as modified at the start of Paragraph 2.4.5. For this test procedure, repeat the test in Subparagraph 2.4.5.6, using Test 2 conditions under the conditions as specified in Table 2-27. Use radar, ADS-B and TCAS II type data input.

1. Verify that all traffic types appear on the DAA traffic display.
2. Verify that the TCAS II Corrective Resolution Advisory is output by the UA DAA processor.

2.4.11.7 Verification of Alerting Prioritization

Class 1 – if the alert prioritization resides in the UA DAA processor, repeat the prioritization test in Subparagraph 2.4.4.3.4.1, Step 1 and Step 3 using Test Vector D9, under the conditions as specified in Table 2-29.

Verify the alerting prioritization with a DAA warning alert as the highest level alert.

Class 2 – if the alert prioritization resides in the UA DAA processor, repeat prioritization test in subparagraph 2.4.4.3.4.1, Step 2 and Step 3 using Test Vector D9 under the conditions as specified in Table 2-27.

Verify the alerting prioritization with TCAS II RA as the highest level alert.

Note: *The alerting prioritization function may reside in the UA or CS DAA processor.*

2.4.11.8 Verification of Guidance Processing

If the guidance processing resides in the UA Processor, follow the Guidance Processing test in Paragraph 2.4.12 under the conditions specified in Table 2-27**.**

2.4.12 Environmental Qualification for CS DAA Processor Test Procedure (§2.3 Ground Testing)

This test verifies the input data received by the CS DAA processor and the output data sent by the CS DAA processor for the purposes of verifying corruption of the software when tested under the ground environmental conditions. It is not necessary to use the traffic display setup and multiple display orientation/mode testing as referenced in Paragraph 2.4.5 for these tests. The manufacturer should record the data and verify the outputs from the recordings. In addition, simulated CS DAA processor traffic and guidance software can be used to generate data output from the input conditions.

1. Repeat the test in Subparagraph 2.4.11.1 under the conditions as specified in Table 2-31 for the CS DAA processor.
2. If the alerting prioritization resides in the CS DAA processor, use Test in Subparagraph 2.4.11.7 for the CS DAA processor.
3. Verification of Guidance Processing

   Class 1 – If the guidance processing resides in the CS DAA processor, repeat the test in Subparagraph 2.4.5.5, Test Condition 2 under the environmental conditions as specified in Table 2-31.
4. Verify that the guidance band data is output by the CS DAA processor.

   Class 2 – If the guidance processing resides in the CS DAA processor, repeat the test in Subparagraph 2.4.5.5, Test Condition 2 under the environmental conditions as specified in Table 2-31.
5. Verify that the horizontal guidance band is output by the CS DAA processor and the vertical guidance bands are suppressed when the TCAS II RA is active.

2.4.13 Environmental Qualification for CS DAA Control Panel Test Procedure – Ground

This test verifies the input data received by the CS DAA, TCAS II and/or radar control panel and the output data sent by the CS for the purposes of verifying the article under the ground environmental conditions.

Verify the operation of the control panel per the test procedure in Paragraph 2.4.6 under the environmental conditions as specified in Table 2-31.

2.4.14 Environmental Qualification for DAA Traffic Display Test Procedure (§2.3 Ground Testing)

This test verifies the input data received by the DAA traffic display and the output on the display for the purposes of verifying the article under the ground environmental conditions.

1. For this test procedure, repeat the test in Subparagraph 2.4.5.5, Test Condition 2, under the environmental conditions as specified in Table 2-31.
2. Verify that all traffic types, alerts and guidance bands appear on the DAA traffic display as described in Test Condition 1.

3. Requirements specific to the correct input format, reception, processing and display of surveillance source input data are verified under standard conditions as part of the test procedures in Subparagraph 2.4.5.6, as modified at the beginning of Paragraph 2.4.5. For this test procedure, repeat the test in Subparagraph 2.4.5.6, Test Condition 1, under the environmental conditions as specified in Table 2-31.

4. Verify that all traffic types, alerts, guidance bands and TCAS II RAs appear on the DAA traffic display as described in Test Condition 1.

2.4.15 Requirement-to-Test Procedure Application Coverage

This paragraph defines the application of test procedures required to provide verification coverage for the MOPS specifications. The manufacturer is required to ensure their specific verification program provides test procedure application in accordance with this paragraph. Table 2-36 provides a matrix that maps requirements to specific test sections or steps. A MOPS requirement may be tested by one or more paragraphs in Subsection 2.4.When this occurs the table describes the requirement coverage across these tests. When there is no specific test provided for a requirement, the table provides the necessary means of compliance to verify that requirement. When the Application column is blank, the tests cited provide evidence of compliance

Table 2-36 Requirement to Test Matrix

Section	Title	Req. #	Section	Application
2	Equipment Performance Requirements and Test Procedures	N/A	N/A	Section Header
2.1	General Requirements	N/A	N/A	Section Header
2.1.1	Airworthiness	002	None	The manufacturer is required to provide compliance details to verify the requirement in this section
2.1.2	Intended Function	003 004	None	The manufacturer is required to provide compliance details to verify these requirements in this section
2.1.3	Federal Communications Commission Rules	005	None	The manufacturer is required to provide compliance details to verify the requirement in this section
2.1.4	Fire Protection	006	None	The manufacturer is required to provide compliance details to verify the requirement in this section
2.1.5	Operation of CS Controls	007	None	The manufacturer is required to provide compliance details to verify the requirement in this section
2.1.6	Accessibility of Controls	008	None	The manufacturer is required to provide compliance details to verify the requirement in this section
2.1.7	Effects of Test	009	None	The manufacturer is required to provide compliance details to verify the requirement in this section
2.1.8	Equipment Interfaces	010	None	The manufacturer is required to provide compliance details to verify these requirements in this section
2.1.9	Design Assurance	None	None	Description Only
2.1.10	DAA Equipment Classes and Articles	None	None	Description Only
2.1.10.1	DAA Equipment Classes	None	None	Description Only
2.1.10.2	DAA Equipment Articles	None	None	Description Only
2.2	Equipment Performance Requirements – Standard Conditions	N/A	N/A	Section Header
2.2.1	General Equipment Characteristics	N/A	N/A	Section Header
2.2.1.1	Latency	None	2.4.2.1.1 Latency	The manufacturer is required to provide compliance means to verify latency on actual hardware equipment

Section	Title	Req. #	Section	Application
2.2.1.2	UA DAA Surveillance Equipment	None	None	Description Only
2.2.1.3	ATAR	014	2.4.2.1.4 ATAR	
2.2.1.4	Airborne Active Surveillance	015	None	The manufacturer is required to provide compliance details to verify the requirement in this section
2.2.1.5	ADS-B System	016 017	2.4.2.1.6 ADS-B System	
2.2.1.6	TCAS II (Class 2)	018	None	The manufacturer is required to provide compliance details to verify these requirements in this section
2.2.2	DAA Input/Output Requirements	None	None	Description Only
2.2.2.1	UA DAA Processor Input Data Requirements	None	None	Description Only
2.2.2.1.1	Ownship State Data	021 022 024	2.4.2.2.1.1 Ownship State Data	
2.2.2.1.1	Ownship State Data	019	None	The manufacturer is required to provide additional compliance means to verify full coverage of this requirement
2.2.2.1.1	Ownship State Data	020	None	The manufacturer is required to provide additional compliance means to verify full coverage of this requirement
2.2.2.1.1	Ownship State Data	023	None	The manufacturer is required to provide additional compliance means to verify full coverage of this requirement
2.2.2.1.1	Ownship State Data	025	None	The manufacturer is required to provide additional compliance means to verify full coverage of this requirement
2.2.2.1.1.1	Flight Intent Data	None	None	Description Only
2.2.2.1.2	ATAR Intruder Data	None	2.4.2.2.1.2 ATAR Intruder Data	
2.2.2.1.2	ATAR Intruder Data	027	None	The manufacturer is required to provide additional compliance means to verify full coverage of this requirement

Section	Title	Req. #	Section	Application
2.2.2.1.3	Active Surveillance Intruder Data	028 519 520 521	None	The manufacturer is required to provide compliance details to verify these requirements in this section
2.2.2.1.4	ADS-B In Intruder Data	029 030 031	None	The manufacturer is required to provide compliance details to verify these requirements in this section
2.2.2.1.4	ADS-B In Intruder Data	032	2.4.2.2.1.4 ADS B In Intruder Data	
2.2.2.1.4.1	Intruder ADS-B Traffic State Vector Report Input Requirements	033	2.4.2.2.1.4.1 Intruder ADS B Traffic State Vector Report Input Requirements	The manufacturer is required to provide additional compliance means to verify item "e" of this requirement
2.2.2.1.4.1	Intruder ADS-B Traffic State Vector Report Input Requirements	034	None	The manufacturer is required to provide compliance details to verify the requirement in this section
2.2.2.1.4.2	ADS-B Intruder Mode Status Data Input Requirements	035	None	The manufacturer is required to provide compliance details to verify the requirement in this section
2.2.2.1.4.3	TIS-B/ADS-R Service Status Data – Optional	None	None	Description Only
2.2.2.1.4.4	TCAS II RA Report	036	None	The manufacturer is required to provide compliance details to verify the requirement in this section
2.2.2.1.4.5	Operational Coordination Message	037	None	The manufacturer is required to provide compliance details to verify the requirement in this section
2.2.2.1.5	TCAS II RA Data for Class 2 Equipment Only	522 523 524 532	None	The manufacturer is required to provide compliance details to verify these requirements in this section
2.2.2.1.6	Surveillance Equipment Operating Status and Health Data	041 042 043	None	The manufacturer is required to provide compliance details to verify these requirements in this section
2.2.2.1.7	Flight Control System (FCS)	None	None	Description Only

Section	Title	Req. #	Section	Application
2.2.2.1.8	Control and Non-Payload Communication(s) (CNPC) Data Link	047 525	None	The manufacturer is required to provide compliance details to verify these requirements in this section
2.2.2.2	UA DAA Processor Output Data Requirements	None	None	Description Only
2.2.2.2.1	Prioritized Track Data	048	2.4.2.2.2.1 Prioritized Track	
2.2.2.2.1	Prioritized Track Data	049	None	The manufacturer is required to provide compliance details to verify the requirement in this section
2.2.2.2.1.1	Unique Traffic ID (Traffic Number)	050	None	The manufacturer is required to provide compliance details to verify the requirement in this section
2.2.2.2.1.2	Flight ID	135	None	The manufacturer is required to provide compliance details to verify the requirement in this section
2.2.2.2.1.3	Time of Applicability (TOA)	051	None	The manufacturer is required to provide compliance details to verify the requirement in this section The manufacturer is required to provide compliance means to verify latency on actual hardware equipment
2.2.2.2.1.4	Intruder Alert/Priority	052	None	The manufacturer is required to provide compliance details to verify the requirement in this section
2.2.2.2.1.5	Source Data Type	053	None	The manufacturer is required to provide compliance details to verify the requirement in this section
2.2.2.2.1.6	Validated ADS-B	None	None	Description Only
2.2.2.2.1.7	Air/Ground Status	054	None	The manufacturer is required to provide compliance details to verify the requirement in this section
2.2.2.2.1.8	Relative Horizontal Position	055 056 057	None	The manufacturer is required to provide compliance details to verify these requirements in this section
2.2.2.2.1.9	Relative Horizontal Position Accuracy	None	None	Description Only
2.2.2.2.1.10	Bearing Invalid	None	None	Description Only
2.2.2.2.1.11	Relative Horizontal Velocity	061 062	None	The manufacturer is required to provide compliance details to verify these requirements in this section
2.2.2.2.1.12	Relative Horizontal Velocity Accuracy	None	None	Description Only

Section	Title	Req. #	Section	Application
2.2.2.2.1.13	Relative Altitude	058 059 060	None	The manufacturer is required to provide compliance details to verify these requirements in this section
2.2.2.2.1.14	Relative Altitude Accuracy	None	None	Description Only
2.2.2.2.1.15	Altitude Invalid	None	None	Description Only
2.2.2.2.1.16	Relative Vertical Speed	063 064 065	None	The manufacturer is required to provide compliance details to verify these requirements in this section
2.2.2.2.1.17	Relative Vertical Speed Accuracy	066	None	The manufacturer is required to provide compliance details to verify the requirement in this section
2.2.2.2.2	DAA System Modes of Operation and Health Status	067	None	The manufacturer is required to provide compliance details to verify the requirement in this section
2.2.2.2.3	TCAS II RA – Equipment Class 2	068	None	The manufacturer is required to provide compliance details to verify the requirement in this section
2.2.2.2.3.1	Flight Control System Commands from the UA DAA Processor	None	None	Description Only
2.2.2.2.4	Onboard Data Recording Capability	069 070	2.4.2.2.2.5 Onboard Data Recording Capability	
2.2.2.2.4	Onboard Data Recording Capability	071	None	The manufacturer is required to provide compliance details to verify the requirement in this section
2.2.2.3	CS DAA Processor Input Requirements	072	None	The manufacturer is required to provide compliance details to verify the requirement in this section
2.2.2.4	CS DAA Processor Output Data Requirements	073	None	The manufacturer is required to provide compliance details to verify the requirement in this section
2.2.2.4.1	CS DAA Processor Health Status Data	074	None	The manufacturer is required to provide compliance details to verify the requirement in this section
2.2.2.5	DAA Control Panel Input Requirements	075	None	The manufacturer is required to provide compliance details to verify the requirement in this section
2.2.2.6	DAA Control Panel Output Requirements	076	None	The manufacturer is required to provide compliance details to verify the requirement in this section
2.2.2.7	CS DAA Traffic Display Input Data Requirements	077	None	The manufacturer is required to provide compliance details to verify the requirement in this section

Section	Title	Req. #	Section	Application
2.2.2.7.1	Ownship Pressure Altitude	078 079	None	The manufacturer is required to provide compliance details to verify the requirement in this section
2.2.2.7.2	Ownship Length and Width Code	080	None	The manufacturer is required to provide compliance details to verify the requirement in this section
2.2.3	Active Surveillance, Equipment Class 2 RA Function and Tracker Performance Requirements	None	None	Description Only
2.2.3.1	DAA Active Surveillance and DAA Equipment Class 2 RA Function Requirement	None	None	Description Only
2.2.3.1.1	DAA Active Surveillance	085 086	2.4.3.1.1 DAA Equipment Class 1 Active Surveillance	
2.2.3.1.2	DAA with TCAS II Resolution Advisory Functionality (Equipment Class 2)	087	2.4.3.1.2 DAA with Optional TCAS II RA Functionality (Equipment Class 2)	
2.2.3.2	DAA Tracker - Surveillance Data Processing and Tracking Requirements	None	None	Description Only
2.2.3.2.1	Track Management	088 089	2.4.3.2.1 Track Management	
2.2.3.2.1.1	Track Initiation	090 091 092 093	2.4.3.2.1.1 Track Initiation	
2.2.3.2.1.2	Track Capacity	094 095 096	2.4.3.2.1.2 Track Capacity	

Section	Title	Req. #	Section	Application
2.2.3.2.1.3	ADS-B Report Processing and Track Maintenance	097	2.4.3.2.1.3 ADS-B Report Processing and Track Maintenance	The manufacturer is required to provide compliance details to verify the requirement in this section
2.2.3.2.1.3.1	ADS-B and ADS-R Report Validity Checks	098 099 100	2.4.3.2.1.3.1 ADS B and ADS R Report Validity Checks	
2.2.3.2.1.3.2	ADS-B Velocity Quality Monitoring	None	None	Description Only
2.2.3.2.1.3.3	Duplicate Address Processing	None	None	Description Only
2.2.3.2.1.3.3.1	Duplicate Address Processing for 1090 MHz Systems	101 102 103 104 105 106 107	2.4.3.2.1.3.3.1 Duplicate Address Processing for 1090 MHz Systems	The manufacturer is required to provide compliance details to verify the requirement in this section
2.2.3.2.1.3.3.2	Duplicate Address Processing for Optional UAT Systems	108	2.4.3.2.1.3.3.2 Duplicate Address Processing for Optional UAT Systems	
2.2.3.2.1.3.3.2	Duplicate Address Processing for Optional UAT Systems	508 509	None	The manufacturer is required to provide compliance details to verify these requirements in this section
2.2.3.2.1.3.4	Additional Validation of ADS-B Traffic Position with Active Surveillance or Radar	109 110	2.4.3.2.1.3.3.3 2.4.3.2.1.3.4 Additional Validation of ADS B Traffic Position with Active Surveillance or Radar	The manufacturer is required to provide compliance details to verify these requirements in this section
2.2.3.2.1.3.4	Additional Validation of ADS-B Traffic Position with Active Surveillance or Radar	526 527	None	The manufacturer is required to provide compliance details to verify these requirements in this section

Section	Title	Req. #	Section	Application
2.2.3.2.1.3.4.1	Validation of Traffic Position with Active Surveillance	111 112 113 114	2.4.3.2.1.3.3.4 2.4.3.2.1.3.4.1 Validation of Traffic Position with Active Surveillance	
2.2.3.2.1.3.4.2	Validation of Traffic Position with Radar Data	115	2.4.3.2.1.3.3.5 2.4.3.2.1.3.4.2 Validation of Traffic Position with Radar Data	
2.2.3.2.1.3.4.2	Validation of Traffic Position with Radar Data	116 117	None	The manufacturer is required to provide compliance details to verify these requirements in this section
2.2.3.2.1.4	Track Termination	118	2.4.3.2.1.4 Track Termination	The manufacturer is required to provide compliance details to verify the requirement in this section
2.2.3.2.1.4	Track Termination	119 120	None	The manufacturer is required to provide compliance details to verify these requirements in this section
2.2.3.2.2	Data Association	121 122 123 124 125	2.4.3.2.2 Data Association	The manufacturer is required to provide compliance details to verify these requirements in this section
2.2.3.2.3	State Estimation	126 129 130 131 528 529	2.4.3.2.3 State Estimation	The manufacturer is required to provide compliance details to verify these requirements in this section The manufacturer is required to provide compliance means to verify updates occur at a minimum of 1 Hz on actual hardware equipment
2.2.3.2.3	State Estimation	127 128	None	The manufacturer is required to provide compliance details to verify these requirements in this section. The manufacturer is required to provide additional compliance means to verify Time of Applicability (TOA) coverage of these requirements

Section	Title	Req. #	Section	Application
2.2.3.2.3.1	Individual Time of Track Extrapolation and Traffic State File Generation	132	2.4.3.2.3.1 Individual Time of Track Extrapolation and Traffic State File Generation	The manufacturer is required to provide compliance details to verify these requirements in this section. Additional testing required by manufacturer: 1) The manufacturer is required to provide additional compliance means to verify Time of Applicability (TOA) coverage of these requirements 2) The manufacturer is required to provide compliance means to verify latency on actual hardware equipment
2.2.4	Track Alerting and Guidance Processing Requirements	None	None	Description Only
2.2.4.1	DAA Alert and Guidance Suppression Requirements	178 179 180 181 182	2.4.4.1 DAA Alert and Guidance Suppression Requirements	
2.2.4.1	DAA Alert and Guidance Suppression Requirements	183	None	The manufacturer is required to provide compliance details to verify these requirements in this section
2.2.4.1.1	Intruder-Specific Alerting and Guidance Suppression	184 185	2.4.4.1.1 Intruder-Specific Alerting and Guidance Suppression	
2.2.4.2	Ownship Intent Information Requirements	186	None	The manufacturer is required to provide compliance details to verify these requirements in this section
2.2.4.3	DAA Alerting Requirements	None	None	Description Only
2.2.4.3.1	DAA Well Clear (DWC) Definition	None	None	Description Only
2.2.4.3.2	Hazard Zone Definition	None	None	Description Only
2.2.4.3.3	Non-Hazard Zone Definition	None	None	Description Only
2.2.4.3.4	Alert Types and Prioritization	None	None	Description Only
2.2.4.3.4.1	Prioritization of Alert Types	187 188 190 510	None	The manufacturer is required to provide compliance details to verify these requirements in this section

Section	Title	Req. #	Section	Application
2.2.4.3.4.1	Prioritization of Alert Types	189	2.4.4.3.4.1 Prioritization of Alert Types	Step 1
2.2.4.3.4.1	Prioritization of Alert Types	191	2.4.4.3.4.1 Prioritization of Alert Types	Step 4 The manufacturer is required to provide additional compliance means to verify downlink order when prioritized by display prioritization order is different than alerting order
2.2.4.3.4.1	Prioritization of Alert Types	192	2.4.4.3.4.1 Prioritization of Alert Types	Step 5 The manufacturer is required to provide compliance means to verify updates occur at minimum 1 Hz on actual hardware equipment
2.2.4.3.4.2	Preventive Alert	193	2.4.4.3.4.2 Preventive Alert	Step 1
2.2.4.3.4.2	Preventive Alert	194 195	2.4.4.3.4.2 Preventive Alert	Step 2 The manufacturer is required to provide compliance details to demonstrate the 20 second threshold (requirement 194) test cases and alternative method threshold (requirement 195) test cases are equivalent to the test vectors in appendix P when encounters are scored using the methods other than the encounter characterization files
2.2.4.3.4.2	Preventive Alert	196	2.4.4.3.4.2 Preventive Alert	Step 3 The manufacturer is required to provide compliance details to verify the requirement in this section when encounters are scored using a means other than the encounter characterization files
2.2.4.3.4.2	Preventive Alert	197	2.4.4.3.4.2 Preventive Alert	Step 4 The manufacturer is required to provide compliance details to verify the requirement in this section

Section	Title	Req. #	Section	Application
2.2.4.3.4.2	Preventive Alert	198 199	2.4.4.3.4.2 Preventive Alert	Step 5 The manufacturer is required to provide compliance details to demonstrate the 75 second threshold (requirement 198) test cases and alternative method threshold (requirement 199) test cases are equivalent to the test vectors in appendix P when encounters are scored using the methods other than the encounter characterization files
2.2.4.3.4.2	Preventive Alert	200	2.4.4.3.4.2 Preventive Alert	Step 6
2.2.4.3.4.2	Preventive Alert	201	2.4.4.3.4.2 Preventive Alert	Step 2 & Step 5 The manufacturer is required to provide compliance details to verify the requirement in this section when encounters are scored using a means other than the encounter characterization files
2.2.4.3.4.3	Corrective Alert	202 203	2.4.4.3.4.3 Corrective Alert	Step 1 & Step 5 The manufacturer is required to provide compliance details to demonstrate the 20 second threshold (requirement 202) test cases and alternative method threshold (requirement 203) test cases are equivalent to the test vectors in appendix P when encounters are scored using the methods other than the encounter characterization files
2.2.4.3.4.3	Corrective Alert	204	2.4.4.3.4.3 Corrective Alert	Step 2 The manufacturer is required to provide compliance using the LL-type test vectors to verify the requirement in this section The manufacturer is required to provide compliance details to verify the requirement in this section when encounters are scored using a means other than the encounter characterization files
2.2.4.3.4.3	Corrective Alert	205	2.4.4.3.4.3 Corrective Alert	Step 3 The manufacturer is required to provide compliance details to verify the requirement in this section

Section	Title	Req. #	Section	Application
2.2.4.3.4.3	Corrective Alert	206 207	2.4.4.3.4.3 Corrective Alert	Step 4 & Step 5 The manufacturer is required to provide compliance details to demonstrate the 75 second threshold (requirement 206) test cases and alternative method threshold (requirement 207) test cases are equivalent to the test vectors in appendix P when encounters are scored using the methods other than the encounter characterization files
2.2.4.3.4.3	Corrective Alert	208	2.4.4.3.4.3 Corrective Alert	Step 5
2.2.4.3.4.3	Corrective Alert	209	2.4.4.3.4.3 Corrective Alert	Step 1 & Step 4 The manufacturer is required to provide compliance details to verify the requirement in this section when encounters are scored using a means other than the encounter characterization files
2.2.4.3.4.4	Warning Alert	210	None	The manufacturer is required to provide compliance details to verify the requirement in this section
2.2.4.3.4.4	Warning Alert	211 212	2.4.4.3.4.4 Warning Alert	Step 1 & Step 5 The manufacturer is required to provide compliance details to demonstrate the 15 second threshold (requirement 211) test cases and alternative method threshold (requirement 212) test cases are equivalent to the test vectors in appendix P when encounters are scored using the methods other than the encounter characterization files
2.2.4.3.4.4	Warning Alert	213	2.4.4.3.4.4 Warning Alert	Step 2 The manufacturer is required to provide compliance using the LL-type test vectors to verify the requirement in this section
2.2.4.3.4.4	Warning Alert	214	2.4.4.3.4.4 Warning Alert	Step 3The manufacturer is required to provide compliance details to verify the requirement in this section

Section	Title	Req. #	Section	Application
2.2.4.3.4.4	Warning Alert	215 216	2.4.4.3.4.4 Warning Alert	Step 4 & Step 5 The manufacturer is required to provide compliance details to demonstrate the 75 second threshold (requirement 215) test cases and alternative method threshold (requirement 216) test cases are equivalent to the test vectors in appendix P when encounters are scored using the methods other than the encounter characterization files
2.2.4.3.4.4	Warning Alert	217	2.4.4.3.4.4 Warning Alert	Step 5
2.2.4.3.4.4	Warning Alert	218	2.4.4.3.4.4 Warning Alert	Step 1 & Step 4 The manufacturer is required to provide compliance details to verify the requirement in this section when encounters are scored using a means other than the encounter characterization files
2.2.4.3.5	Alerting Special Cases	None	None	Description Only
2.2.4.3.5.1	Radar Only	None	None	Description Only
2.2.4.3.5.1.1	Preventive	219	2.4.4.3.5.1.1 Radar Only – Preventive	The manufacturer is required to invalidate all non-radar inputs for test vectors
2.2.4.3.5.1.2	Corrective	220	2.4.4.3.5.1.2 Radar Only – Corrective	The manufacturer is required to invalidate all non-radar inputs for test vectors The manufacturer is required to execute test vector H5 to demonstrate corrective alerts occur with radar only conditions
2.2.4.3.5.1.2	Corrective	221	2.4.4.3.5.1.2 Radar Only – Corrective	The manufacturer is required to invalidate all non-radar inputs for test vectors The manufacturer is required to execute test vector H5 to demonstrate corrective alerts occur with radar only conditions
2.2.4.3.5.1.3	Warning	222	None	The manufacturer is required to provide compliance details to verify the requirement in this section
2.2.4.3.5.1.3	Warning	223	2.4.4.3.5.1.2 Radar Only – Corrective	The manufacturer is required to provide compliance details to verify the requirement in this section

Section	Title	Req. #	Section	Application
2.2.4.3.5.2	No Bearing	None	None	Description Only
2.2.4.3.5.2.1	Preventive	224	2.4.4.3.5.2.1 No Bearing – Preventive	
2.2.4.3.5.2.2	Corrective	225	2.4.4.3.5.2.2 No Bearing – Corrective	Steps1 & Step 2
2.2.4.3.5.2.2	Corrective	226	2.4.4.3.5.2.2 No Bearing – Corrective	Step 3 & Step 4 The manufacturer is required to provide additional test scenario to verify that [HMD_p>⟦HMD`⟧^*] term is ignored in the corrective non-hazard zone
2.2.4.3.5.2.3	Warning	227	2.4.4.3.5.2.3 No Bearing – Warning	Steps1 & Step 2
2.2.4.3.5.2.3	Warning	228	2.4.4.3.5.2.3 No Bearing – Warning	Step 3 & Step 4 The manufacturer is required to provide additional test scenario to verify that [HMD_p>⟦HMD`⟧^*] term is ignored in the warning non-hazard zone
2.2.4.3.5.3	No Altitude	None	None	Description Only
2.2.4.3.5.3.1	Preventive	229	2.4.4.3.5.3.1 No Altitude – Preventive	Step 1 & Step 2
2.2.4.3.5.3.2	Corrective	230	2.4.4.3.5.3.2 No Altitude – Corrective	Step 1 & Step 2
2.2.4.3.5.3.2	Corrective	231	2.4.4.3.5.3.2 No Altitude – Corrective	Step 3 & Step 4 The manufacturer is required to provide additional test scenario to verify that [d_h>V] term is ignored in the corrective non-hazard zone
2.2.4.3.5.3.3	Warning	232	2.4.4.3.5.3.3 No Altitude – Warning	Step 1 & Step 2

Section	Title	Req. #	Section	Application
2.2.4.3.5.3.3	Warning	233	2.4.4.3.5.3.3 No Altitude – Warning	Step 3 & Step 4 The manufacturer is required to provide additional test scenario to verify that [d_h>V] term is ignored in the corrective non-hazard zone
2.2.4.4	Guidance Processing Requirements	234 235	None	The manufacturer is required to provide compliance details to verify these requirements in this section The manufacturer is required to provide compliance means to verify that updates occur at minimum 1 Hz on actual hardware equipment
2.2.4.4	Guidance Processing Requirements	236	2.4.4.4 Guidance Processing Requirements	Step 3 The manufacturer is required to provide compliance means to verify updates occur at minimum 1 Hz on actual hardware equipment
2.2.4.4	Guidance Processing Requirements	237	None	The manufacturer is required to provide compliance details to verify these requirements in this section The manufacturer is required to provide compliance means to verify latency on actual hardware equipment
2.2.4.4	Guidance Processing Requirements	238	2.4.4.4 Guidance Processing Requirements	Step 4 The manufacturer is required to provide compliance details to verify this requirement in this section
2.2.4.4	Guidance Processing Requirements	239 240	None	The manufacturer is required to provide compliance details to verify these requirements in this section
2.2.4.4.1	DAA Maneuver Guidance to Maintain DWC	None	None	Description Only
2.2.4.4.1.1	Preventive Maneuver Guidance	241	2.4.4.4.1.1 Preventive Maneuver Guidance	Step 1
2.2.4.4.1.1	Preventive Maneuver Guidance	242	2.4.4.4.1.1 Preventive Maneuver Guidance	Step 2
2.2.4.4.1.1	Preventive Maneuver Guidance	243	2.4.4.4.1.1 Preventive Maneuver Guidance	Step 3

Section	Title	Req. #	Section	Application
2.2.4.4.1.1	Preventive Maneuver Guidance	244	2.4.4.4.1.1 Preventive Maneuver Guidance	Step 4
2.2.4.4.1.2	Corrective Maneuver Guidance	245	2.4.4.4.1.3 Warning Maneuver Guidance	Step 1
2.2.4.4.1.2	Corrective Maneuver Guidance	246	2.4.4.4.1.3 Warning Maneuver Guidance	Step 2
2.2.4.4.1.2	Corrective Maneuver Guidance	247	None	The manufacturer is required to provide compliance details to verify these requirements in this section
2.2.4.4.1.2	Corrective Maneuver Guidance	248	2.4.4.4.1.3 Warning Maneuver Guidance	Step 3
2.2.4.4.1.2	Corrective Maneuver Guidance	249	None	The manufacturer is required to provide compliance details to verify these requirements in this section
2.2.4.4.1.2	Corrective Maneuver Guidance	250	2.4.4.4.1.3 Warning Maneuver Guidance	Step 4
2.2.4.4.1.3	Warning Maneuver Guidance	251	2.4.4.4.1.3 Warning Maneuver Guidance	Step 1
2.2.4.4.1.3	Warning Maneuver Guidance	252	2.4.4.4.1.3 Warning Maneuver Guidance	Step 2
2.2.4.4.1.3	Warning Maneuver Guidance	253	2.4.4.4.1.3 Warning Maneuver Guidance	Step 6 & Step 7
2.2.4.4.1.3	Warning Maneuver Guidance	254	2.4.4.4.1.3 Warning Maneuver Guidance	Step 3
2.2.4.4.1.3	Warning Maneuver Guidance	255	None	The manufacturer is required to provide compliance details to verify these requirements in this section

Section	Title	Req. #	Section	Application
2.2.4.4.1.3	Warning Maneuver Guidance	256	2.4.4.4.1.3 Warning Maneuver Guidance	Step 4
2.2.4.4.2	DAA Maneuver Guidance to Regain DWC	257 258 259	None	The manufacturer is required to provide compliance details to verify these requirements in this section
2.2.4.4.2	DAA Guidance to Regain DWC	260	2.4.4.4.2 DAA Guidance to Regain DWC	Step 4, Step 5 & Step 6
2.2.4.4.2	DAA Guidance to Regain DWC	261 262	None	The manufacturer is required to provide compliance details to verify these requirements in this section
2.2.4.4.2	DAA Guidance to Regain DWC	263	2.4.4.4.2 DAA Guidance to Regain DWC	Step 9
2.2.4.4.2	DAA Guidance to Regain DWC	264	2.4.4.4.2 DAA Guidance to Regain DWC	Step 10, Step 11 & Step 12
2.2.4.4.2	DAA Guidance to Regain DWC	265 266 267	None	The manufacturer is required to provide compliance details to verify these requirements in this section
2.2.4.4.2	DAA Guidance to Regain DWC	530	2.4.4.4.2 DAA Guidance to Regain DWC	Step 3
2.2.4.4.3	Guidance Processing for Multi-AC Encounter w/ Corrective RA and DAA Warning Alert	268	2.4.4.4.3 Guidance Processing for an MTE with a Corrective RA and DAA Warning Alert – Class 2	Step 1, Step 2 & Step 3
2.2.4.4.3	Guidance Processing for Multi-AC Encounter w/ Corrective RA and DAA Warning Alert	269	2.4.4.4.3 Guidance Processing for an MTE with a Corrective RA and DAA Warning Alert – Class 2	Step 4, Step 5 & Step 6

Section	Title	Req. #	Section	Application
2.2.4.4.4	Guidance Processing Special Cases	None	None	Description Only
2.2.4.4.4.1	Maintain DAA Well Clear	None	None	Description Only
2.2.4.4.4.1.1	Radar Only	None	None	Description Only
2.2.4.4.4.1.1.1	Preventive Maneuver Guidance	270	2.4.4.4.4.1.1.1 Preventive Maneuver Guidance – Radar Only	Step 1 The manufacturer is required to ensure Radar Only sensor inputs used in this section encounters
2.2.4.4.4.1.1.2	Corrective Maneuver Guidance	271	2.4.4.4.4.1.1.2 Corrective Maneuver Guidance – Radar Only	Step 1 & Step2 The manufacturer is required to ensure Radar Only sensor inputs used in this section encounters
2.2.4.4.4.1.1.3	Warning Maneuver Guidance	272	2.4.4.4.4.1.1.3 Warning Maneuver Guidance – Radar Only	Step 1 & Step 2 The manufacturer is required to ensure Radar Only sensor inputs used in this section encounters
2.2.4.4.4.1.2	No Bearing	None	None	Description Only
2.2.4.4.4.1.2.1	Preventive Maneuver Guidance	273	2.4.4.4.4.1.2.1 Preventive Maneuver Guidance – No Bearing	
2.2.4.4.4.1.2.2	Corrective Maneuver Guidance	274	2.4.4.4.4.1.2.2 Corrective Maneuver Guidance – No Bearing	
2.2.4.4.4.1.2.3	Warning Maneuver Guidance	275	2.4.4.4.4.1.2.3 Warning Maneuver Guidance – No Bearing	
2.2.4.4.4.1.3	No Altitude	None	None	Description Only
2.2.4.4.4.1.3.1	Preventive Maneuver Guidance	276	2.4.4.4.4.1.3.1 Preventive Maneuver Guidance – No Altitude	

Section	Title	Req. #	Section	Application
2.2.4.4.4.1.3.2	Corrective Maneuver Guidance	277	2.4.4.4.4.1.3.2 Corrective Maneuver Guidance – No Altitude	The manufacturer is required to provide compliance details to verify these requirements in this section
2.2.4.4.4.1.3.3	Warning Maneuver Guidance	278	2.4.4.4.4.1.3.3 Warning Maneuver Guidance – No Altitude	The manufacturer is required to provide compliance details to verify these requirements in this section
2.2.4.4.4.2	Regain DAA Well Clear	None	None	Description Only
2.2.4.4.4.2.1	Radar Only	279	2.4.4.4.4.2.1 Radar Only Special Case	
2.2.4.4.4.2.2	No Bearing	280	2.4.4.4.4.2.2 No Bearing Special Case	
2.2.4.4.4.2.3	No Altitude	281	2.4.4.4.4.2.3 No Altitude Special Case	
2.2.4.5	Collision Avoidance Interoperability Requirements for Guidance	None	None	Description Only
2.2.4.5.1	Class 2 Collision Avoidance (CA) RA Guidance	282	2.4.4.5.1 Class 2 CA RA Guidance	Steps 1-4 & Step 8
2.2.4.5.1	Class 2 Collision Avoidance (CA) RA Guidance	283	None	The manufacturer is required to provide compliance details to verify these requirements in this section
2.2.4.5.1	Class 2 Collision Avoidance (CA) RA Guidance	284	2.4.4.4.4.2.3 No Altitude Special Case	Steps 5, 6, 7 & 9
2.2.4.5.1	Class 2 Collision Avoidance (CA) RA Guidance	285	None	The manufacturer is required to provide compliance details to verify these requirements in this section
2.2.4.5.2	Vertical DAA Guidance	None	None	Description Only

Section	Title	Req. #	Section	Application
2.2.4.5.2.1	Determining Intruders’ Vertical RA Capability	286 287	2.4.4.5.2.1 Determining Intruders’ Vertical RA Capability	
2.2.4.5.2.2	Determining Intruders’ Vertical Resolution Advisory Complement (VRC) Information	288	2.4.4.5.2.2 Determining Intruders’ VRC Information	Steps 1-6 The manufacturer is required to provide additional test scenario to verify VRC = 3 registers the intruder VRC of “None”
2.2.4.5.2.2	Determining Intruders’ Vertical Resolution Advisory Complement (VRC) Information	289	2.4.4.5.2.2 Determining Intruders’ VRC Information	Steps 7-10 The manufacturer is required to provide additional test scenario to verify VRC = 3 and VRC =0 registers the intruder VRC of “None”
2.2.4.5.2.2	Determining Intruders’ Vertical Resolution Advisory Complement (VRC) Information	290	2.4.4.5.2.2 Determining Intruders’ VRC Information	Steps 11-14 The manufacturer is required to provide additional test scenario to verify VRC = 3 and VRC =0 registers the intruder VRC of “None”
2.2.4.5.2.2	Determining Intruders’ Vertical Resolution Advisory Complement (VRC) Information	291	2.4.4.5.2.2 Determining Intruders’ VRC Information	Steps 15-20
2.2.4.5.2.2	Determining Intruders’ Vertical Resolution Advisory Complement (VRC) Information	292	2.4.4.5.2.2 Determining Intruders’ VRC Information	Steps 21 -22
2.2.4.5.2.3	Vertical DAA Guidance Modification	293	2.4.4.5.2.3 Vertical DAA Guidance Modification	Steps 1-2
2.2.4.5.2.3	Vertical DAA Guidance Modification	294	2.4.4.5.2.3 Vertical DAA Guidance Modification	Steps 3-4

Section	Title	Req. #	Section	Application
2.2.4.5.2.3	Vertical DAA Guidance Modification	295	2.4.4.5.2.3 Vertical DAA Guidance Modification	Steps 5-6
2.2.4.5.2.3	Vertical DAA Guidance Modification	296	2.4.4.5.2.3 Vertical DAA Guidance Modification	Steps 7-8
2.2.4.5.2.3	Vertical DAA Guidance Modification	297	2.4.4.5.2.3 Vertical DAA Guidance Modification	Steps 9-10
2.2.4.5.2.3	Vertical DAA Guidance Modification	298	2.4.4.5.2.3 Vertical DAA Guidance Modification	Steps 11-12
2.2.4.5.2.3	Vertical DAA Guidance Modification	299	2.4.4.5.2.3 Vertical DAA Guidance Modification	Step 13 The manufacturer is required to vary the VRC vertical speed during the test
2.2.4.5.2.3	Vertical DAA Guidance Modification	500	2.4.4.5.2.3 Vertical DAA Guidance Modification	Steps 14-15 The manufacturer is required to vary the VRC vertical speed during the test
2.2.4.5.3	Horizontal DAA Guidance	501	2.4.4.5.3 Horizontal DAA Guidance	Steps 1-4
2.2.4.5.3	Horizontal DAA Guidance	502	2.4.4.5.3 Horizontal DAA Guidance	Steps 5-8
2.2.4.5.3	Horizontal DAA Guidance	503	2.4.4.5.3 Horizontal DAA Guidance	Steps 9-11

Section	Title	Req. #	Section	Application
2.2.4.5.3	Horizontal DAA Guidance	504	2.4.4.5.3 Horizontal DAA Guidance	Steps 11-12
2.2.4.5.3	Horizontal DAA Guidance	505	2.4.4.5.3 Horizontal DAA Guidance	Steps 13-14
2.2.4.5.3	Horizontal DAA Guidance	506	2.4.4.5.3 Horizontal DAA Guidance	Steps 15-16
2.2.4.5.3	Horizontal DAA Guidance	507	2.4.4.5.3 Horizontal DAA Guidance	Steps 17-18
2.2.5	DAA Traffic Display Subsystem Requirements	N/A	N/A	Section Header
2.2.5.1	General DAA Traffic Display Requirements	None	None	Description Only
2.2.5.2	Traffic Display Criteria (TDC) Requirements	300	2.4.5.1.2 Traffic Display Criteria	Test 1a Test 1d
2.2.5.2	Traffic Display Criteria (TDC) Requirements	301	2.4.5.1.2 Traffic Display Criteria	Test 1a Test 1b Test 1c Test 1d
2.2.5.2.1	Default Traffic Display Criteria	302	2.4.5.1.2.1 Alternative Traffic Display Criteria	
2.2.5.3	DAA Traffic Display Information Requirements	303	2.4.5.1.1.1 Ownship Symbol - General	Ownship Position
2.2.5.3	DAA Traffic Display Information Requirements	303	2.4.5.1.3 Traffic Information	Range & Altitude bands: Steps 1, 2, & 6
2.2.5.3	DAA Traffic Display Information Requirements	304	2.4.5.1.3 Traffic Information	Steps 14, 17, & 18 The manufacturer is required to provide additional compliance means to verify traffic altitude coverage of this requirement
2.2.5.4	Interface Requirements	N/A	N/A	Section Header

Section	Title	Req. #	Section	Application
2.2.5.4.1	DAA Traffic Display Latency Requirements	305	2.4.5.1.2.4 DAA Traffic Display Latency	Step 1 Additional testing required by manufacturer: 1) The manufacturer is required to provide additional compliance means to verify traffic altitude coverage of this requirement 2) The manufacturer is required to provide compliance means to verify latency on actual hardware equipment
2.2.5.4.2	Time of Applicability of Traffic State Vector (SV) Data	306	2.4.5.1.2.4 DAA Traffic Display Latency	Step 2 The manufacturer is required to provide compliance means to verify updates occur at minimum 1 Hz on actual hardware equipment
2.2.5.5	Display Design Requirements – General	N/A	N/A	Section Header
2.2.5.5.1	Display Characteristics	307	2.4.5.9 Display Visibility	Step 2
2.2.5.5.2	Dynamics	None	None	Description Only
2.2.5.5.3	Labels	None	None	Description Only
2.2.5.5.4	Symbols	308	2.4.5.1.3 Traffic Information	Step 10
2.2.5.6	Display Elements Requirements	None	None	Description Only
2.2.5.6.1	Ownship Symbol	309	2.4.5.1.1.1 Ownship Symbol - General	Step 1
2.2.5.6.1	Ownship Symbol	310	2.4.5.1.1.1 Ownship Symbol - General	Step 3
2.2.5.6.1	Ownship Symbol	311	2.4.5.1.1.1 Ownship Symbol - General	Step 2
2.2.5.6.1	Ownship Symbol	312	2.4.5.1.1.2 Ownship Symbol – Directionality	
2.2.5.6.2	Traffic Information Formats	None	None	Description Only

Section	Title	Req. #	Section	Application
2.2.5.6.2.1	Data Tags	313	2.4.5.1.3 Traffic Information	Step 11
2.2.5.6.2.1	Data Tags	314	2.4.5.1.3 Traffic Information	Step 12
2.2.5.6.2.1	Data Tags	315	2.4.5.1.3 Traffic Information	Step 13, 14
2.2.5.6.2.1	Data Tags	316	2.4.5.1.3 Traffic Information	Step 16
2.2.5.6.2.2	Data Blocks	317	2.4.5.1.3.1 Traffic - Data Blocks	Step 1
2.2.5.6.2.2	Data Blocks	318	2.4.5.1.3.1 Traffic - Data Blocks	Step 1, 2
2.2.5.6.2.3	Traffic Symbols	319	2.4.5.1.2.3 Number of Traffic Elements	Step 1
2.2.5.6.2.3.1	Traffic Symbol Location	320	2.4.5.1.3 Traffic Information	Step 7
2.2.5.6.2.3.2	Traffic Symbols and Variations	None	None	Description Only
2.2.5.6.2.3.2.1	Basic Directional Traffic	321	2.4.5.1.3.2 Traffic - Directionality	Step 1, 2
2.2.5.6.2.3.2.1	Basic Directional Traffic	322	2.4.5.1.3 Traffic Information	Step 8
2.2.5.6.2.3.2.1	Basic Directional Traffic	323	2.4.5.1.3.2 Traffic - Directionality	Step 7
2.2.5.6.2.3.2.1	Basic Directional Traffic	324	2.4.5.1.3 Traffic Information	Step 9
2.2.5.6.2.3.2.2	Basic Non-directional Traffic	325	2.4.5.1.3.2 Traffic - Directionality	Step 6

Section	Title	Req. #	Section	Application
2.2.5.6.2.3.2.2	Basic Non-directional Traffic	326	2.4.5.1.3 Traffic Information 2.4.5.1.3.2 Traffic - Directionality	Step 8 Step 7
2.2.5.6.2.3.2.2	Basic Non-directional Traffic	327	2.4.5.1.3.2 Traffic - Directionality	Step 7
2.2.5.6.2.3.2.2	Basic Non-directional Traffic	328	2.4.5.1.3.2 Traffic - Directionality	Step 8
2.2.5.6.2.3.2.3	Traffic Directionality Depiction	329	2.4.5.1.3.2 Traffic - Directionality	Step 5
2.2.5.6.2.3.2.3	Traffic Directionality Depiction	330	2.4.5.1.3.2 Traffic - Directionality	Step 3
2.2.5.6.2.3.2.4	Maneuver Guidance Traffic	331	2.4.5.3.1 DAA Alert Symbology	Test 1, Step 6
2.2.5.6.2.3.2.5	Alert Types and Symbols	332	2.4.5.3.1 DAA Alert Symbology	Test 1, Step 7
2.2.5.6.2.3.2.5	Alert Types and Symbols	333	2.4.5.3.1 DAA Alert Symbology	Test 1, Step 8
2.2.5.6.2.3.2.5	Alert Types and Symbols	334	2.4.5.3.1 DAA Alert Symbology	Test 1, Steps 1, 3, 4
2.2.5.6.2.3.2.5	Alert Types and Symbols	335	2.4.5.3.1 DAA Alert Symbology	Test 1, Steps 2, 5
2.2.5.6.2.3.2.5	Alert Types and Symbols	336	2.4.5.1.2 Traffic Display Criteria	Test 2

Section	Title	Req. #	Section	Application
2.2.5.6.2.3.2.5	Alert Types and Symbols	531	2.4.5.3.1 DAA Alert Symbology	Test 2 The manufacturer is required to provide additional compliance means to verify the symbol modification criteria of this requirement
2.2.5.6.2.3.2.5.1	Preventive Alert	337	2.4.5.3.1 DAA Alert Symbology	Test 1, Step 3
2.2.5.6.2.3.2.5.2	Corrective Alert	338	2.4.5.3.1 DAA Alert Symbology	Test 1, Step 4
2.2.5.6.2.3.2.5.3	Warning Alert	339	2.4.5.3.1 DAA Alert Symbology	Test 1, Step 5
2.2.5.6.2.3.2.6	Alerting Special Cases	None	None	Description Only
2.2.5.6.2.3.2.6.1	No Bearing	340	2.4.5.3.1.1 DAA Alert Symbology for No-Bearing Targets	Step 1
2.2.5.6.2.3.2.6.1	No Bearing	341	2.4.5.3.1.1 DAA Alert Symbology for No-Bearing Targets	Step 2
2.2.5.6.2.3.2.6.1	No Bearing	342	2.4.5.3.1.1 DAA Alert Symbology for No-Bearing Targets	Step 3
2.2.5.6.2.3.2.6.1	No Bearing	343	2.4.5.3.1.1 DAA Alert Symbology for No-Bearing Targets	Step 4
2.2.5.6.2.3.2.6.1	No Bearing	344	2.4.5.3.1.1 DAA Alert Symbology for No-Bearing Targets	Step 7

Section	Title	Req. #	Section	Application
2.2.5.6.2.3.2.6.2	No Altitude and Altitude High Uncertainty	345	2.4.5.3.1.1 DAA Alert Symbology for No-Bearing Targets	Step 6
2.2.5.6.2.3.2.6.2	No Altitude and Altitude High Uncertainty	346	2.4.5.3.1.1 DAA Alert Symbology for No-Bearing Targets	Step 5
2.2.5.6.2.3.2.7	TCAS II Alert Symbols for TCAS II/DAA Integrated Systems	347	2.4.5.4 TCAS II Alert Symbology for Integrated Systems	Step 1
2.2.5.6.2.3.2.7	TCAS II Alert Symbols for TCAS II/DAA Integrated Systems	348	2.4.5.4 TCAS II Alert Symbology for Integrated Systems	Step 2
2.2.5.6.2.3.2.7	TCAS II Alert Symbols for TCAS II/DAA Integrated Systems	349	2.4.5.4 TCAS II Alert Symbology for Integrated Systems	Step 3, 4
2.2.5.6.2.3.2.7	TCAS II Alert Symbols for TCAS II/DAA Integrated Systems	350	2.4.5.4 TCAS II Alert Symbology for Integrated Systems	Step 5
2.2.5.6.3	Number of Traffic Elements	351	2.4.5.1.2 Traffic Display Criteria	Test 1d Step 1, 4, 7 The manufacturer is required to provide additional compliance means to verify the maximum display capacity exceeded indication
2.2.5.6.3	Number of Traffic Elements	351	2.4.5.1.2.3 Number of Traffic Elements	Step 2 The manufacturer is required to provide additional compliance means to verify the maximum display capacity exceeded indication
2.2.5.6.4	Information Elements	None	None	Description Only
2.2.5.6.4.1	Traffic Monitored by TCAS II	None	None	Description Only

Section	Title	Req. #	Section	Application
2.2.5.6.4.2	Traffic Application Capability	352	2.4.5.10 Additional Applications and Designated Traffic	
2.2.5.6.4.3	Traffic Altitude	353	2.4.5.1.3.5.2 Traffic – Multiple Altitude Types	Step 1
2.2.5.6.4.3	Traffic Altitude	354	2.4.5.1.3.5.2 Traffic – Multiple Altitude Types	Step 2
2.2.5.6.4.3	Traffic Altitude	355	2.4.5.1.3.5.1 Traffic – Relative Altitude	Step 6
2.2.5.6.4.3	Traffic Altitude	356	2.4.5.1.3.5.1 Traffic – Relative Altitude	Step 5
2.2.5.6.4.3.1	Traffic Relative Altitude	357	2.4.5.1.3.5.1 Traffic – Relative Altitude	Step 2
2.2.5.6.4.3.1	Traffic Relative Altitude	358	2.4.5.1.3.5.1 Traffic – Relative Altitude	Step 3
2.2.5.6.4.3.1	Traffic Relative Altitude	359	2.4.5.1.3.5.1 Traffic – Relative Altitude	Step 4
2.2.5.6.4.3.1	Traffic Relative Altitude	360	2.4.5.1.3.5.1 Traffic – Relative Altitude	Step 1
2.2.5.6.4.3.2	Traffic Actual Altitude	361	2.4.5.1.3.5.2 Traffic – Multiple Altitude Types	Step 3
2.2.5.6.4.3.2	Traffic Actual Altitude	362	2.4.5.1.3.5.2 Traffic – Multiple Altitude Types	Step 4

Section	Title	Req. #	Section	Application
2.2.5.6.4.3.2	Traffic Actual Altitude	363	2.4.5.1.3.5.2 Traffic – Multiple Altitude Types	Step 5
2.2.5.6.4.3.3	Traffic Geometric Altitude	364	2.4.5.1.3.5.2 Traffic – Multiple Altitude Types	Step 6
2.2.5.6.4.3.3	Traffic Geometric Altitude	365	2.4.5.1.3.5.2 Traffic – Multiple Altitude Types	Step 7
2.2.5.6.4.3.4	Traffic Pressure Altitude	366	2.4.5.1.3.5.2 Traffic – Multiple Altitude Types	Step 8, 9
2.2.5.6.4.3.4	Traffic Pressure Altitude	367	2.4.5.1.3.5.2 Traffic – Multiple Altitude Types	Step 10
2.2.5.6.4.4	Traffic Vertical Direction	368	2.4.5.1.3 Traffic Information	Step 14
2.2.5.6.4.4	Traffic Vertical Direction	369	2.4.5.1.3 Traffic Information	Step 15
2.2.5.6.4.5	Traffic Identification	370	2.4.5.1.3 Traffic Information	Step 19
2.2.5.6.4.6	Traffic Ground Speed	371	2.4.5.1.3.3 Traffic - Ground Speed	Step 2
2.2.5.6.4.6	Traffic Ground Speed	372	2.4.5.1.3.3 Traffic - Ground Speed	Step 1
2.2.5.6.4.7	Traffic Category (Emitter Category)	373	2.4.5.1.3.6 Traffic – Emitter Category	
2.2.5.6.4.8	Traffic Emergency Priority Status	None	None	Description Only
2.2.5.6.4.9	Traffic Horizontal Velocity Vector	374	2.4.5.1.3.4 Traffic - Horizontal Velocity Vector	Step 1

Section	Title	Req. #	Section	Application
2.2.5.6.4.9	Traffic Horizontal Velocity Vector	375	2.4.5.1.3.4 Traffic - Horizontal Velocity Vector	Step 3
2.2.5.6.4.9	Traffic Horizontal Velocity Vector	376	2.4.5.1.3.4 Traffic - Horizontal Velocity Vector	Step 4
2.2.5.6.4.9	Traffic Horizontal Velocity Vector	377	2.4.5.1.3.4 Traffic - Horizontal Velocity Vector	Step 5
2.2.5.6.4.9	Traffic Horizontal Velocity Vector	378	2.4.5.1.3.4 Traffic - Horizontal Velocity Vector	Step 2
2.2.5.6.4.10	Traffic Range	379	2.4.5.1.2.2 Traffic Digital Range Resolution	
2.2.5.7	Guidance Display Requirements	None	None	Description Only
2.2.5.7.1	DAA Guidance to Maintain DWC	380	2.4.5.5 DAA Guidance to Maintain and Regain DWC	Step 1
2.2.5.7.1	DAA Guidance to Maintain DWC	381	2.4.5.5 DAA Guidance to Maintain and Regain DWC	Step 2
2.2.5.7.1	DAA Guidance to Maintain DWC	382	2.4.5.5 DAA Guidance to Maintain and Regain DWC	Step 3
2.2.5.7.1	DAA Guidance to Maintain DWC	383	2.4.5.5 DAA Guidance to Maintain and Regain DWC	Step 4

Section	Title	Req. #	Section	Application
2.2.5.7.1	DAA Guidance to Maintain DWC	384	2.4.5.5 DAA Guidance to Maintain and Regain DWC	Step 5
2.2.5.7.1	DAA Guidance to Maintain DWC	385	2.4.5.5 DAA Guidance to Maintain and Regain DWC	Step 6
2.2.5.7.1	DAA Guidance to Maintain DWC	386	2.4.5.5 DAA Guidance to Maintain and Regain DWC	Step 7
2.2.5.7.1	DAA Guidance to Maintain DWC	387	2.4.5.5 DAA Guidance to Maintain and Regain DWC	Step 8
2.2.5.7.1	DAA Guidance to Maintain DWC	388	2.4.5.5 DAA Guidance to Maintain and Regain DWC	Step 9
2.2.5.7.2	DAA Guidance to Regain DWC	389	2.4.5.5 DAA Guidance to Maintain and Regain DWC	Step 10
2.2.5.7.2	DAA Guidance to Regain DWC	390	2.4.5.5 DAA Guidance to Maintain and Regain DWC	Step 11
2.2.5.7.2	DAA Guidance to Regain DWC	391	2.4.5.5 DAA Guidance to Maintain and Regain DWC	Step 12

Section	Title	Req. #	Section	Application
2.2.5.7.2	DAA Guidance to Regain DWC	392	2.4.5.5 DAA Guidance to Maintain and Regain DWC	Step 13
2.2.5.7.3	TCAS II Resolution Advisory Guidance for TCAS II/DAA Integrated Systems	393	2.4.5.6 TCAS-II Resolution Advisory Guidance for Integrated Systems	The manufacturer is required to provide compliance details to verify the requirement in this section
2.2.5.8	DAA Traffic Display Characteristics	N/A	N/A	Section Header
2.2.5.8.1	Display Range	394	2.4.5.2 Traffic Display Controls	Step 2
2.2.5.8.1	Display Range	395	2.4.5.2 Traffic Display Controls	Step 3
2.2.5.8.1	Display Range	396	2.4.5.1.3 Traffic Information	Step 2
2.2.5.8.2	Range Rings	397	2.4.5.1.3 Traffic Information	Step 3
2.2.5.8.2	Range Rings	398	2.4.5.1.3 Traffic Information	Step 4
2.2.5.8.2	Range Rings	399	2.4.5.1.3 Traffic Information	Step 5
2.2.5.8.2	Range Rings	400	2.4.5.2.1 Altitude Bands	Step 1
2.2.5.8.2	Range Rings	401	2.4.5.2.1 Altitude Bands	Step 2
2.2.5.8.4	Display Orientation	402	2.4.5.1.1.3 Ownship Symbol – Display Orientation	Step 1, 2, 3
2.2.5.8.4	Display Orientation	403	2.4.5.1.1.3 Ownship Symbol – Display Orientation	Step 4

Section	Title	Req. #	Section	Application
2.2.5.8.4	Display Orientation	404	2.4.5.1.1.3 Ownship Symbol – Display Orientation	Step 5
2.2.5.8.5	Traffic Coasting Indicator	None	None	Description Only
2.2.5.9	Display Design Requirements – Other	N/A	N/A	Section Header
2.2.5.9.1	Traffic Display Symbol Prioritization for Overlay	None	None	Description Only
2.2.5.9.2	DAA System Health Display Monitoring Function	405	2.4.5.7 System Status	Step 1
2.2.5.9.3	Display of Status Indication	406	2.4.5.7 System Status	Step 2
2.2.5.9.3	Display of Status Indication	407	2.4.5.7 System Status	Step 3
2.2.5.9.3	Display of Status Indication	408	2.4.5.7 System Status	Step 4
2.2.5.9.3	Display of Status Indication	409	2.4.5.7 System Status	Step 5
2.2.5.9.3	Display of Status Indication	410	2.4.5.7 System Status	Step 6
2.2.5.9.3	Display of Status Indication	411	2.4.5.11 DAA Traffic Display Alert and Guidance Suppression	
2.2.5.9.3	Display of Status Indication	412	2.4.5.7 System Status	Step 7
2.2.5.9.3	Display of Status Indication	413	2.4.5.7 System Status	Step 8
2.2.5.10	Input and Control Requirements – General	None	None	Description Only
2.2.5.10.1	Display Range	414	2.4.5.2 Traffic Display Controls	Step 1

Section	Title	Req. #	Section	Application
2.2.5.10.2	Altitude Band	415	2.4.5.2 Traffic Display Controls	Step 4
2.2.5.10.3	Traffic Altitude Selection	416	2.4.5.2 Traffic Display Controls	Step 5
2.2.5.10.4	Traffic Selection	417	2.4.5.2 Traffic Display Controls	Step 6
2.2.5.10.5	De-cluttering	418	2.4.5.2 Traffic Display Controls	Step 8
2.2.5.10.5	De-cluttering	419	2.4.5.2 Traffic Display Controls	Step 9
2.2.5.10.6	Brightness Control	420	2.4.5.2 Traffic Display Controls	Step 7
2.2.5.11	CS Integration Requirements	None	None	Description Only
2.2.5.11.1	Multi-function Display	421	2.4.5.8 Multifunction Displays	Step 1
2.2.5.11.1	Multi-function Display	422	2.4.5.8 Multifunction Displays	Step 2, 3, 4, 5
2.2.5.11.1	Multi-function Display	423	2.4.5.8 Multifunction Displays	Step 7
2.2.5.11.1	Multi-function Display	424	2.4.5.8 Multifunction Displays	Step 6
2.2.5.11.1.1	DAA Aural Alerts	425	2.4.5.3.2 DAA Aural Alerts	Test 1, Step 1
2.2.5.11.1.1	DAA Aural Alerts	426	2.4.5.3.2 DAA Aural Alerts	Test 1, Step 2

Section	Title	Req. #	Section	Application
2.2.5.11.1.1	DAA Aural Alerts	427	2.4.5.3.2 DAA Aural Alerts	Test 1, Step 3
2.2.5.11.1.1	DAA Aural Alerts	428	None	The manufacturer is required to provide compliance details to verify the requirement in this section
2.2.5.11.1.1	DAA Aural Alerts	429	2.4.5.3.2 DAA Aural Alerts	Test 2, Step 1
2.2.5.11.1.1	DAA Aural Alerts	430	2.4.5.3.2 DAA Aural Alerts	Test 2, Step 2
2.2.5.11.1.1	DAA Aural Alerts	431	2.4.5.3.2 DAA Aural Alerts	Test 2, Step 3
2.2.5.11.1.1	DAA Aural Alerts	432	2.4.5.3.2 DAA Aural Alerts	Test 1, Step 4 Test 2, Step 5
2.2.5.11.1.1	DAA Aural Alerts	433	2.4.5.3.2 DAA Aural Alerts	Test 2, Step 6
2.2.5.11.1.1	DAA Aural Alerts	434	None	The manufacturer is required to provide compliance details to verify the requirement in this section
2.2.6	DAA Pilot Selected Mode	435 436 437	2.4.6 DAA Pilot Selected Mode	The manufacturer is required to provide additional compliance means to verify coverage of additional modes and maintenance modes of this requirement
2.2.6.1	DAA Subsystem Pilot Selected Mode	438	2.4.6 DAA Pilot Selected Mode	Test 1
2.2.6.1	DAA Subsystem Pilot Selected Mode	439	2.4.6 DAA Pilot Selected Mode	Test 2
2.2.6.1	DAA Subsystem Pilot Selected Mode	440 441 442	2.4.6 DAA Pilot Selected Mode	Test 3 The manufacturer is required to provide additional compliance means to verify coverage of additional modes and maintenance modes of this requirement
2.2.7	Pilot Entry Subsystem	None	2.4.7 Pilot Entry Subsystem	Reserved
2.2.8	DAA Subsystem Operational Status	443	2.4.8 DAA Subsystem Operational Status	

Section	Title	Req. #	Section	Application
2.2.8	DAA Subsystem Operational Status	444	2.4.8 DAA Subsystem Operational Status	The manufacturer is required to provide additional compliance means to verify coverage of additional operational status conditions of this requirement
2.2.8.1	DAA Subsystem Operational Status Reporting Requirement	457 458 459	2.4.8.1 DAA Sub-System Operational Status Reporting Requirement	
2.2.8.2	DAA Sub-System Initiation Test (Similar to or same as a Built-in Test (BIT))	460 461	2.4.8.2 DAA Sub-System Initiation Test	
2.2.8.3	DAA Sub-System Initiation Operational Status Test Report	462	2.4.8.3 DAA Sub-System Initiation Test Fail Report	
2.2.8.4	DAA Subsystem Operational Status Display	463	2.4.8.4 DAA Sub-System Operational Status Display	
2.2.8.5	DAA Sub-System Lack of Operating Mode Report	464	2.4.8.5 DAA Sub-System Lack of Operational Status Report	
2.2.9	High-level DAA Operational Monitoring Function	465 466 467	2.4.9 High-level DAA Operational Monitoring Function	
2.2.9.1	High-level DAA Operational Monitoring Function Display	468	2.4.9.1 High-level DAA Operational Monitoring Function Display	

Section	Title	Req. #	Section	Application
2.2.9.2	High-level DAA Operational Monitoring Function, Master Caution Warning Light/System	469	2.4.9.2 High-level DAA Operational Monitoring Function Master Caution Warning Light/System	
2.2.10	Restart after Power Interruption while in Flight	None	None	Description Only
2.3	DAA Equipment Environmental Testing – Overview	470	Reference Sections 2.3.1, 2.3.2 and 2.3.3	The manufacturer is required to provide compliance details to verify the requirement in this section
2.3.1	Use of Special Purpose Software	471 472 473	Reference Test Criteria in Section 2.3.1	The manufacturer is required to provide compliance details to verify these requirements in this section
2.3.2	DAA Airborne Equipment Required Performance - Environmental Test Conditions	474	Reference Test Criteria in Section 2.3.2	The manufacturer is required to provide compliance details to verify the requirement in this section
2.3.3	DAA Ground-Based Equipment Required Performance – Environmental Conditions	476	Reference Test Criteria in Section 2.3.3	The manufacturer is required to provide compliance details to verify the requirement in this section
2.4	Equipment Test Procedures	None	None	The Manufacturer is required to ensure all requirements in sections 2.1 and 2.2 are integrated into the verification data used as part of the product certification package
3	Manufacturer Considerations for Installed Equipment	N/A	N/A	Section Header
3.1	Equipment Installation	N/A	N/A	Section Header
3.1.1	Accessibility	511	None	The manufacturer is required to provide compliance details to verify the requirement in this section
3.1.2	Aircraft Environment	512	None	The manufacturer is required to provide compliance details to verify the requirement in this section
3.1.3	Display Visibility	513	None	The manufacturer is required to provide compliance details to verify the requirement in this section

Section	Title	Req. #	Section	Application
3.1.4	Dynamic Range	514	None	The manufacturer is required to provide compliance details to verify the requirement in this section
3.1.5	Failure Protection	515 516	None	The manufacturer is required to provide compliance details to verify these requirements in this section
3.1.6	Interference Effects	517	None	The manufacturer is required to provide compliance details to verify these requirements in this section
3.1.7	Inadvertent Turnoff	518	None	The manufacturer is required to provide compliance details to verify these requirements in this section
3.1.8	UA and CS Power Sources	None	None	Description Only
3.2	Installed Equipment Performance Considerations	N/A	N/A	Section Header
3.3	Installed Equipment Tests	None	None	The Manufacturer is required to ensure all requirements in Subsection 3.1 are integrated into the verification data used as part of the aircraft certification package
3.3.1	Ground Tests	None	None	The manufacturer is required to provide compliance details to verify this section The manufacturer is required to provide compliance means to verify latency on actual hardware equipment
3.3.1.1	Equipment Function	None	None	The manufacturer is required to provide compliance details to verify this section
3.3.1.2	Interference Effects	None	None	The manufacturer is required to provide compliance details to verify this section
3.3.2	Flight Evaluation Test Procedures	None	None	The manufacturer is required to provide compliance details to verify this section The manufacturer is required to provide compliance means to verify latency on actual hardware equipment
4	Aircraft Operational Performance Characteristics	None	None	The manufacturer is required to provide compliance details to verify this section

3 Manufacturer Considerations for Installed Equipment

This section contains no design requirements. The purpose of this section is to provide useful considerations regarding equipment designed to meet these MOPS when that equipment is installed and used as a DAA system.

For the most part, installed performance requirements are the same as those contained in Section 2, which were verified through bench and environmental tests. However, certain requirements may be affected by the physical installation (e.g., antenna patterns, receiver sensitivity, etc.) and can only be verified after installation. The installed performance limits or validation requirements are generally provided in separate installation guidance related to the function(s) provided. These are often provided in the form of Advisory Circulars (ACs) (or their non-U.S. equivalents) specific to equipment installation.

Equipment designed to meet these MOPS generally requires separate approval for installation and use on an aircraft system. This section is intended to provide some installation related considerations which the designer may want to consider in the design such that the equipment may also be able to obtain any additional required installation or use approvals when correctly installed in an aircraft system.

3.1 Equipment Installation

3.1.1 Accessibility

Controls and displays provided for in-flight operations **shall (511)** be readily accessible from the PIC's normal body position when controlling the UA. The appropriate PIC must have an unobstructed view of displayed data when in the normal seated position.

3.1.2 Aircraft/Control Station Environment

Equipment **shall (512)** be compatible with the environmental condition present in the specific location in the UAS where the equipment is installed.

3.1.3 Display Visibility

Display intensity **shall (513)** be suitable for data interpretation under all UAS CS lighting conditions, such as total darkness, florescent lighting, or natural reflected sunlight. It will depend on UAS CS locations. See Paragraph 2.3.3 of these MOPS for various CS locations and associated environmental conditions.

Note: *Visors, glare-shields or filters may be an acceptable means of maximizing visibility in daylight.*

3.1.4 Dynamic Range

Operation of the equipment **shall (514)** not be adversely affected by aircraft maneuvering or changes in attitude encountered in normal flight conditions.

3.1.5 Failure Protection

Any probable failure of the equipment **shall (515)** not degrade the normal operation of equipment or systems connected to it. Likewise, the failure of interfaced equipment or systems **shall (516)** not degrade normal operation of this equipment.

Note: *Systems may have loss or malfunction of the DAA equipment function due to failures of required interfaced equipment. For example, a failure of the radar altimeter may degrade normal operation of a TCAS II system. When a DAA equipment function is dependent on proper function of interfaced equipment, this should be considered in the system-level safety assessment. Installation approval may depend on system-level mitigation of probable failures with techniques such as detection and annunciation, and/or redundancy such that the failure is no longer probable.*

3.1.6 Interference Effects

The equipment onboard the UA and in the CS **shall (517)** not be the source of harmful conducted or radiated interference, nor be adversely affected by conducted or radiated interference from other equipment or systems installed in the aircraft.

Note: *Electromagnetic compatibility problems noted after installation of this equipment may result from such factors as the design characteristics of previously installed systems or equipment and the physical installation itself. It is not intended that the equipment manufacturer design for all installation environments. The installing facility is responsible for resolving any incompatibility between this equipment and previously installed equipment in the aircraft. The various factors contributing to the incompatibility must be considered.*

3.1.7 Inadvertent Turnoff

Appropriate protection **shall (518)** be provided to avert the inadvertent turnoff of the equipment onboard the UA and/or the CS

3.1.8 UA and CS Power Sources

These MOPS have no requirements for connecting installed equipment to the UA and CS power source(s). Paragraph 2.4.1 contains recommendations for bench test power sources, and additional requirements for power sources and connections for installed equipment can be found in RTCA DO-160G.

Note: *Different categories of UA and CS and different types of equipment may have different requirements for operation through momentary loss of power or during switching of power sources (see Paragraph 2.2.10). Equipment designers should consider the intended types of installation for the equipment and any UA- and CS-level requirements for the availability of function.*

3.2 Installed Equipment Performance Considerations

The installed equipment should meet the requirements of Subsection 2.1 and Subsection 2.2, except for areas where the MOPS tests are intended to provide adequate margins to accommodate installation variances. These might include things like antenna patterns where aircraft structures such as vertical stabilizers etc. might result in the installed antenna being unable to pass the MOPS bench test requirements when installed. In such cases, the MOPS tests specify a test configuration and the MOPS performance requirements are intended to be met with the specified test configuration. Where the equipment cannot meet the MOPS, then a deviation request must be submitted to the appropriate authority for an approval, along with any equipment operating limitations and the justification for the deviation.

In addition to meeting the equipment requirements of Subsections 2.1 and 2.2, the installed equipment or the aircraft in which it is installed may need to meet additional requirements for installation or operational approval. Some installations may require a higher or lower level of performance than what is defined in these MOPS. These installations are based on integration with other systems onboard the aircraft that may share the same interfaces with the DAA system. They may inherently have better availability and integrity for the DAA system design, or the DAA system may be intended to operate under limited conditions or have other operating mitigations beyond the scope of these MOPS. Therefore, it is important for the installer to ensure compatibility of the DAA design with other equipment on the UA and integration with other systems.

3.3 Installed Equipment Tests

Test procedures for installed equipment are generally contained in separate installation or operational approval guidance such as ACs or their non-U.S. equivalents. However, the following test procedures provide one means of determining installed equipment performance. Although specific test procedures are cited, it is recognized that other methods may be preferred by the installer. These alternate procedures may be used if they provide at least equivalent information. In such cases, the procedures cited herein should be used as one criterion in evaluating the acceptability of the alternate procedures.

3.3.1 Ground Tests

Ensure all equipment is installed according to the manufacturer's installation manual.

3.3.1.1 Equipment Function

Before testing on the ground, ensure that all ground personnel are not in the radar perimeter radiation hazard zone prior to turning on the air-to-air radar system.

Perform a DAA self-test. Verify all systems are normal. Make note of any anomalies.

Verify the appropriateness and location of the controls and visual annunciations.

Evaluate the location and lighting of controls for night operation.

Cycle all modes of DAA operation to check operational acceptability.

Vary all controls of the equipment through their full range to determine that the equipment is operating according to the manufacturer's instruction and that each control performs its intended function.

If on the ramp, call ATC to verify that the active surveillance and/or ADS-B Out is reporting correctly.

3.3.1.2 Interference Effects

With the equipment energized, operate the other electrically operated aircraft equipment and systems to determine that significant conducted or radiated interference does not exist. Evaluate all reasonable combinations of control setting and operating modes.

Operate communication and navigation equipment on the low, high and at least one but preferably four mid-band frequencies. Make note of systems or modes of operation that should also be evaluated during flight. If appropriate, repeat tests using emergency power with the aircraft's batteries alone and the inverters operating.

3.3.2 Flight Evaluation Test Procedures

The installed performance of the equipment is required to be able to perform in the class of airspace it is intended to operate.

Verify all operational modes in flight. Verify the prioritization of the alerts under the respective scenarios and conditions.

4 AIRCRAFT OPERATIONAL PERFORMANCE CHARACTERISTICS

When equipment is designed and manufactured to meet these MOPS, and it is properly installed in an aircraft in accordance with applicable installation and operational approval guidance and regulations, it is expected that all system-level functional and operational performance criteria will be met.

The equipment when installed contributes to the operation and performance of the MOPS functions at the system level. Other system-level contributions such as redundant or additional equipment may also be required. The equipment design should consider the types and characteristics of the system for which installation of this equipment is intended, as well as the MOPS function at a system level, and the equipment should be designed such that the equipment's contribution to system-level operational and functional requirements is adequate.

This Page Intentionally Left Blank

5 MEMBERSHIP

RTCA Special Committee 228
MOPS for Unmanned Aircraft Systems

SC-228 Chairs	**Organization**
Richard Heinrich	Rockwell Collins, Inc.
Paul McDuffee	The Insitu Group, Inc.
SC-228 Secretary	
Kristina Carr	Federal Aviation Administration
WG-1 Chairs	
Brandon Suarez	General Atomics Aeronautical Systems, Inc.
Don Walker	Federal Aviation Administration
WG-1 Secretary	
Paul Campbell	Federal Aviation Administration
WG-2 Chairs	
John Moore	Rockwell Collins, Inc.
Stephen Van Trees	Federal Aviation Administration
WG-2 Secretary	
Lee Nguyen	Federal Aviation Administration
Program Directors	
Harold Moses, Al Secen	RTCA, Inc.

Member	**Organization**
Kathy Abbott	Federal Aviation Administration
Hal Adams	Accord Software & Systems, Inc.
Jaeyoung Ahn	Electronics and Telecommunications Research Institute (ETRI)
Abe Akhiyat	Ohio State University
Courtney Albers	GE Aviation
Paul Albuquerque	Federal Aviation Administration
Robert Alger	SRC, Inc.
Oliver Allen	Naval Air Warfare Center (Exempt)
Song An	Northrop Grumman Corporation
Cristina Angulo	European Aviation Safety Agency (EASA)

Member	Organization
Evan Arnold	NextGen Air Transportation Consortium
Donald Arnstein	The MITRE Corporation
Keith Arthur	NASA
John Ashley	The MITRE Corporation
Naiel Askar	General Atomics Aeronautical Systems, Inc.
Mark Askelson	University of North Dakota
Kevin Aurandt	Federal Aviation Administration
Sean Baity	AAI Corporation
Michael Bakula	Embry-Riddle Aeronautical University
RJ Balanga	NASA
Chad Balentine	Air Line Pilots Association
Mike Ball	Beyond Aerospace Ltd.
William Banfi	BAE Systems, Inc.
Dmitri Baraban	The MITRE Corporation
John Barry	Federal Aviation Administration
Jessica Bartik	U.S. Air Force
Franco Basti	Thales Group
Vernol Battiste	NASA
Raymond Bayh	BAE Systems, Inc.
Robert Becklund	Northern Plains UAS Test Site (NPUASTS)
Tim Behnke	Northrop Grumman Corporation
Walter Bender	The Johns Hopkins University
William Benner	Regulus Group
Gunnar Berg	Federal Aviation Administration
Terry Blumer	Harris Corporation
Tony Boci	Harris Corporation
Mathias Boddicker	U.S. Navy
Hans Bohlin	Swedish Defence Materiel Administration
Sophie Bousquet	Airbus
Frank Box	The MITRE Corporation
Joseph Boyd	The MITRE Corporation
Ruy Brandao	Honeywell International, Inc.
Scott Brenton	Northeast UAS Airspace Integration Research Alliance (NUAIR)
Jeff Breunig	The MITRE Corporation
Dallas Brooks	New Mexico State University PSA & ASL
Barry Buelow	Certification Services, Inc.
David Buhrman	Federal Aviation Administration
Geoff Butler	General Atomics Aeronautical Systems, Inc.
David Cain	General Atomics Aeronautical Systems, Inc.
Sean Calhoun	Calhoun Analytics
Paul Campbell	Federal Aviation Administration
David Cannane	U.S. Air Force

Member	Organization
Vincent Capobianco	U.S. Navy
Kim Cardosi	US Department of Transportation
Joslin Carino	Federal Aviation Administration
Kristina Carr	Federal Aviation Administration
Victor Carreno	Compass Engineering
John Carroll	Northrop Grumman Corporation
Tamara Casey	Ligado Networks
Scott Casoni	Federal Aviation Administration
Perry Casselle	Federal Aviation Administration
Joseph Castaldi	Insitu Inc.
Mike Castaneda	General Atomics Aeronautical Systems, Inc.
Jong-Suk Chae	Electronics and Telecommunications Research Institute (ETRI)
Keith Chandler	Human Solutions, Inc.
Sherry Chappell	Federal Aviation Administration
Deepak Chauhan	Federal Aviation Administration
Meir Chemla	Israel Aerospace Industries LTD
David Chen	Federal Aviation Administration
Robert Chen	Northrop Grumman Corporation
Won-Zon Chen	JeSTAR Associates
Sachin Chhibber	Ligado Networks
Gary Church	Aviation Management Associates, Inc.
Kathryn Ciaramella	Federal Aviation Administration
James Cieplak	Exelis
Dave Cirulli	CEMSol
Kevin Clark	Volpe National Transportation Systems Center
Donna Clements	NASA
Mark Cochran	ATAC
John Coffey	National Oceanic and Atmospheric Administration (NOAA)
Rodney Cole	MIT Lincoln Laboratory
Brad Coleman	Broadcast Microwave Services, Inc. (BMS, Inc.)
Eric Coleman	L-3 Communications
Andrew Cone	NASA
Jack Connolly	NASA
Sean Connor	AirMap
Maria Consiglio	NASA
Stephen Cook	Northrop Grumman Corporation
Chris Corgnati	Crown Consulting, Inc.
Emilie Cowen	MIT Lincoln Laboratory
Lawrence Cowles	Federal Aviation Administration
Earl Cox	AeroVironment (EUROCAE member)
Stephen Creaghan	Volpe National Transportation Systems Center
Bill Crozier	Federal Aviation Administration

Member	Organization
Vincent Crum	U.S. Air Force
Sara Darrah	Booz Allen Hamilton (USAF Exempt)
Brian Davis	Embry-Riddle Aeronautical University
James Davis	Sagetech Corporation
Matt DeGarmo	The MITRE Corporation
Arthur DeLeon	SAIC
Nick Demidovich	Federal Aviation Administration
Ed DeMott	Kellington Law Group
Mark Dickinson	Federal Aviation Administration
Dee Ann Divis	Inside GNSS (Media)
Perla Domingo	RTCA, Inc.
Dewar Donnithorne-Tait	EUROCAE
Mark Draper	U.S. Air Force
Ann Drumm	MIT Lincoln Laboratory
Michael Dudley	NASA
Robert Duffer	Federal Aviation Administration
Aaron Dutle	NASA
Santanu Dutta	Ligado Networks
April Eaton	L-3 Communications
Bruce Eckstein	Harris Corporation
Matthew Edwards	MIT Lincoln Laboratory
Greg Elcock	General Atomics Aeronautical Systems, Inc.
Melissa Emery	A-P-T Research, Inc.
Daniel Eng	NASA
Alexander Engel	EUROCAE
Jacquelyn Erinne	Federal Aviation Administration
Regina Estkowski	The Boeing Company
Ramon Estrada	General Atomics Aeronautical Systems, Inc.
Joseph Ethier	Sierra Nevada Corporation
Eric Euteneuer	Honeywell International, Inc.
Edward Falkov	State Research Institute of Aviation Systems (GosNIIAS)
Art Feinberg	Intelligent Automation, Inc.
Mike Feldmann	GE Aviation
Norman Fenlason	The MITRE Corporation
Lisa Fern	NASA
Tom Ferrell	Ferrell and Associates Consulting, Inc.
Steve Fetter	Cobham Aerospace Communications
Melanie Flavin	Federal Aviation Administration
Nicholas Flom	Northern Plains UAS Test Site (NPUASTS)
JoAnn Ford	Federal Aviation Administration
Jason Foulk	General Atomics Aeronautical Systems, Inc.
Denise Fountain	DoD Policy Board on Federal Aviation

Member	Organization
Michael Franceschini	Honeywell International, Inc.
Kate Fraser	General Aviation Manufacturers Association
Paul Frederick	U.S. Navy
Eric Fredricks	Federal Aviation Administration
Donna Froehlich	Aurora Sciences LLC
Alex Fu	Federal Aviation Administration
Ken Fugate	Federal Aviation Administration
Craig Fuller	The Fuller Company
Michael Gagne	Ligado Networks
Mike Gallagher	The Padina Group
Stephen George	Federal Aviation Administration
Peter Georgiou	Federal Aviation Administration
Izabela Gheorghisor	The MITRE Corporation
Chris Giacoponello	Thales Group
Ben Gielow	Amazon Prime Air
Kyle Gilbertson	Trimble Military and Advanced Systems (Trimble MAS)
Kevin Gildea	Federal Aviation Administration
Kendall Gillespie	U.S. Air Force
Alex Glatfelter	Harris Corporation
Leo Globus	The MITRE Corporation
Luis Gonzalez	Becker Avionics, Inc.
Michael Gordon-Smith	Esterline CMC Electronics
Richard Graeff	U.S. Air Force
Scott Graham	Northrop Grumman Corporation
Jay Greenberg	The Boeing Company
Jim Gregory	Ohio State University
Dan Griffith	MIT Lincoln Laboratory
Laurie Grindle	NASA
Jim Griner	NASA
Elena Gromova	State Research Institute of Aviation Systems (GosNIIAS)
Paul Guckian	Qualcomm Technologies, Inc.
Michael Guterres	The MITRE Corporation
Bruno Gutierres	Airbus
Davis Hackenberg	NASA
Christine Haissig	Christine Haissig Consulting LLC (Exempt, see note)
Mike Hall	The MITRE Corporation
Jonathan Hammer	Noblis Inc.
Marvin Hammond	Technology Providers, Inc.
Tom Haritos	Embry-Riddle Aeronautical University
Eric Harkleroad	MIT Lincoln Laboratory
Matt Haskin	U.S. Air Force
Kelly Hayhurst	NASA

Member	Organization
Richard Healing	R Cubed Engineering LLC
Christopher Hegarty	The MITRE Corporation
Jean Marie Heim	Harris Corporation
Richard Heinrich	Rockwell Collins, Inc.
Robert Helgeson	Federal Aviation Administration
Adam Hendrickson	U.S. Army
Jens Hennig	General Aviation Manufacturers Association
Steve Henriksen	Harris Corporation
Robert Hess	Lockheed Martin Corporation
Jeff Hettick	General Atomics Aeronautical Systems, Inc.
Ruth Hirt	Federal Aviation Administration
Hau Ho	Northrop Grumman Corporation
Ty Hoang	NASA
Alan Hobbs	San Jose State University Foundation (Exempt)
Kathlyn Hoekstra	Federal Aviation Administration
Keith Hoffler	Adaptive Aerospace Group
Eric Hoffman	EUROCONTROL
Daniel Hoy	US Government Accountability Office
Scott Huffman	General Atomics Aeronautical Systems, Inc.
Derek Hufty	Federal Aviation Administration
Robert Hughes	Northrop Grumman Corporation
Steven Hylinski	Adaptive Aerospace Group
Doug Isaacson	NASA
Devin Jack	Adaptive Aerospace Group
Chris Jackman	Google
Barry Jackson	Cahon Systems Inc
Ravi Jain	Federal Aviation Administration
Jusu Jang	MOA SOFT Corporation
Michael Jarrell	NASA
Richard Jennings	Federal Aviation Administration
Margaret Jenny	RTCA, Inc.
Robert Johns	AAI Corporation
Kip Johnson	MIT Lincoln Laboratory
Marca Johnson	JSWalker Group/Aviation Solutions, Inc.
Marcus Johnson	NASA
Henry Jones	Federal Aviation Administration
Robert Joslin	Federal Aviation Administration
Richard Kahne	DoD Policy Board on Federal Aviation
Bill Kaliardos	Federal Aviation Administration
Jacob Kay	Bihrle Applied Research, Inc.
Viva Kelley	U.S. Army
Wendie Kellington	Kellington Law Group

Member	**Organization**
Alper Kendi	STM A.S
Peter Kennett, PE	Volpe National Transportation Systems Center
Philip Kenul	NOAA
Rick Kervin	Human Solutions, Inc.
Heewook Kim	Electronics and Telecommunications Research Institute (ETRI)
Sam Kim	NASA
Lance King	Northrop Grumman Corporation
Skyler Kleinschmidt	NASA
Jeffrey Knickelbein	Cobham Aerospace Communications
Akiko Kohmura	Electronic Navigation Research Institute (ENRI)
Emre Koksal	Ohio State University
Tatsuya Kotegawa	General Atomics Aeronautical Systems, Inc.
Scott Kotler	Lockheed Martin Corporation
Lisa Kowalski	NASA
Satish Krishnan	General Atomics Aeronautical Systems, Inc.
Josh Kuntzman	U.S. Air Force
Fabrice Kunzi	General Atomics Aeronautical Systems, Inc.
Rochelle Labao	Qualcomm Technologies, Inc.
Maurice Labonde	International Civil Aviation Organization
David Landon	L-3 Communications
Marcie Langelier	U.S. Navy
Jarrett Larrow	Federal Aviation Administration
Seungman Lee	NASA
Charles Leeper	The Johns Hopkins University
Jerry LeMieux	Delta Air Lines, Inc.
Ted Lester	The MITRE Corporation
Elliot Lewis	NASA
Ray Lewis	U.S. Navy
Kwang Jae Lim	Electronics and Telecommunications Research Institute (ETRI)
James Limardo	BAE Systems, Inc.
Chas Lin	Federal Aviation Administration
Greg Loegering	Northrop Grumman Corporation
Kolie Lombard	SAIC
Anthony Long	Federal Aviation Administration
J. J. Lu	General Atomics Aeronautical Systems, Inc.
William "Chris" Lucius	Air Line Pilots Association
Beth Lyall	Research Integrations, Inc.
George Lyddane	SAIC
Torsten Mack	Insitu Inc.
Tim Maguire	Federal Communications Commission (FCC)
Evan Maki	MIT Lincoln Laboratory
Alfonso Malaga	Honeywell International, Inc.

Member	**Organization**
Heather Maliska	NASA
Justin Maloney-Hahn	Telephonics Corp
Chuck Manberg	L-3 Communications
Sheila Mariano	Federal Aviation Administration
Kelly Markin	The MITRE Corporation
Johan Martensson	EUROCONTROL
Terry Martin	Queensland University of Technology
Neil Masco	U.S. Army
Robert Maskasky	U.S. Navy
Frank Matus	Thales Group
Russell Mayes	RPA Communications (Exempt)
Frank McCormick	Certification Services, Inc.
Robert McCullen	ACSS
Scott McLellan	Federal Aviation Administration
Kyle McMullen	National Institute for Aviation Research (NIAR) at Wichita State Univ.
Bill McWhirter	U.S. Air Force
Paul Mettus	LS Technologies LLC
Tony Militello	The MITRE Corporation
Mark Minges	U.S. Air Force
Walter Monk	CSSI, Inc.
Rose Mooney	Mid-Atlantic Aviation Partnership
John Moore	Rockwell Collins, Inc.
Patrick Moorman	The Padina Group
Joe Morgan	Aspenta International, Inc.
Eric Mueller	NASA
Steve Mulloy	Tetra Tech (Exempt, see note)
Cesar Munoz	NASA
Alistair Munro	Airbus
Jim Murphy	NASA
Rodney Murphy	Federal Aviation Administration
Jennifer Murray	NASA
Laurence Mutuel	Sierra Nevada Corporation
Nassib Nabaa	Sierra Nevada Corporation
Mitch Narins	Federal Aviation Administration
Juan Narvid	Federal Aviation Administration
Michael Neale	Federal Aviation Administration
Paul Nelepovitz	Embry-Riddle Aeronautical University
Don Nellis	Federal Aviation Administration
Gregg Nesemeier	Federal Aviation Administration
Kelly Neubecker	ENSCO, Inc.
Bridger Newman	Air Line Pilots Association
Jay Neylon	Federal Aviation Administration

Member	**Organization**
Lee Nguyen	Federal Aviation Administration
Rick Niles	The MITRE Corporation
Fredrik Nordstroem	Airbus
Gary Norek	Federal Aviation Administration
Orville Nyhus	Honeywell International, Inc.
Michelle O'Leary	Regulus Group
Siu O'Young	Seamatica Aerospace Limited
William Oehlschlager	Federal Aviation Administration
Michael Ogundoju	Federal Aviation Administration
Michael Olive	Honeywell International, Inc.
Andre Oliveira	Tekever Lt.
Jonathan Oliver	The Aerospace Corporation
Doug Olsen	University of North Dakota
Wesley Olson	MIT Lincoln Laboratory
David Olster	Saab Sensis Corporation
Barney Owens	U.S. Army
Thomas Pagano	Regulus Group
A. James Pala	Air Line Pilots Association
George Palmer	AX Enterprize LLC
Adam Panken	MIT Lincoln Laboratory
Robert Pappas	Federal Aviation Administration
John Paranzino	Regulus Group
Ajay Parikh	Ligado Networks
Scott Parks	General Atomics Aeronautical Systems, Inc.
Bharath Parthasarathy	Garmin Ltd.
Hannan Parvizian	volans-i, Inc.
Frank Paskiewicz	The Padina Group
Vidyut Patel	Federal Aviation Administration
Brian Patterson	The MITRE Corporation
Steven Payne	U.S. Air Force
Johan Pellebergs	Saab Group
Steven Pennington	U.S. Air Force
John Philbin	Northrop Grumman Corporation
Ajit Pillai	General Atomics Aeronautical Systems, Inc.
Daniel Plawecki	Northrop Grumman Corporation
Stephen Plishka	Federal Aviation Administration
Steve Plummer	Federal Aviation Administration
Ethan Pratt	Bihrle Applied Research, Inc.
Brian Ramsay	The MITRE Corporation
Christian Ramsey	Exelis
Debra Randall	NASA
Murali Rangarajan	The Boeing Company

Member	**Organization**
Steve Rawson	AAI Corporation
Joseph Raynes	The Johns Hopkins University
Mark Reed	Air Line Pilots Association
Stephen Reny	U.S. Air Force
Jeffrey Richards	National Air Traffic Controllers Association (NATCA)
Cortney Robinson	Aerospace Industries Association (AIA)
Jennifer Rogers	Northrop Grumman Corporation
Robert Rorie	NASA
Danny Roth	NASA
Jonah Rouse	U.S. Air Force
Stacey Rowlan	L-3 Communications
Andrew Roy	Aviation Spectrum Resources, Inc.
Jason Rupert	A-P-T Research, Inc.
Kristen Ryan	Northrop Grumman Corporation
Wes Ryan	Federal Aviation Administration
Lev Sadovnik	Sierra Nevada Corporation
Bob Saffell	Rockwell Collins, Inc.
Daniel Salvano	SAIC
Confesor Santiago	NASA
Salomon Satche	Federal Communications Commission (FCC)
Sabrina Saunders-Hodge	Federal Aviation Administration
Ruby Sayyed	International Air Transport Association
Joe Schmidt	Compass Engineering
Vincent Schultz	NASA
Jenipher Scott	U.S. Air Force
Kelvin Scribner	Sagetech Corporation
Stuart Searight	Federal Aviation Administration
Sunita Shah	Cobham Aerospace Communications
Gu Shimin	CARERI
Robert Shively	NASA
Akhilesh Shrestha	ARCON Corporation
Josh Silbermann	The Johns Hopkins University
Siva Sivananthan	ARCON Corporation
James Sizemore	Federal Aviation Administration
Jim Skalski	Federal Aviation Administration
Peter Skaves	Federal Aviation Administration
Trent Skidmore	Ohio University – Avionics Engineering Center
Samantha Smearcheck	Calhoun Analytics
Andrew Smith	Harris Corporation
Bernald Smith	Soaring Society of America
Mark Smith	L-3 Communications
Michael Smith	General Atomics Aeronautical Systems, Inc.

Member	Organization
Timothy Snodgrass	Rockwell Collins, Inc.
Kyle Snyder	NextGen Air Transportation Consortium
Jason Sohlke	The Johns Hopkins University
Jeffrey Sparrow	Federal Aviation Administration
Mike Sperry	Northrop Grumman Corporation
Charles Spinelli	The Boeing Company
Eric Spitz	Harris Corporation
Thomas Spriesterbach	The Johns Hopkins University
Wade Stanfield	Thales Group
Richard Stansbury	Embry-Riddle Aeronautical University
Rolf Stefani	ARINC Incorporated
Brett Steffey	Federal Aviation Administration
Timothy Steiner	Federal Aviation Administration
Jonathan Stephens	Defence Equipment & Support (UK MoD)
John Stevens	SOAR Oregon
Dawson Stott	NextGen Air Transportation Consortium
David Strohm	United Airlines, Inc.
Mark Stubbs	Defence Equipment & Support (UK MoD)
Brandon Suarez	General Atomics Aeronautical Systems, Inc.
Neal Suchy	Federal Aviation Administration
Erin Sunshine	The MITRE Corporation
Christopher Swider	Federal Aviation Administration
Harris Teague	Qualcomm Technologies, Inc.
Brandi Teel	RTCA, Inc.
James Thammarath	General Atomics Aeronautical Systems, Inc.
Sid Theis	RDRTec, Inc.
Chris Theisen	Northern Plains UAS Test Site (NPUASTS)
Erik Theunissen	Information Systems Delft
Greg Thibeault	The MITRE Corporation
David Thipphavong	NASA
Mark Thompson	Northrop Grumman Corporation
Andrew Thurling	AeroVironment (EUROCAE member)
Filippo Tomasello	European Aviation Safety Agency (EASA)
Thanh Trang	Federal Aviation Administration
Randall Trent	L-3 Communications
Jim Troxel	L-3 Communications
Michael Tseytlin	Facebook
Jessie Turner	The Boeing Company
Mathias Van Den Bossche	Thales Group
Harrell Van Norman	U.S. Air Force
Stephen Van Trees	Federal Aviation Administration
Nicolas Van Wambeke	Thales Group

Member	Organization
Matthew Velazquez	Textron
Filip Verhaeghe	(UN)MANNED
John Vian	The Boeing Company
Anthony Vilante	Federal Aviation Administration
Daniel Vivanco	The MITRE Corporation
Gary Viviani	Insitu Inc.
Tom Vogl	Rockwell Collins, Inc.
Nestor Voronka	M42 Technologies
Kim Vu	NASA
Mike Vukas	Federal Aviation Administration
Chinh Vuong	Federal Aviation Administration
Edgar Waggoner	NASA
Richard "Dickie" Waggoner	U.S. Air Force
Don Walker	Federal Aviation Administration
John Walker	JSWalker Group/Aviation Solutions, Inc.
William (Bill) Walker	Northrop Grumman Corporation
David Walsh	Federal Aviation Administration
Thomas Walsh	Federal Aviation Administration
Chris Wargo	Mosaic ATM, Inc.
Jeremy Warren	Booz Allen Hamilton (USAF Exempt)
Karin Weber	US Department of Transportation
Jeff Weeldreyer	L-3 Communications
Steve Weidner	National Air Traffic Controllers Association (NATCA)
Andy White	Defense Research Associates
Michelle White-Heon	Raytheon
Fred Wieland	Intelligent Automation, Inc.
Jeffrey Wilbert	Northrop Grumman Corporation
Christopher Wilkening	Bihrle Applied Research, Inc.
Charlie Williams	The MITRE Corporation
Dan Williams	Federal Aviation Administration
Jim Williams	Dentons Aviation Practice
Kevin Williams	Federal Aviation Administration
Ian Wilson	The Boeing Company
Andrea Wolf	U.S. Air Force
Mark Wuennenberg	Transport Canada
Jack Yang	General Atomics Aeronautical Systems, Inc.
Ralph Yost	Federal Aviation Administration
Ray Young	Northeast UAS Airspace Integration Research Alliance (NUAIR)
James Ziarno	Harris Corporation

A APPENDIX A: OPERATIONAL SERVICES AND ENVIRONMENT DESCRIPTION (OSED)

A.1 Introduction

This document provides the Operational Services and Environment Description (OSED) for the Phase 1 RTCA SC-228 Unmanned Aircraft System (UAS) Detect and Avoid (DAA) Minimum Operational Performance Standards (MOPS). The purpose of this OSED is to provide a basis for assessing and establishing operational, safety, performance, and interoperability requirements for DAA systems.

Because UAS platforms lack an onboard human operator with natural vision to comply with the requirements of Title 14 of the Code of Federal Regulations (14 CFR), Part 91, §91.111a, §91.113, and §91.181, a DAA system is being standardized in order to establish an acceptable alternative means of compliance. The DAA system is used to avoid nearby aircraft (hereafter referred to as “intruders”).

This OSED describes using a MOPS-compliant DAA Class 1 or Class 2 system (see Subsection A.3) with sensors onboard an Unmanned Aircraft (UA) operating under Instrument Flight Rules (IFR) while transiting through Class D, Class E up to Flight Level (FL) 180, or Class G airspace to or from Class A or Special Use Airspace (SUA). When equipped with a Class 2 system The UA will include integrating DAA with the Traffic Alert and Collision Avoidance System Model 2 (TCAS II) system capable of providing Resolution Advisories (RAs). Operations within Class A or SUA are out of scope for Phase 1 equipment. This OSED does not apply to UAS operations conducted below 500’ in accordance with 14 CFR Part 107.

The DAA Phase 1 MOPS, the guiding RTCA SC-228 Terms of Reference (TORs), and this OSED focus on airborne DAA systems with sensors onboard the UA, and do not specifically address issues regarding ground-based DAA systems.

The scenarios in this OSED expand upon the Federal Aviation Administration (FAA) UAS Concept of Operations (CONOPS),[16] and provide additional operational detail necessary for DAA MOPS development.

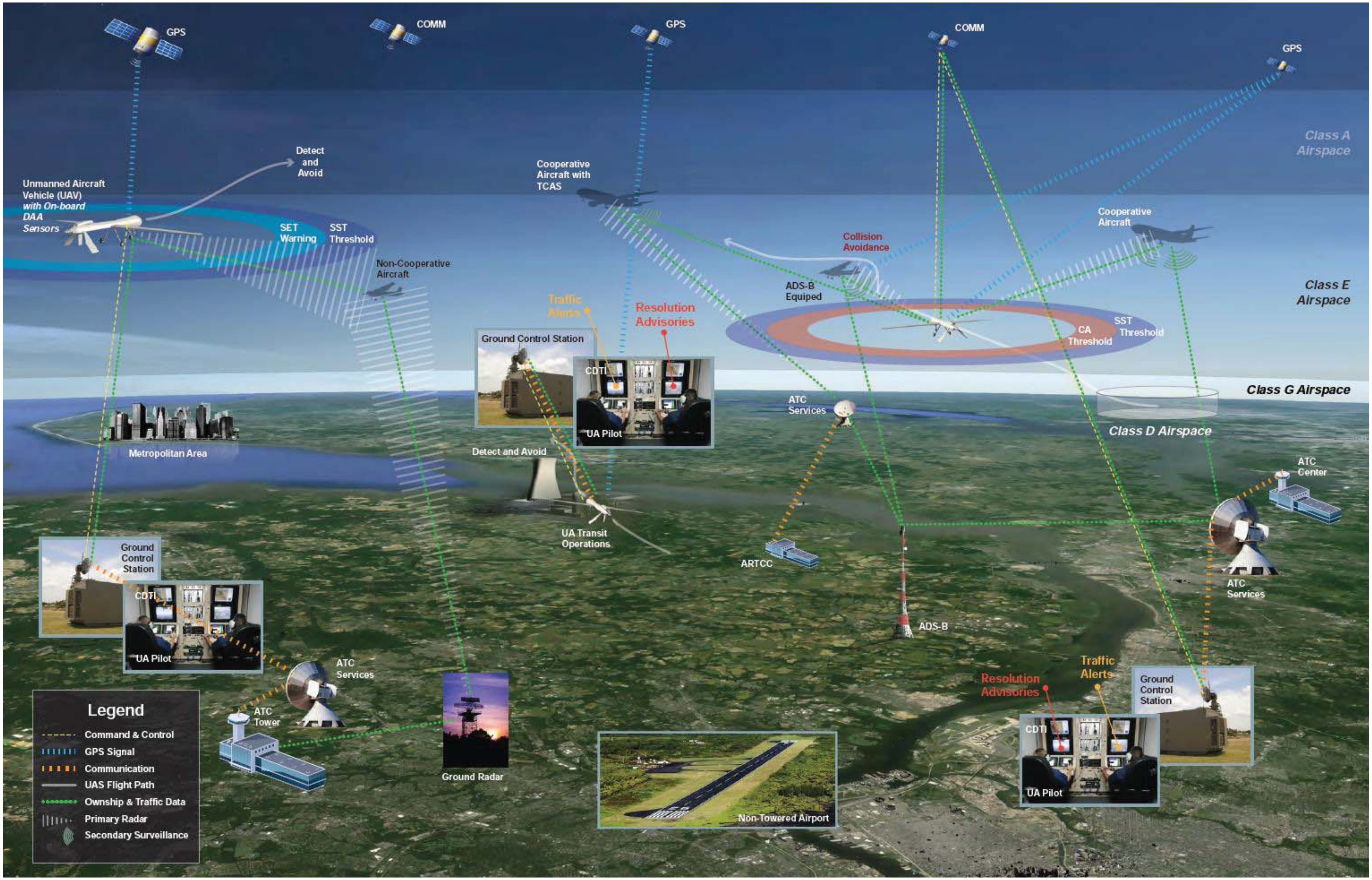
In developing the services and environment description, the OSED identifies Operational Assumptions (ASSUMP-OSED.##) and Operational Requirements (OR.##) which are necessary to bound the scope of the document. Operational Assumptions, while important, do not establish a requirement upon the system or other actors in the environment. Operational Requirements do establish a requirement; however, the object of the requirement will always be an actor “external to the DAA System” (e.g., requirements on pilot or controller training or responsibilities). Operational Assumptions are summarized in Subsection A.7 and Operational Requirements are summarized in Subsection A.8.

[16] Federal Aviation Administration (2012). Integration of Unmanned Aircraft Systems into the National Airspace System, Concept of Operations V2.0, September 28, 2012

A.2 Environment

UAS with Phase 1 MOPS DAA equipment are expected to operate in the U.S. National Airspace System (NAS) as of the publishing date of these MOPS, including planned NextGen changes such as the Automatic Dependent Surveillance-Broadcast (ADS-B) Out mandate in 2020. The following paragraphs describe the environment where DAA equipment will operate, focusing on the conditions and factors expected to influence the design and operation of DAA equipment. This information provides the needed context to understand DAA operations and describe the operational scope being validated in Phase 1. It is not meant to be a complete list of all assumptions or details needed to perform modeling and simulation as part of the DAA requirements development or validation.

Figure A-1, based on an FAA UAS integration high-level operational concept graphic, shows activities and functions, interdependencies, capabilities, and supporting technologies for Phase 1 DAA operations.



<u>Figure A-1</u> **DAA System Environment**

A.2.1 Airspace

This paragraph contains a description of classes and complexities of airspace where Phase 1 in-scope encounters may occur.

The Phase 1 DAA system is meant for operations transiting into, out of, or through Class D, E up to Flight Level 180 (FL180),[17] and G airspace as defined in 14 CFR §91 (and depicted in Figure A-2 from the FAA Aeronautical Information Manual (AIM)) to or from Class A airspace or SUA. The Phase 1 DAA system will facilitate departures and arrivals to an airport or launch/recovery zone in Class D, E, or G airspace, exclusive of surface operations, operations in the airport Visual Flight Rules (VFR) traffic pattern,[18] and operations in Class B or C airspace.

> **ASSUMP-OSED.1** DAA systems will be used during transit into, out of, or through Class D, E up to FL180, and G airspace, to or from Class A airspace or SUA.

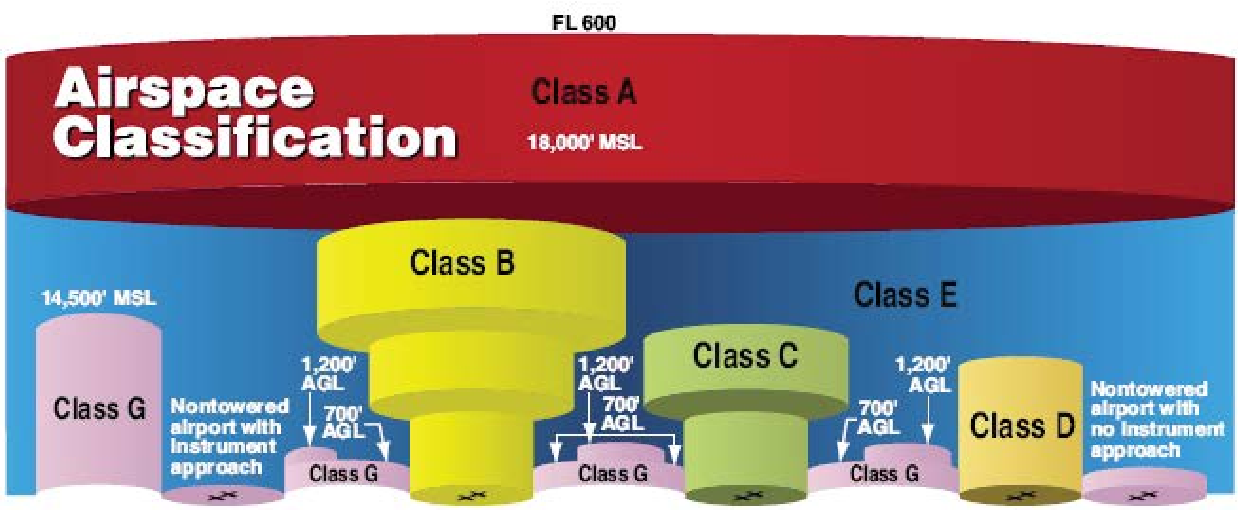


Figure A-2 Airspace Classes (faasafety.gov)

Operations outside the performance capabilities of the DAA system are not considered in this OSED (e.g., surface operations, operations below the clutter-driven radar operating altitude, takeoffs and landings, accepting visual separation clearances, etc., as documented under operational limitations in Paragraph 1.2.3). One or more authorized method(s) of separation, such as Air Traffic Control (ATC) tower procedures, ground observers, ground-based DAA systems, chase aircraft, or segregated airspace, must be used near the takeoff or landing location and other areas where Phase 1 DAA equipment is not designed to operate. An approved procedure will be in place to transition from using the DAA system to maintain DAA Well Clear (DWC) to another method of separation. DAA equipment may be used for traffic situational awareness and as an aid to communications with ATC in other airspace (Class A, restricted airspace, traffic pattern, etc.), but not for aircraft separation or maintaining DWC.

[17] Operations in Class E airspace above FL600 and in oceanic airspace is outside the Phase 1 MOPS scope.
[18] See FAA AIM 4-3-3 or FAA Joint Order (JO) 7110.65W 3-10-1; this includes overhead maneuvers.

ASSUMP-OSED.2 DAA systems will not be used for separation in surface operations, operations in the airport VFR traffic pattern, operations in Class A, B or C airspace, or operations outside of the performance capabilities of the DAA system.

ASSUMP-OSED.3 Operational limitations will be placed on UAs using DAA systems due to airspace regulations, vehicle performance, or the technical capabilities of the DAA system.

For operational limitations placed on the use of the DAA system, the Pilot-in-Command (PIC) will have access to information and controls necessary to ensure operations are conducted within the limitations. The information may be from onboard sensors, ground sensors, or databases. Included in such operational limitations would be the status and geographical extent of the Control and Non-Payload Communications (CNPC) data link coverage. Operational limits are typically included in an Airplane Flight Manual and/or Pilot's Operating Handbook, but other documents may be used for UA systems.

OR.1 The UAS PIC shall have access to information and controls related to the environment and operation of the UAS necessary to ensure that the UA remains within DAA-imposed operational limitations.

Two-way communications with ATC must be established and maintained while in Class D airspace for all aircraft (FAA AIM 3-2-5.b.3). In Class E and G airspace, communications with ATC are not required when operating under VFR outside of control towered airport areas (14 CFR §91.127(c)). DAA-equipped UAS operating under IFR will be in two-way communications with ATC, as will other IFR aircraft. Radio communications and some NextGen communications architectures also provide partial traffic situational awareness to UAS pilots through the "party-line" nature of the communications.

OR.2 The UAS PIC shall maintain two-way communication with ATC where applicable, in order to query, respond to, and be informed of traffic advisories and traffic-related safety alerts, and develop avoidance strategies in a timely and expedient manner, commensurate with the urgency and phase of flight.

ATC is not required to provide separation services for VFR aircraft in Class D, E and G airspace (FAA AIM 3-2-5.e, 3-2-6.f), but is required to provide separation services between IFR aircraft and other IFR aircraft (FAA AIM 4-4-11) in Class D and E airspace.

14 CFR §91.117 is a factor that affects intruder behavior, stating that no person may operate an aircraft below 10,000' Mean Sea Level (MSL) at an indicated airspeed of more than 250 knots (288 miles per hour (mph).). There is an exception for aircraft with minimum safe speeds greater than 250 knots; e.g., some military aircraft and heavy aircraft on departure. The 250-knot speed limit provides an upper bound closure rate for the vast majority of intruders below 10,000' MSL. In particular, non-cooperative intruders (those without transponders and/or ADS-B Out) are only expected below 10,000' MSL or below 2500' Above Ground Level (AGL), therefore 250 knots provides an upper bound on their expected speed.

Oceanic airspace is not considered in this OSED.

A.2.1.1 Airspace Cooperative Surveillance Equipage Rules

As depicted in Figure A-3, per §91.225, ADS-B Out equipment is required after January 1, 2020 in Class E airspace above 10,000' MSL (except below 2500' AGL), in and above Class B and C airspace, and within 30 NM of the large airports listed in Appendix D of Part 91. This is the same part of Class E airspace where transponder equipage is required per §91.215. There are exceptions in both §91.225 and §91.215 for aircraft not originally certificated with an electrical system or for one-time ATC approvals for situations like ferrying inoperative equipment.

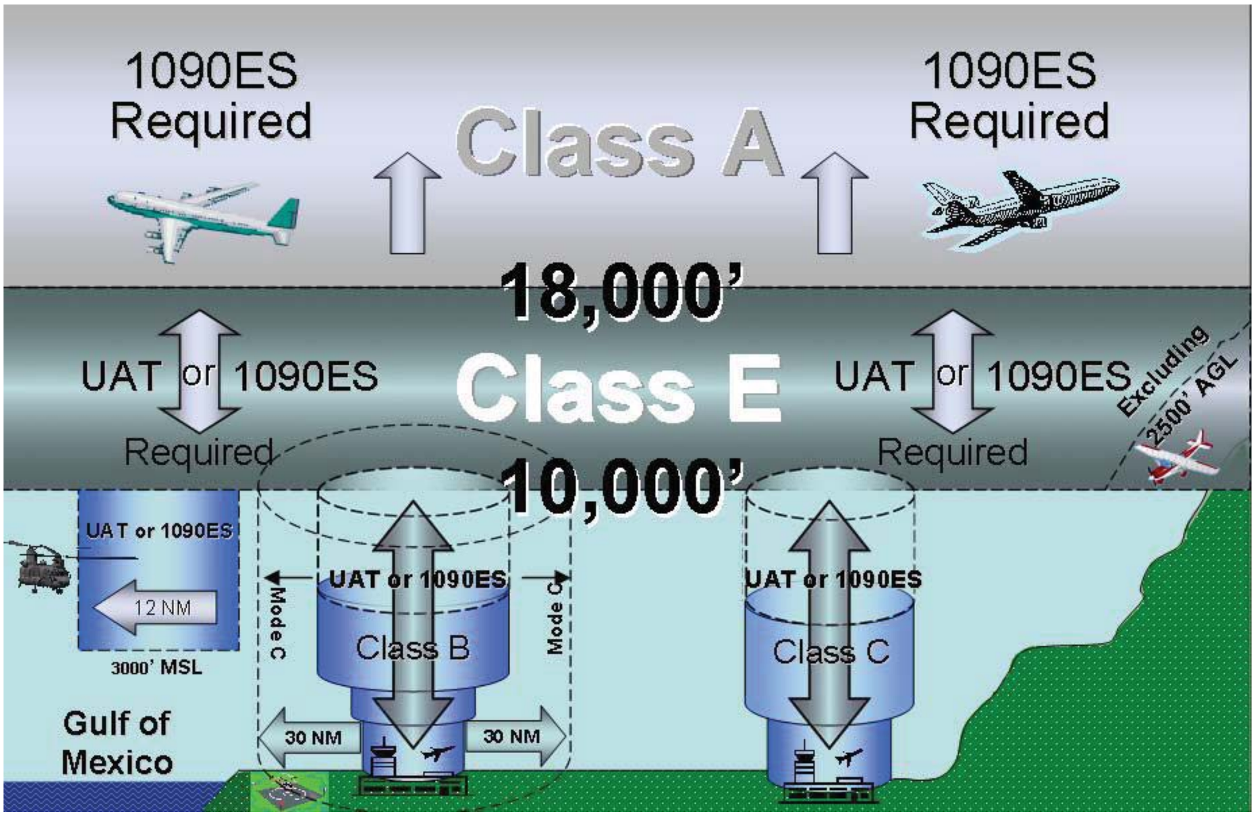


Figure A-3 ADS-B Out Required Airspace

DAA equipment will operate in ADS-B and transponder rule airspace, per §91.225 and §91.215, as well as airspace where no such equipage requirements exists. Therefore UAs equipped with DAA will encounter intruders with no cooperative surveillance equipment, with ADS-B Out or non-ADS-B Out transponders. Aircraft must leave any transponder and ADS-B Out equipment on if installed and functioning, even outside of rule airspace (14 CFR §91.215 (c) and §91.225 (f)).

Within ADS-B rule airspace after 2020, FAA forecasts expect 100% of aircraft to be equipped with rule-compliant ADS-B Out systems.[19] However, due to equipage failures, degradations, aircraft without electrical systems (below FL180), and temporary ATC waivers, 99.9% is a more realistic assumption.

[19] FAA SBS Program Manager Report, Slide 1, 25 September 2014

ASSUMP-OSED.4 99.9% of aircraft in ADS-B rule airspace (post-2020) below FL180 and 100% of aircraft above FL180 will have rule-compliant ADS-B Out.

Outside of rule airspace, a conservative assumption used by the TCAS community is that 15% will not be equipped with a transponder (or equipped with Mode A transponder only), 71% will have ADS-B Out (FAA forecasts 83% of transponder equipped aircraft[20]), and the remaining 14% will have Mode C transponders only. As used by the TCAS community, it is assumed that 80% of ADS-B equipage will use 25' altitude reporting increments (resolution) and the remaining 20% will use 100' altitude resolution. According to an analysis by the FAA Technical Center in Atlantic City, NJ, 64% of aircraft are TCAS II equipped. However, their data is not broken down by altitude layer, so while more aircraft will be equipped above FL180 and less outside of rule airspace, Sixty-four percent is used in this OSED for all airspace. Table A-1 summarizes the intruder equipage assumptions.

ASSUMP-OSED.5 Outside of ADS-B rule airspace, 15% of aircraft will have no transponder or a Mode A transponder, 14% will have Mode C with 100' altitude resolution and no ADS-B Out, and 71% will have ADS-B Out, of which 14% have 100' altitude resolution and 57% have 25' altitude resolution.

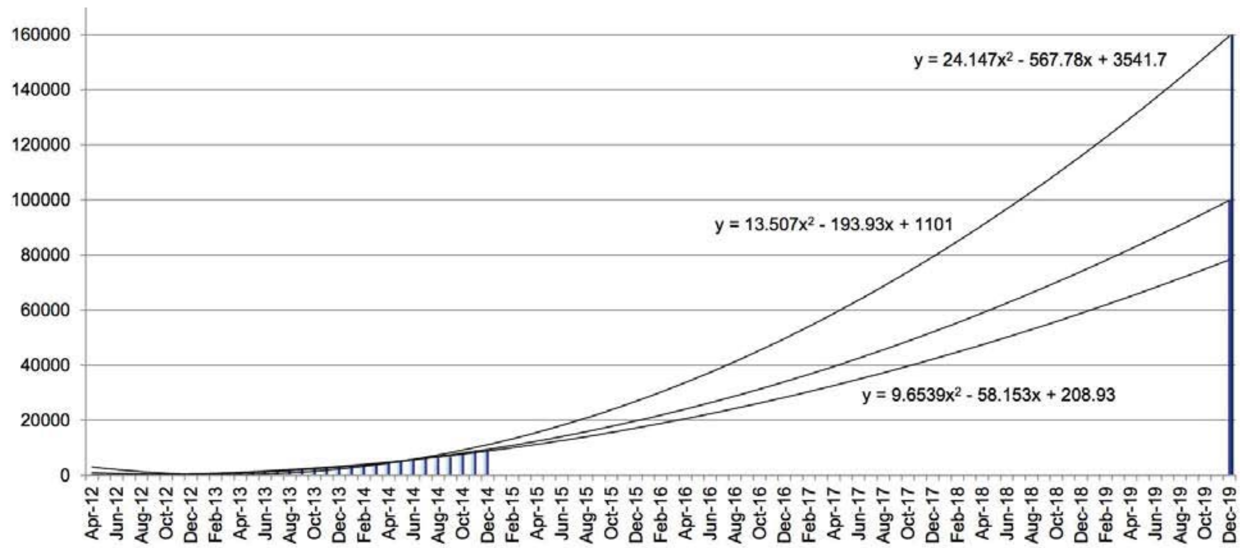
Table A-1 Intruder Equipage Assumptions Post-2020

Airspace	Speed Limit	No Transponder (or Mode A Transponder)	Mode C Only (100' Resolution)	ADS-B Out (1090 or UAT)	ADS-B Out with 100' Altitude Resolution	ADS-B Out with 25' Altitude Resolution	TCAS II
Outside Rule Airspace	< 250 knots	15%	14%	71%	14%	57%	< 64%
Inside Rule Airspace < 10,000'	< 250 knots	0.1%	0%	99.9%	19.9%	80%	64%
Inside Rule Airspace > 10,000' and < FL180	none	0.1%	0%	99.9%	19.9%	80%	64%
Inside Rule Airspace > FL180	none	0%	0%	100%*	20%	80%	> 64%

* Transponder failures and ATC waivers are considered abnormal failure conditions

[20] FAA SBS Program Manager Report, Slide 2, 25 September 2014

Assumptions regarding ADS-B equipage data prior to 2020 depend heavily on the current equipage, which changes daily with market forces driving equipage. The FAA has made some rough projections based on historical equipage data from April 2012 to December 2014, which are presented in Figure A-4 (from the FAA Surveillance and Broadcast Services (SBS) Office, Avionics Monitoring Review, Jan 16th, 2015). Prior to 2020, aircraft listed in Table A-1 under ADS-B Out that have not yet equipped with ADS-B Out, will have either a Mode C or Mode S transponder with the same altitude resolution as listed in the table.



By End of Year	Projected Equipage (based on historical growth curve to Dec 2014)	Projection based 100K by 1/1/2020	Projection based on 160K by 1/1/2020
Jan 1st, 2016	17,141	19,726	26,889
Jan 1st, 2017	28,260	33,931	49,632
Jan 1st, 2018	42,160	52,027	79,329
Jan 1st, 2019	58,840	74,012	115,989
Jan 1st, 2020	78,301	100,000	160,000

Figure A-4 ADS-B Link Version 2 Equipage Projection to January 1, 2020

Aircraft equipped with Technical Standards Order (TSO)-C199 Traffic Awareness Beacon System (TABS) are not accounted for in this environment description. The number of aircraft that will equip with TABS is unknown at this time, so it is unknown how many uncooperative aircraft in the NAS when these MOPS were published will become cooperative in the future due to TABS. DAA equipment may use surveillance of TABS-equipped aircraft to the extent that the TABS-equipped aircraft can be tracked by active surveillance and ADS-B In equipment.

A.2.1.2 Alaskan and Hawaiian Airspace Differences

Some equipage requirements are different for Hawaii and Alaska than for the 48 contiguous states and the District of Columbia. The requirement for transponders and ADS-B Out above 10,000' MSL is not applicable in Hawaii and Alaska. However, this may not affect DAA equipment performance since it is unlikely that aircraft not equipped with a transponder or ADS-B Out will be traveling faster than 250 knots above 10,000' MSL (per §91.117), and thus can be treated the same as unequipped aircraft below 10,000' MSL from an analysis perspective.

ASSUMP-OSED.6 Aircraft above 10,000' MSL in Hawaii and Alaska without ADS-B Out or transponders will have velocities and accelerations similar to those unequipped aircraft below 10,000' MSL.

Another difference is that Hawaii does not have Class A airspace, and thus does not have an ADS-B requirement above FL180 per §91.225. However, since aircraft that operate above FL180 will most likely operate in Honolulu Class B airspace and Kahului Class C airspace, they will have ADS-B Out after January 1, 2020. Aircraft must leave transponder and ADS-B Out equipment on if installed and functioning, even outside of rule airspace (14 CFR §91.215(c) and §91.225 (f)).

A.2.2 Aircraft Density

The density of other aircraft in which the DAA system must operate will range from zero to the densest Class E airspace in the NAS, which from TCAS experience is the Los Angeles (LA) basin region or the New York City metroplex. Densities at busy Class D airports may be even denser (e.g., Daytona Beach, Van Nuys), but separation in these high-density environments will be done by other separation means than those that fall within the transit operations definition for Phase 1 DAA equipment. High-density hot spots for soaring and lighter-than-air operations (e.g., hot-air balloon areas in California and New Mexico) may increase non-cooperative aircraft densities.

The DAA system must also operate in Class D, E, and G airspace of various complexities. The most complex airspace that could be encountered would be Class E airspace surrounding metroplex airports. However, this complex airspace is likely within the Mode C and ADS-B veil per 14 CFR §91.215 and §91.225, where intruders will be cooperative and thus likely detected and tracked at a greater range.

RTCA DO-185B TCAS II assumes a maximum density of 0.06 aircraft per Square Nautical Mile NM^2 (aircraft/NM^2) of Mode C and Mode S intruders in higher altitude airspace and 0.3 aircraft/NM^2 in lower altitude airspace. RTCA DO-242A,[21] the ADS-B Minimum Aviation System Performance Standards (MASPS) uses the Los Angeles (LA) Basin 2020 assumption of 0.32 aircraft/NM^2 within 5 NM from LA, decreasing to 0.00375 aircraft/ NM^2 225 NM away from Los Angeles International Airport (LAX).

As part of the 1090 MHz Spectrum Mitigation Alternatives Analysis,[22] data was collected around John F. Kennedy International Airport (JFK) in 2011 of the peak Instantaneous Aircraft Count (IAC) within various ranges of JFK. This data has been converted to aircraft/NM^2, as shown in Table A-2. This data, along with RTCA DO-185B TCAS II density assumptions, are two-dimensional densities that include all aircraft flying over a portion of the earth's surface.

[21] DO-242A Change 1 – Minimum Aviation System Performance Standards for Automatic Dependent Surveillance Broadcast (ADS-B), 13 December 2006
[22] Tom Pagano, Surveillance Spectrum Congestion Mitigation Analysis Phase 2: 1090 MHz Alternatives Analysis; draft FAA report – to be published by March 2017.

Table A-2 Aircraft Density Based on 2011 JFK Data

Range (NM)	10	20	30	50	70	100	150	200	300
IAC	16	43	77	157	240	355	554	760	1180
Aircraft per NM^2	0.0509	0.0342	0.0272	0.0200	0.0156	0.0113	0.0078	0.0060	0.0042

The JFK data should be extrapolated to account for future traffic growth. Traffic growth projections used for the 1090 MHz Spectrum Mitigation Alternatives Analysis range from 1.1% to 4.1%. Using roughly the median traffic growth rate, the aircraft density doubles around 2030, resulting in densities ranging from 0.008 to 0.1 aircraft/NM^2, which is still less than the RTCA DO-185B TCAS II density assumptions of 0.06 to 0.3 maximum aircraft/NM^2 in high-altitude En Route airspace to dense metroplex airspace.

Using the RTCA DO-185B TCAS II density assumptions of 0.3 to 0.06 maximum aircraft/NM^2 for DAA equipment design is a conservative assumption for all United States (US) airspace densities well past 2030. The higher density end of this range will be near major metroplexes within the Mode C veil, and therefore, the vast majority of aircraft in high-density airspace will be cooperative (transponders and possibly ADS-B Out).

> **ASSUMP-OSED.7** DAA equipment will operate in airspaces with maximum densities ranging from 0.3 aircraft/NM^2 near metroplexes, to 0.06 aircraft/NM^2 in high-altitude En Route airspace.

A.2.3 Altitudes

Phase 1 in-scope encounters may occur at altitudes ranging from 1000' AGL, or the minimum sensor capability, to FL180 (beginning of Class A airspace). This includes the potential for encounters at -1,000' MSL, to capture below sea level locations. Class E airspace above FL600 is out of scope for Phase 1 DAA equipment. Other than helicopters, powered parachutes, and weight-shift control aircraft, 500' AGL is the minimum safe altitude per 14 CFR 91.119(c) for all aircraft over non-congested areas. Operations between 500 and 1000' AGL are considered part of the takeoff or landing phase and separation will be handled by other means.

Sensor performance may limit the operational altitude further for a particular DAA system. For example, one DAA system may require reverting to an alternate means of separation at 700' AGL, while another DAA system may require the change at a different discrete altitude. The UAS PIC will be responsible for respecting the operational limitations of the DAA system (see OR.1).

Air traffic control voice communications use pressure altitude and barometric corrected pressure altitude (MSL) reports from pilots. In order to operate in the NAS and follow ATC instructions, UAS must report altitude information according to existing standards, both manually through voice communications and automatically through transponder systems. This is assumed since the DAA UA is operating under IFR (see ASSUMP-OSED.8).

A.2.4 Flight Rules

The Phase 1 MOPS DAA UAS will always operate under IFR and comply with all applicable regulations and operational rules. This involves filing and following an IFR flight plan.

ASSUMP-OSED.8 DAA-equipped UAS will operate under IFR.

OR.3 The UAS PIC shall be able to follow ATC instruction for IFR flight for the intended flight environment, including published routes and procedures for which the UA is equipped.

OR.4 The UAS PIC must comply with the CFR, operational rules and regulations and, when applicable, should follow other guidance and procedures used for manned aircraft.

Intruders may be operating under VFR or IFR. UAS with DAA are not expected to encounter Special VFR (SVFR) intruders since SVFR aircraft are only operating in the airport traffic area, which is out of the operational scope for Phase 1 DAA equipment. However, if the DAA UAS did encounter a SVFR intruder while using DAA, the PIC would treat the intruder like any other VFR or IFR intruder and attempt to maintain DWC.

DAA equipment will not enable the PIC of the DAA-equipped UA to accept visual separation, delegated separation, visual approach, or contact approach responsibilities.

A.2.5 Intruders

A.2.5.1 Intruder Equipage

The intruder may be equipped with a Mode A transponder, a Mode A/C transponder, or a Mode S transponder with or without ADS-B Out (1090ES or UAT). The intruder may have no transponder or ADS-B Out system given that the Phase 1 operational scope (Class D, E, and G) includes airspace outside the transponder- (14 CFR §91.215) and ADS-B (14 CFR §91.225) mandated airspace. Even within transponder and ADS-B-mandated airspace, aircraft may not be operating that equipment, either because the aircraft was not originally certified with an electrical system, or the aircraft is operating with an ATC authorized deviation (14 CFR §91.215(d), §91.225(g)). See Paragraph A.2.1.1 for more detailed equipage forecasts broken down by airspace.

Intruders may be operating with 1200 or discrete (non-1200) Mode A codes. Intruders with 1200 Mode A codes will be operating under VFR. Intruders with discrete Mode A codes may be operating under VFR and receiving ATC traffic advisories or operating under IFR.

Intruders may be equipped with any version of TCAS, including future Airborne Collision Avoidance System Models (ACAS X) variants. Intruders may also be equipped with DAA equipment specified by these MOPS. DAA equipment must be interoperable with TCAS equipment and ACAS X equipment as defined in Appendix M.

Intruders may or may not have communications radios as communication with ATC is not required in Class E or G airspace. Additionally, intruders may not be communicating with ATC in any airspace during No-Radio (NORDO) operations.

A.2.5.2 Intruder Physical Characteristics

Intruders for Phase 1 in-scope encounters may be one of the following aircraft categories: airplane, rotorcraft, glider, lighter than air (airship and balloon), or powered lift. Those aircraft may be manned or unmanned.

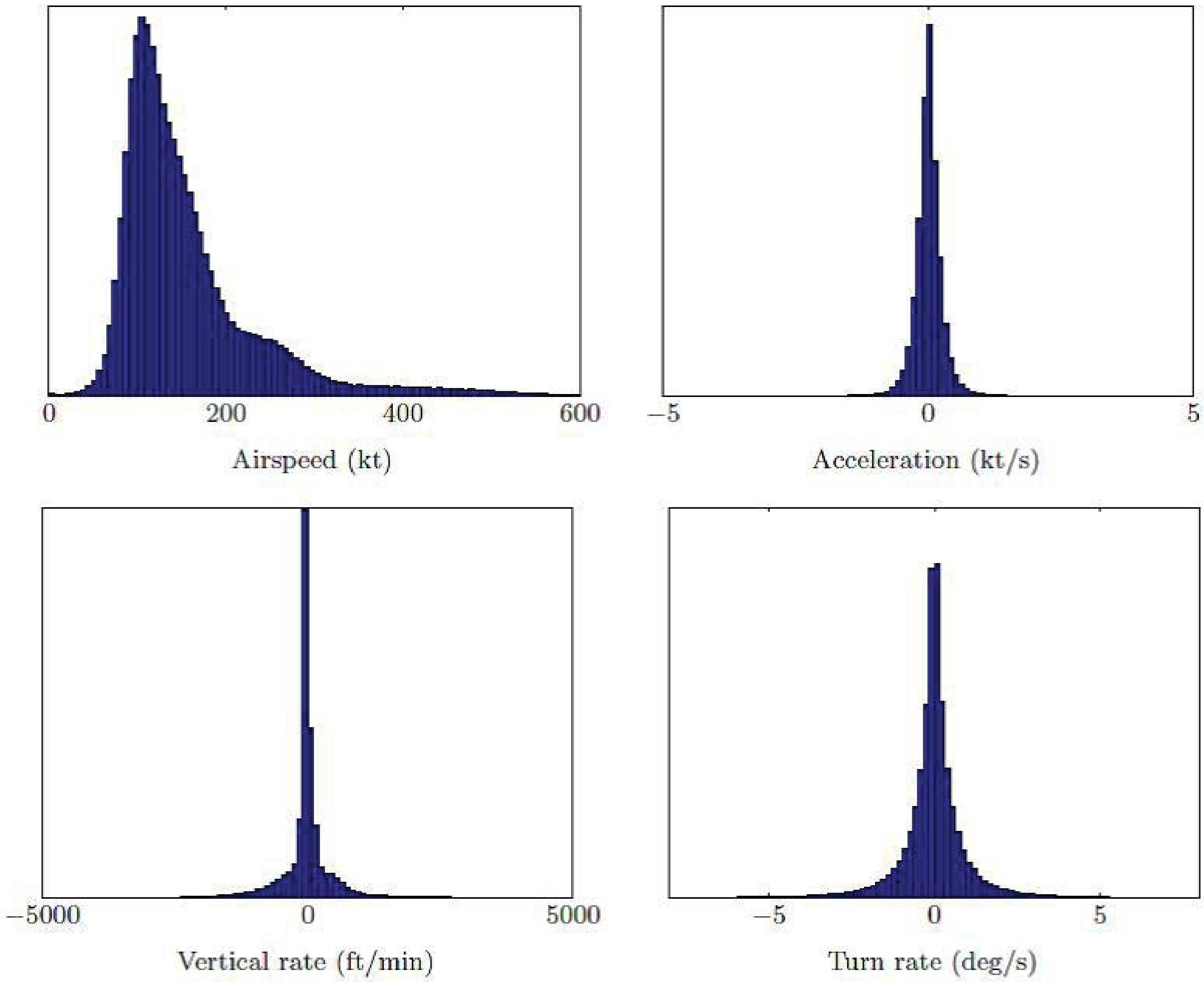
> **ASSUMP-OSED.9** Phase 1 DAA equipment will perform its intended function with intruder encounters in the following aircraft categories: airplane, rotorcraft, glider, lighter than air (airship and balloon), and powered lift. Those aircraft may be manned or unmanned.

Encounters with the following are out of scope for Phase 1 DAA equipment: Powered and unpowered parachutes, weight-shift-control aircraft, and space vehicles. These vehicles are out of scope due to the difficulty in detecting them and the existence of procedural means of avoiding areas of known operations.

Aircraft encountered can potentially have a maximum velocity up to 600 knots[23] (250 knots below 10,000' MSL), a maximum vertical rate of 5,000' per minute (fpm),[24] and a maximum horizontal acceleration of 1.5 times the acceleration of gravity (g).[25] Data from the Massachusetts Institute of Technology Lincoln Laboratory (MIT LL) correlated and uncorrelated encounter models indicate that a maximum vertical rate of 4,000 to 5,000 fpm is appropriate.[26], [27] Figure A-5 and Figure A-6 show the distributions of airspeed, vertical velocity, acceleration, and turn rate for intruders in the MIT LL correlated and uncorrelated encounter models. The correlated encounter model characterizes aircraft involved in encounters where at least one aircraft has a non-1200 Mode 3/A transponder code. The uncorrelated encounter model characterizes aircraft involved in encounters where both aircraft have 1200 Mode 3/A transponder codes. The data in these encounter models can be used for DAA safety and performance analyses.

---

[23] TCAS assumes a maximum closing speed of 1200 knots, DO-185B §2.2.4.6, 19 June 2008
[24] DO-317A, §2.2.3.1.3.1, 13 December 2011, based on DO-185B, §2.2.4.6, 19 June 2008,which requires a maximum 10,000-fpm relative altitude rate, which can be divided into 5000 fpm per aircraft
[25] DO-317A, §2.2.3.1.3.1, 13 December 2011, based on horizontal acceleration of high-performance business jets during surface takeoff and landing
[26] Kochenderfer et al. "Correlated Encounter Model for Cooperative Aircraft in the National Airspace System Version 1.0." Project Report ATC-344. MIT Lincoln Laboratory. 24 Oct 2008
[27] Kochenderfer et al. "Uncorrelated Encounter Model of the National Airspace System Version 1.0." Project Report ATC-345. MIT Lincoln Laboratory. 14 Nov 2008



<u>Figure A-5</u> **Correlated Encounter Model Aircraft Behavior Distributions (ATC-344 Figure 13)**

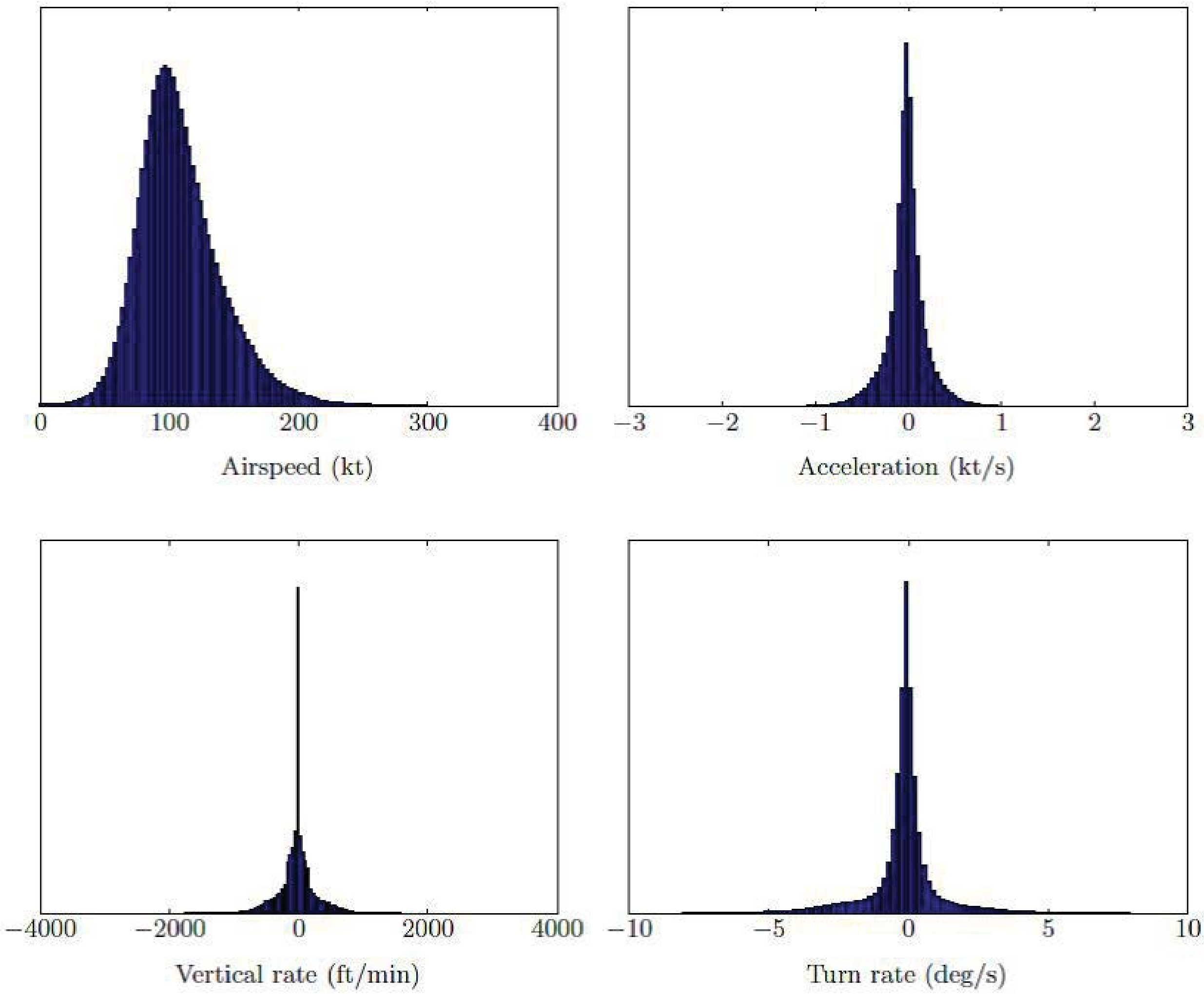


Figure A-6 **Uncorrelated Encounter Model Aircraft Behavior Distributions (ATC-345 Figure 8)**

The distributions shown in Figure A-5 and Figure A-6 from the MIT LL correlated and uncorrelated models are based on observed flight path data from aircraft in the NAS prior to the introduction of UAS. They do not include behaviors and performance of future UAS. It is expected that future UAS will have equivalent or lower performance (airspeed, acceleration, vertical rate, and turn rate) than existing manned aircraft. So while a large number of UAS introduced to the NAS will change the shape of the distributions, they should not affect the maximum values used for DAA analyses. During deployment of Phase 1 DAA MOPS equipment, there will be a small number of UAS in the operational airspace compared with manned aircraft.

A.2.5.3 Intruder Encounter Geometries

Intruders can be approaching from any horizontal aspect. This means they may be converging, overtaking, overtaken, or head on encounters per the right of way rules in 14 CFR §91.113. However, due to the forward motion of the ownship, the majority of intruders will be approaching from the front of the ownship. National Aeronautics and Space Administration (NASA) Airspace Concept Evaluation System (ACES) simulations of future UAS flight paths through the NAS show the distribution of horizontal encounter angles (Figure A-7 and Figure A-8).[28, 29] Forty seconds prior to a Loss of Well Clear (LoWC), 90% of aircraft are in front of the ownship (±90 degrees relative horizontal angle) and 92% of aircraft are within ±110 degrees. This data is based on a wide range of UA speeds (46-340 knots) and intruder speeds observed in recorded NAS data. However, as ownship speed decreases, the number of intruders encountered in front of the ownship will decrease. Slower ownship speeds will result in an increased percentage of encounters where the ownship is being overtaken.

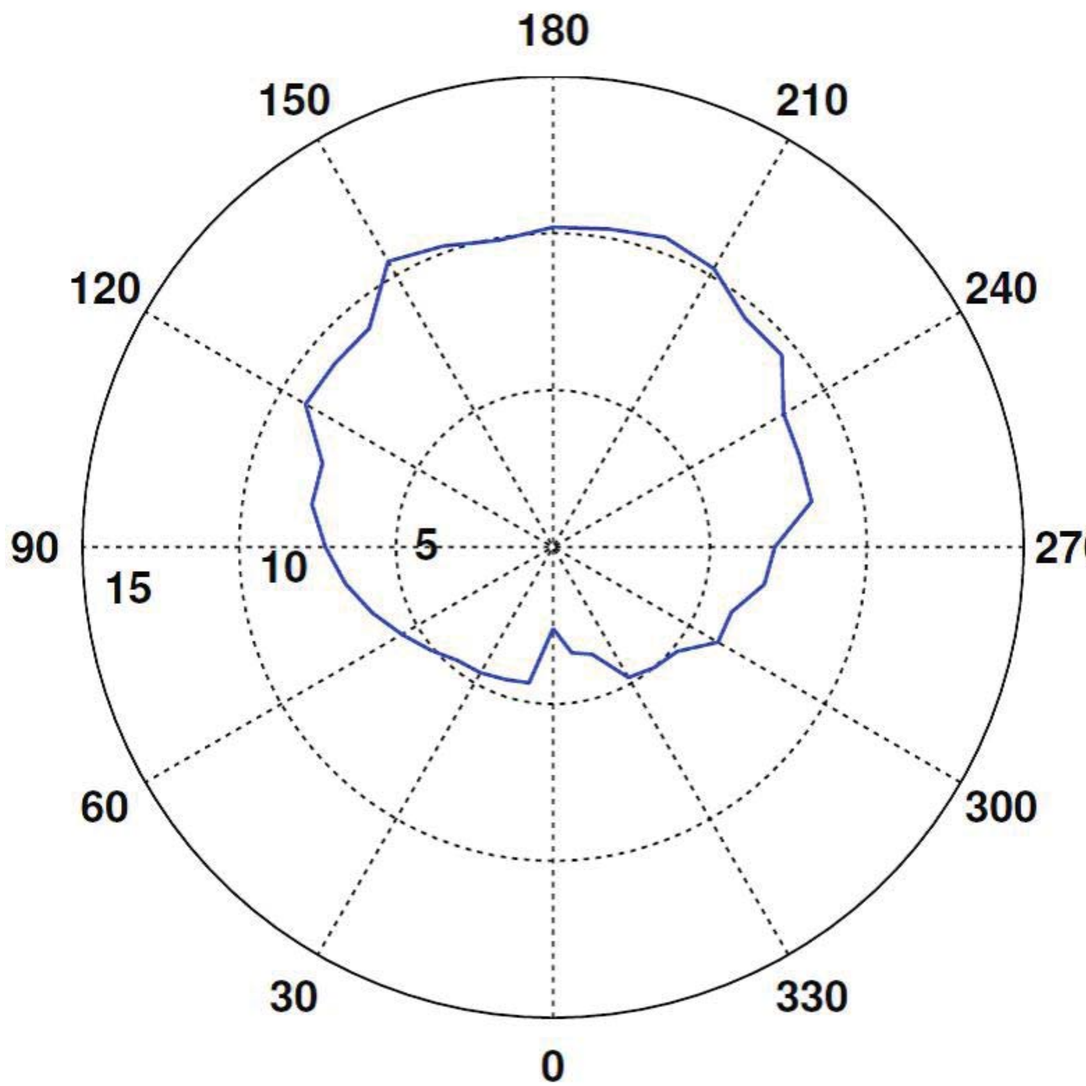


Figure A-7 **NASA ACES Relative Heading Data**

[28] Johnson, M., Mueller, E., Santiago, C. "Investigating the Impacts of a Separation Standard for UAS Operations in En Route and Transition Airspace." AIAA. http://techport.nasa.gov:80/file/6579

[29] Park, C., Lee, S.M., and Mueller, E. "Investigating Detect-and-Avoid Surveillance Performance for Unmanned Aircraft Systems." 14th AIAA Aviation Technology, Integration, and Operations Conference. Atlanta, GA. 16-20-June 2014. http://techport.nasa.gov:80/file/6575

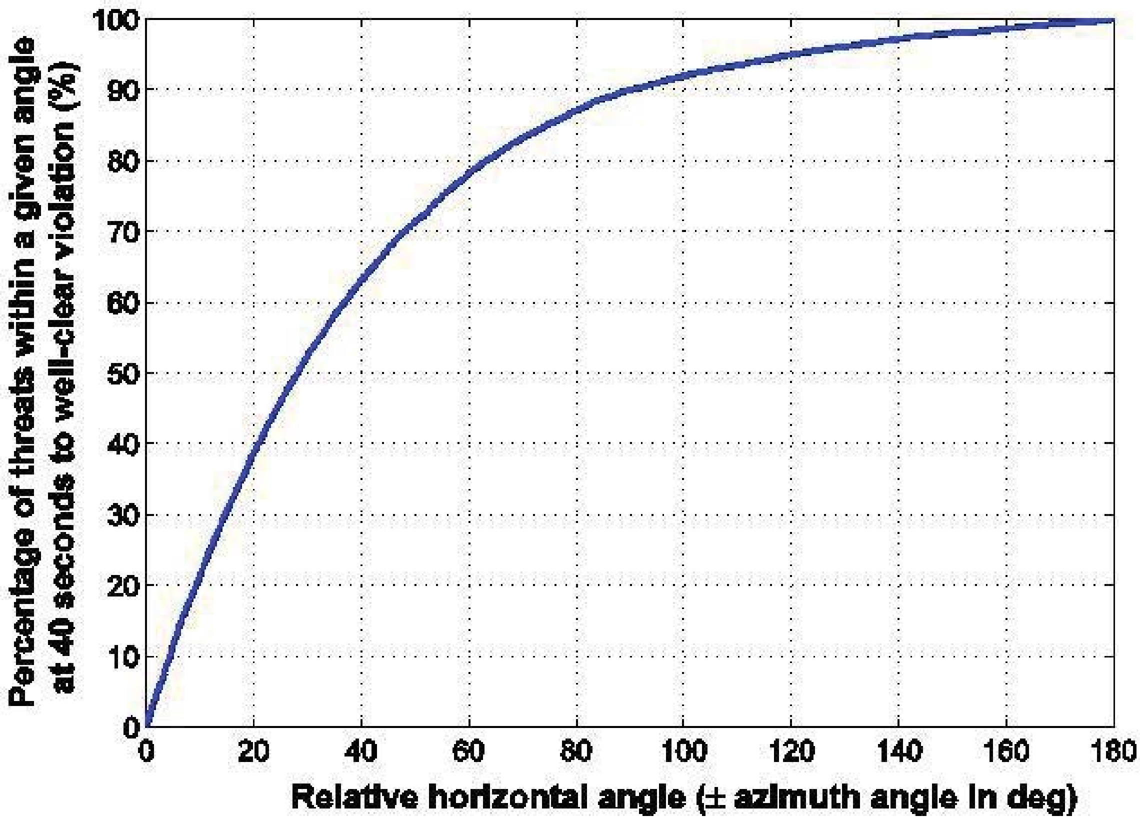


Figure A-8 **NASA ACES Horizontal Angle of Threats**

Encounters can also occur with all vertical geometries. The ownship UA may be climbing or descending at any rate up to its maximum rate within its operating envelope or may be level. Likewise intruders may be climbing, descending, or level.

One other special encounter geometry to consider is the slow closure rate. If the ownship UA and the intruder are operating at similar speeds with nearly identical ground tracks, the closure rate may be very small. This could provide a technical challenge both in the detection of such intruders by sensors and to alerting algorithms.

A.2.6 Meteorological, Topographical, and Environmental Conditions

The DAA system will perform its intended function in Visual Meteorological Conditions (VMC) and Instrument Meteorological Conditions (IMC). DAA equipment is not expected to provide a means of detecting meteorological conditions, remaining in VMC, maintaining VFR visibility minimums, or maintaining cloud separation minimums. DAA-equipped UAS will operate in clouds and the DAA system will continue to operate.

When conditions are above the minimum VFR visibility and outside of clouds, the DAA UA could encounter both VFR and IFR traffic that is cooperative or non-cooperative. However, inside of clouds or when visibility is below VFR minimum (due to meteorological conditions such as heavy rain), the DAA UA is unlikely to encounter intruders. In such conditions it would be illegal for a non-IFR aircraft to be flying. DAA system performance may be reduced in low visibility conditions where non-cooperative VFR traffic won't be operating.

The DAA system will perform its intended function during day and night operations under all atmospheric conditions in which the UA is certified to fly. For example, if the UA is certified for flight into known icing, then the DAA system must be capable of operating in known icing conditions as well. However, since icing conditions only occur when visible moisture is present or when there is high relative humidity, weather may be below VFR visibility minimums and the DAA UA is unlikely to encounter non-cooperative VFR intruders that are not being separated by ATC using IFR separation. Therefore the performance demands on the DAA non-cooperative surveillance subsystem may be less in icing conditions.

The DAA system will function over all terrain and ground geographies that could be overflown in the NAS. This includes populated areas, unpopulated areas, desert, forests, bodies of water, mountainous terrain, snow-covered areas, etc.

Likewise, the DAA system will function over other man-made topographical features such as wind farms that may interfere with certain DAA systems. However, if DAA equipment is incapable of flying over certain topographical features, operational limitations will be placed on the use of the DAA equipment. The UAS PIC must have the information to remain within any imposed operational limitations (see OR.1).

Finally, the DAA system will function in the presence of birds, wildlife, and other natural environment features. For example, birds may interfere with certain DAA Systems. For certain operations, encounters with birds that could be detected by an airborne radar may be just as common as encounters with other aircraft. Estimated bird encounter rates are dynamic and depend on location, altitude, season, and time of day. In general terms, bird encounters may occur on the rough order of magnitude of once per hour or more. In general, avoiding collision with birds should be considered appropriate use of DAA technology, even though bird avoidance is not considered a minimum requirement.

A.2.7 Equipment Environment

A.2.7.1 Airborne Equipment Environment

DAA equipment onboard the UA will be qualified for the aircraft environment in which it is certified to operate, just as avionics are environmentally qualified for use on manned aircraft. The airborne DAA equipment does not need to operate before takeoff or after landing since those phases of flight are being handled by other separation means.

A.2.7.2 Control Station (CS) Environment

DAA equipment in the UAS CS may exist in a number of environmental conditions.

If the UAS CS is onboard another aircraft, then the DAA CS equipment is expected to be environmentally qualified just as other airborne avionics.

The DAA equipment may also be located in weather protected and non-weather protected stationary, ground vehicle, or maritime environments. DAA equipment may even be part of a portable UAS CS.

DAA equipment for the CS will be qualified for the appropriate environment in which it is expected to operate.

A.3 DAA System Description

The DAA system consists of the DAA equipment, the UAS PIC,[30] and other UAS articles necessary to maneuver for traffic intruders. All equipment will be approved in accordance with applicable rules and regulations (see OR.4).

ASSUMP-OSED.10 The DAA system will have appropriate airworthiness and operational approval.

The DAA equipment provides surveillance of the airspace surrounding the UA and provides the UAS PIC a means of compliance with 14 CFR Part 91, §91.111(a), §91.113, and §91.181, once these regulations are updated with provisions for UAS applications. The DAA surveillance equipment, including antennas, provides a means for the UAS PIC to electronically detect and track both cooperative and non-cooperative aircraft.[31] Traffic and other DAA system information will be sent to the CS for display to UAS PICs in a manner that enables them to perform their responsibilities. Additionally, future UAS PIC/operator training will include unique UAS and DAA characteristics (e.g., latency, maneuverability) so that the UAS PIC can select appropriate maneuvers as required to comply with right-of-way rules under 14 CFR §91.113, to maintain DWC under 14 CFR §91.181, and operate not so close as to create a collision hazard under 14 CFR §91.111.

OR.5 The UAS PIC shall use the UAS DAA equipment to properly maneuver the UA in accordance with ATC clearances and instructions, as well as Right-of-Way (ROW) rules under §91.113, to remain well clear of and avoid creating a collision hazard with other aircraft under 14 CFR §91.111.

DAA equipment is not being designed to allow the PIC of the DAA-equipped UA to accept visual separation, delegated separation, visual approach, or contact approach responsibilities, although such capabilities may be enabled in the future.

OR.6 The UAS PIC shall refuse visual separation, delegated separation, visual approach, and contact approach responsibilities if the DAA equipment is not certified to support the operation.

The DAA system provides a display of traffic which is useful when communicating with ATC.

- The DAA display provides traffic information which aids the pilot in identifying aircraft traffic called out by the controller.
- The DAA display provides a suggestive guidance which aids the pilot in identifying aircraft traffic which poses a risk of loss of DAA Well Clear (DWC).

[30] This hosed does not attempt to allocate responsibility for specific DAA functionality to individual members of the flight crew; instead, the hosed assumes a single UAS pilot, similar to manned aircraft under 14 CFR §91.3. Pilot and crew training for a specific DAA system may allocate responsibilities differently.

[31] In this document, cooperative aircraft are those with a Mode A, C, or S transponder and/or ADS-B Out and non-cooperative aircraft are those without a transponder or ADS-B Out.

- The DAA display provides a suggestive display to indicate maneuvers which are predicted to enter the DAA Hazard Zone (caution alerts and remain well clear guidance); the pilot uses the display to select a course of action and request an amended clearance from ATC
- The DAA display provides a suggestive display to indicate maneuvers which are predicted to enter the DAA Hazard Zone in the immediate future (warning alerts and remain well clear guidance) or a limited directive display to assist the pilot in leaving the Hazard Zone safely (regain well clear guidance); immediate pilot action is require to prevent a loss of DWC or regain DWC.

Two types of maneuvers can be performed using the DAA equipment:

1. DAA Well Clear (DWC) Maneuvers – Maneuvers performed within a timeframe nominally sufficient to coordinate with ATC to maintain DAA Well Clear or regain DAA Well Clear safely, and
2. Resolution Advisory (RA) Maneuvers – (only when equipped with the Class 2 DAA system) Maneuvers performed to prevent an intruder from penetrating the collision volume,[32] which require immediate execution followed by ATC notification.

DWC maneuvers may be performed in the vertical and/or horizontal dimensions. TCAS II RA maneuvers will be performed in the vertical dimension (climbs and descents). TCAS II RA maneuvers are expected to be initiated as a last resort before the Closest Point of Approach (CPA). TCAS II is intended to engage when all other modes of separation fail. DAA Class 2 equipage, and associated RA maneuvers, are described as optional in this OSED; however, this function may be required if the DWC function alone cannot meet the appropriate safety level.

DWC maneuvers to maintain DWC will occur against both VFR and IFR intruders, but only after ATC coordination is attempted.

The DAA equipment provides a graphical display of traffic, including all necessary traffic information, decision aids,[33] and appropriate visual and aural alert(s) to allow the UAS PIC to effectively maneuver the UA in accordance with ATC clearances and instructions, the right-of-way rules under §91.113, to maintain DWC of traffic, and to avoid other aircraft.

The DAA equipment includes:

1. Sensor(s) onboard the unmanned aircraft to detect and track surrounding cooperative (i.e., transponder-equipped) and non-cooperative aircraft within the surveillance volume

[32] The collision volume is the same as the Near Mid-Air Collision (NMAC) boundary, 500’ horizontally and ±100’ vertically.
[33] Decision aids could include threat bubbles on the traffic display, threat bands on the navigation display, etc.

Note:

1. *Those onboard sensors may include ADS-B and ADS-R receivers, which use ground infrastructure.*
2. *The surveillance volume is the volume of space where the onboard sensors can detect and track intruders. The surveillance volume size may be different for each sensor.*

ASSUMP-OSED.11 DAA sensors for detecting intruders will be onboard the UA in Phase 1.

2. Airborne and Control Station (CS)-based processing of the onboard DAA sensor data
3. A DAA traffic display in the CS for the UAS PIC, that includes ownship position information, maintain DWC alert information, and other decision aids34
4. DWC alerts to the UAS PIC of intruder traffic projected to come close to the DWC boundary
5. DWC decision aids (maneuver guidance) to assist the UAS PIC in determining an appropriate action to maintain or regain DWC

Each intruder may have one of the three alert statuses:

1. DWC Preventive Alert – A caution-level alert intended to draw the PIC's attention to traffic that would trigger a corrective alert if either the ownship or intruder maneuvers in the vertical (or possibly horizontal) direction. It is expected that the PIC, upon receiving a preventive alert, will refrain from a change in altitude (or possibly heading) unless necessary, and will monitor the intruder aircraft for a change in altitude (or horizontal direction). If an ownship maneuver is required, the PIC will take into account the position and path of the intruder beforehand.
2. DWC Corrective Alert – A caution-level alert intended to get the attention of the PIC, get the PIC to determine a needed maneuver and start coordination with ATC. This is the initiating point in which maneuvering will likely be started based on PIC judgment. The corrective alert necessitates immediate awareness of the PIC and subsequent PIC response.
3. DWC Warning Alert – A warning-level alert intended to inform the PIC that immediate action is required to maintain DWC. The warning alert necessitates immediate awareness of the PIC and a prompt ownship maneuver.

For Class 2 equipage, the UA may be equipped with a TCAS II capable of providing RAs. TCAS II RA[35] information is presented to the UAS PIC when an intruder is a collision threat under 14 CFR §91.123 (warning level, since it requires an immediate pilot action). The RA may either be manually executed by the UAS PIC if the CNPC link latency is low, or automatically executed onboard the UA, with UAS PIC override capability, depending on the implementation. The UAS PIC override capability is intended to address the possible situation where the TCAS II may not be tracking a

[34] The DAA traffic display will be similar to the ADS-B CDTI defined in DO-317, but will include additional information or guidance necessary for DAA systems.
[35] TCAS II may be required if the DAA system alone cannot meet the appropriate safety level.

second intruder that is being tracked by the DAA non-cooperative sensor. DAA and TCAS II equipment will be appropriately integrated to prevent conflicting guidance from being presented to the PIC. Other equipment and functions, such as the CNPC data link and ownship state sensors, as defined at the beginning of this subsection, are necessary for and enable DAA, but are not considered part of the DAA equipment,. The needed CNPC data link performance, including acceptable availability, latency, and integrity, is covered in the DAA system requirements.

The UAS PIC will have the ability to control the flight path of the UA under all operating conditions in which the CNPC data link is available. Acceptable interruption/availability of the CNPC data link in the context of DAA is defined in Appendix K. An interruption of the CNPC data link in excess of the DAA-specific value is not considered to be a normal operating condition.

> **ASSUMP-OSED.12** The UAS PIC will have the ability to control the flight path of the UA to execute any DWC maneuvers for all operating conditions in which the CNPC data link is available and related systems are operating properly.

Appropriate procedures will be in place to ensure new pilots are appropriately briefed on the traffic situation prior to UAS control handoff, if control of the UAS is handed off from one pilot to another (whether in the same CS or a different CS).

> **OR.7** UAS operations involving the transfer of UA PIC responsibilities from one pilot to another (whether in the same CS or a different CS) shall ensure the availability of DAA traffic information to the next PIC to provide continuity in UA flight control and command authority over the UAS and the DAA system.

Class 1 DAA equipment, during Phase 1, only provides a traffic display with decision aids for maintaining DWC; the UAS PIC will determine the appropriate maneuver and command the UA to perform that maneuver via the CNPC data link. The Class 2 DAA equipment may optionally involve automatic execution of RA maneuvers that will not be dependent on the CNPC data link. The CNPC data link will facilitate UAS PIC override of TCAS II maneuvers.

> **OR.8** Threshold values for CNPC data link performance (e.g., availability, continuity, integrity) shall define the nominal operating conditions of the DAA equipment.

A.3.1 Top-level Architecture

Figure A-9 depicts the top level DAA architecture as it relates to external systems, both on the UA, other aircraft, and in the CS. Optional items are shown surrounded by dashed lines. This diagram is meant to give the reader of this OSED an understanding of how the various articles relate, but should not be interpreted as representing the final requirements, allocations, or physical boxes of the DAA system.

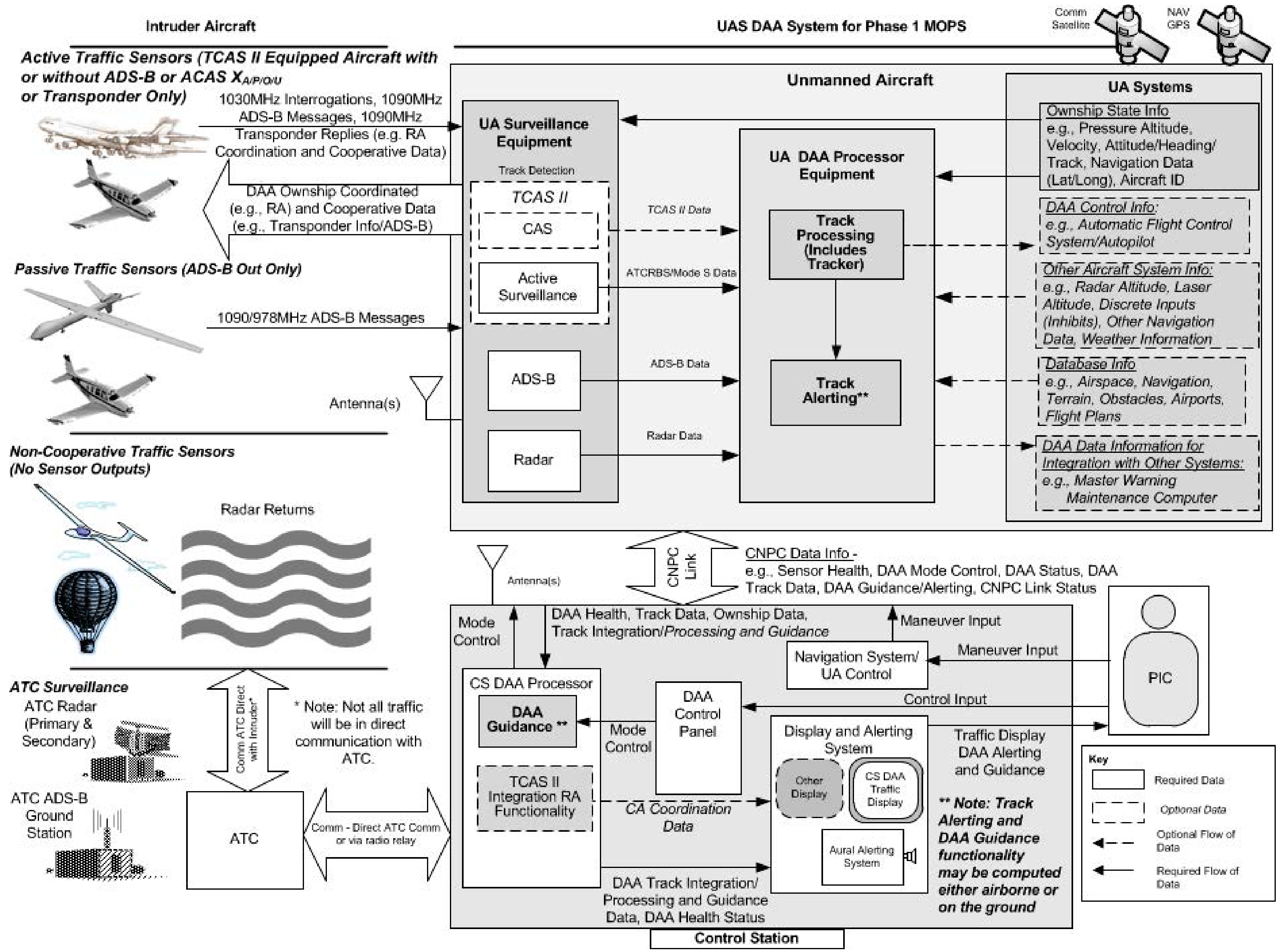


Figure A-9 Notional DAA System Diagram

The functional block for the DAA receiver and transmitter system and transponder consists of an ADS-B receiver, an active 1030 MHz transponder interrogator, and a 1090 MHz transponder receiver. The transponder also supports Mode S messages to enable coordination with TCAS-equipped intruders. The DAA radar provides information about cooperative and non-cooperative intruders to the UA DAA equipment functional block.

The data from the sensors is combined and processed within the UA DAA equipment, and intruder tracks are created. These tracks are used by onboard DWC and TCAS II, when equipped as a Class 2 system. The DAA UA processor and TCAS II may share the same physical processor and common functions. Other onboard information, such as position and altitude, is provided to the UA DAA equipment to enable the DWC and CA functions.

The Class 2 system may optionally send commands to the onboard automatic Flight Control System (FCS) or autopilot for automatic execution of RAs as well as to the PIC to facilitate an override capability.

Data from the UA DAA equipment is sent via the CNPC data link to the CS. Further processing of the data is done by the CS DAA processor before it is sent to the DAA traffic display. Visual and aural alerts are provided to the UAS PIC. UAS PIC-initiated DWC maneuvers are sent back to the UA through the CNPC data link and executed through the existing FCS.

The UAS PIC maintains two-way communications with ATC via direct Very-High/Ultra-High Frequency (VHF/UHF) communications, via a radio relay in the UA, and possibly via direct ground link in the future. ATC also communicates with some intruders via radio. ATC tracks intruders and UA via existing surveillance systems.

A.3.1.1 CNPC Data Link

The top-level DAA architecture contains a CNPC data link so that the UAS PIC at the CS can receive DAA data about intruders and command DWC maneuvers and perform other functions. However, the CNPC data link is not considered DAA equipment.

A.3.1.2 DAA Lost Link

A DAA lost link occurs whenever the specified DAA Transaction Expiration Time (TET) is exceeded due to a degradation or unavailability of the CNPC system, including equipment failures. TET is defined as the maximum time for completion of a transaction, after which peer parties (the UAS PIC and ATC) should revert to an alternate procedure. See Appendix K for more information on TET.

The alternate procedures will involve:

- An indication or alert to the UAS PIC of the DAA lost link condition
- The UAS PIC informing ATC of the loss of DAA

If there is a lost CNPC link (can’t command the aircraft), then there is a DAA lost link after the DAA TET. However, if the CNPC link is just degraded, the UAS may or may not be DAA lost link depending on whether the TET is exceeded or not.

Controllers will need to know about DAA failures, including those due to a degradation in the CNPC system, in addition to UAS lost CNPC link situations when UAS PIC can't control the UA (see OR.12).

Once notified of the loss of DAA functionality, ATC will prioritize instructions to intruders over instructions to the UAS PIC. The declaration of an emergency will be left to operational specifications, PIC judgment, and ATC judgment. During DAA lost link, the PIC will likely not have the ability to control the UA, or commands to the UA may be significantly delayed.

If there is a total failure of the CNPC system, appropriate lost-link flight paths and maneuvers will be executed, but those procedures are outside the scope of this OSED. Lost-link procedures may need to take into account recent maneuvers made by the PIC in response to DAA alerts to prevent aircraft turning back towards an intruder.

> **OR.9** The UA shall perform approved, preplanned, and predictable lost CNPC data link maneuvers in the event of an operational failure of the CNPC data link.

Automatic execution of DWC maneuvers during DAA lost link is not in the Phase 1 DAA MOPS scope.

If the UA is equipped with a Class 2 DAA system with automatic maneuver execution, automatic response to RAs will continue during DAA lost link. Therefore, the UAS with Class 2 DAA may respond automatically to RAs during DAA lost link, without PIC input. The safety of Automatic Execution or the RA during a lost-link event will need to be evaluated for systems which implement the optional function. In general it should always be "safe" to execute an RA, even if it is unnecessary. A safety study would need to show that the risk of "auto-execution induced collision" during a lost CNPC link event is less than the risk of "do-nothing collision." The impact on ATC workload and NAS efficiency of automatic execution of RAs during lost CNPC events should be a small fraction compared to the impact of UAS RAs in general.

Air traffic control will know whether the UA has an automatic TCAS II system onboard based on IFR flight plan information. In current operations, controllers usually know if an aircraft in a lost communications event has an operational TCAS onboard if the aircraft has filed an IFR flight plan.

A.3.1.3 Loss of DAA System

A DAA system failure occurs whenever a required DAA subsystem reports failed status. The UAS PIC needs to be aware of the current status of the DAA system. For a Class 1 DAA system, the PIC needs to know the status of DAA sensors, DAA link and CNPC link; failure of any of these components constitutes the loss of DAA functionality. For Class 2 systems which implement automatic RA execution onboard the UA, loss of DAA link may represent a degraded DAA functionality while maintaining a partial collision avoidance function against most transponder equipped aircraft.

> **OR.10** The UAS PIC controlling the UA during its flight operation shall explicitly acknowledge any DAA failures or contingency modes in a manner consistent with the DAA system's certification basis.

Controllers will need to know about DAA failures and degraded modes of operation. Once notified of the loss of DAA, ATC will prioritize instructions to intruders over instructions to the UAS PIC. The declaration of an emergency will be left to operational specifications, PIC judgment, and ATC judgment.

A.4 DAA Activities

This subsection describes the DAA-related activities and the actors that perform the activities.

A.4.1 Actors

A.4.1.1 DAA Equipment

DAA equipment onboard the UA surveils the surrounding airspace and provides DAA traffic information and alerts to the UAS PIC using DAA equipment at the CS.

A.4.1.2 UAS Pilot-in-Command (PIC)

The UAS PIC is the human controlling the UAS who acts on information provided by ATC, UA control equipment, and the DAA equipment. The UAS PIC is sometimes referred to just as "pilot" in this document. When referencing the UAS PIC's regulatory responsibilities, Pilot-in-Command (PIC) is used. This OSED does not attempt to allocate responsibility for specific DWC functionality to individual members of the flight crew; instead, the OSED assumes a single UAS PIC, similar to manned aircraft under 14 CFR §91.3. Pilot and crew training for a specific DAA system may allocate responsibilities differently.

A.4.1.3 Air Traffic Control (ATC)

Air Traffic Control (ATC) refers to the facility and associated controller(s) responsible for the airspace in which the UAS is currently operating.

A.4.1.4 ATC Automation Systems

ATC automation systems include surveillance systems, processing, alerting, and traffic displays used by the Air Traffic Controller.

A.4.1.5 Intruder

An intruder is another manned or unmanned aircraft projected to cross the UA's well-clear boundary.

A.4.2 Activity Diagram

See the following DAA and TCAS II activity diagrams, which depict the notional way that activities unfold during an encounter. There are no times associated with each functional block. Additionally, multiple paths through the diagrams may be occurring simultaneously. For example, ATC could be issuing an instruction while the DAA system declares an intruder a threat. The activities in the diagrams could also be occurring in parallel for multiple intruders.

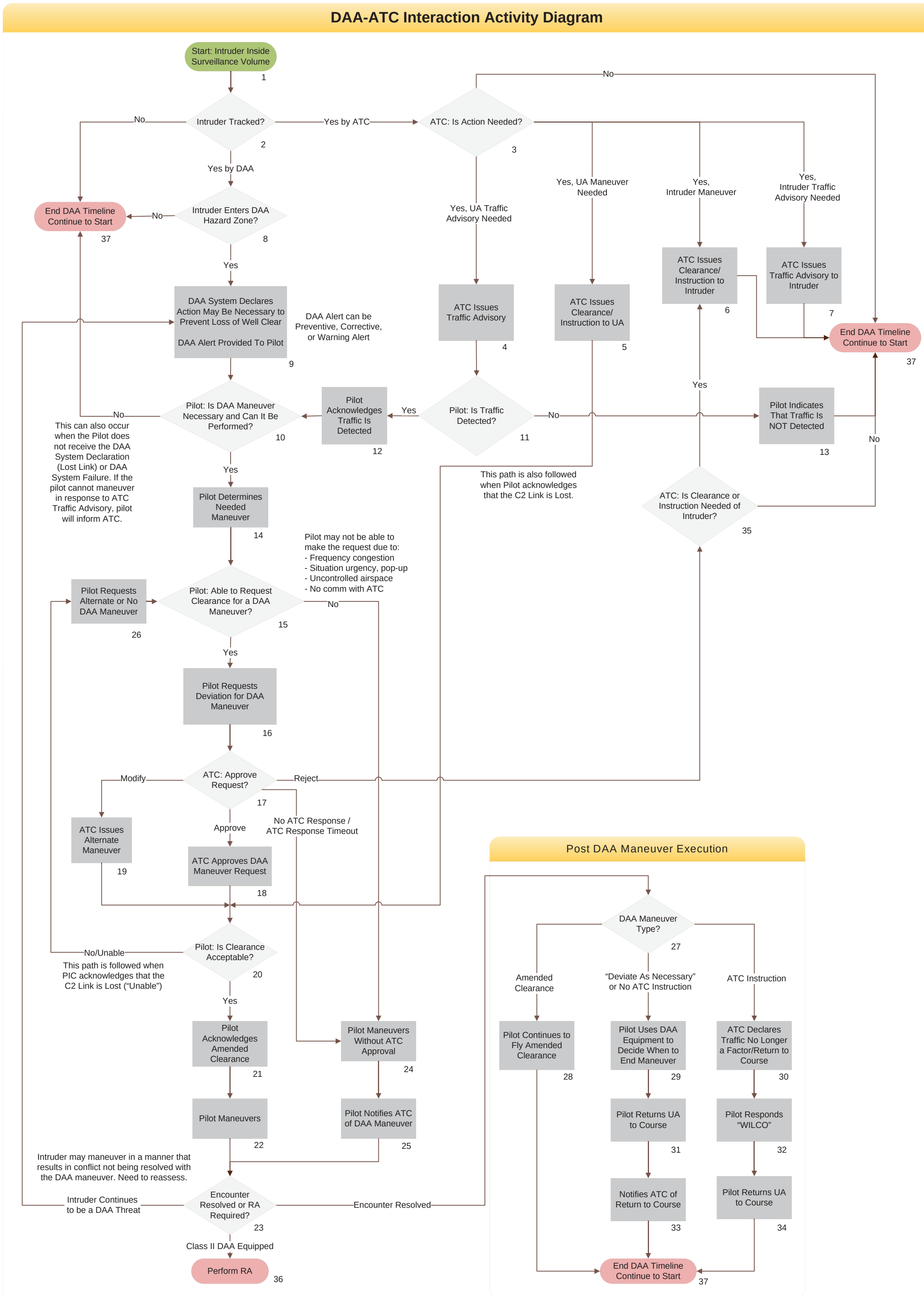


Figure A-10 DAA – ATC Interaction Activity Diagram

A.4.3 DAA Activity Descriptions

Table A-3 Descriptions of Activities Outlined in Figure A-10

#	Activity	Performer(s)	Information Input	Information Output	Activity Description
1	Start: Intruder Inside Surveillance Volume	-	-	-	The activity diagram starts or continues here during the period in which an intruder is inside the surveillance volume of either the DAA system or the ATC surveillance system.
2	Intruder Tracked by DAA System	DAA Equipment	Sensory Data	Intruder Tracks	Decision Are intruder tracks produced as a result of scanning the surveillance volume? This may be sensor performance dependent.
2	Intruder Tracked by ATC Radar	ATC Automation Systems	Sensory Data	Intruder Tracks	Decision Are intruder tracks produced as a result of scanning the surveillance volume?
8	Intruder Predicted to Enter DAA Hazard Zone?	DAA Equipment	Intruder Tracks, Ownship State Data, Ownship Performance Data, DAA Hazard Zone Thresholds	Alert Threshold Crossing Flag	Decision Determines if track is predicted to cross one of the DAA Hazard Zone thresholds. If it has, it is declared a threat. If it hasn't, continue surveillance.
9	DAA System Declares Action May Be Necessary to Prevent a LoWC DAA Alert Provided to Pilot	DAA Equipment	Alert Threshold Crossing Flag	DWC Alert	Activity Provide the PIC with a DWC preventive, corrective, or warning alert. The alert level may change on subsequent passes.

#	Activity	Performer(s)	Information Input	Information Output	Activity Description
10	Pilot: Is DWC Maneuver Necessary and Can It Be Performed?	Pilot	Air Traffic Picture (Traffic Display), Alert Threshold Crossing Flag, Knowledge of Intruder Intent (from ATC Communications (Comms) when Available), Traffic Advisory(s), Ownship State Data	Decision that Maneuver is Necessary (Y/N)	Decision Pilot uses training, judgment, and display of traffic to assess the threat and the need to maneuver. If the PIC can't maneuver in response to ATC Traffic Advisory, the PIC will inform ATC.
14	Pilot Determines Needed Maneuver	Pilot	Information from #10, Ownship Performance Data, Current Clearance and ATC Instructions	Pilot Preferred maneuver for Deviation or Amended Clearance Alternatively, Need for ATC Instructions or Vector	Activity Pilot uses training and judgment to determine the best maneuver to resolve the threat and maintain DWC in accordance with ROW rules.
15	Pilot: Able to Request Clearance for a DWC Maneuver?	Pilot	Knowledge of Current ATC Comms Congestion, Estimated Time to LoWC, Knowledge of Current Class of Airspace (e.g., Class G)	Pilot Assessment of Criticality, and Urgency of Making a Request to ATC	Decision Pilot uses estimated time remaining to LoWC to assess the need to contact ATC prior to executing a maneuver.
16	Pilot Requests Deviation for a DWC Maneuver	Pilot, ATC	Selected Maneuver from #14	Convey maneuver Need to ATC, Waiting for ATC Response	Activity Pilot conveys to ATC the need to maneuver or request for amended clearance or vector.

#	Activity	Performer(s)	Information Input	Information Output	Activity Description
17	ATC: Approve Request?	ATC	ATC Automation and Surveillance, Pilot Maneuver Request from #16	ATC Instructions (Approve, Reject, New Instructions)	Decision ATC uses training operating procedures to approve, modify or reject the requested maneuver. Response times out if controller workload doesn't permit or communications problems or when the UA is predicted to enter the Warning Hazard Zone and the DAA Warning Alert occurs.
18	ATC Approves DWC Maneuver Request	ATC, Pilot	ATC Instructions to Approve	Convey Approval of Maneuver as Requested	Activity ATC conveys approval of requested maneuver to Pilot.
20	Pilot: Is Clearance Acceptable?	Pilot	ATC Instructions, Current Air Traffic Picture	Acceptability of Instructions	Decision Pilot uses the current air traffic picture to assess the acceptability of the ATC instructions.
21	Pilot Acknowledges Amended Clearance	Pilot, ATC	Acceptability of Instructions, Established ATC Comms	Convey Pilot Understanding and Intent to Comply	Activity Pilot reads back clearance and conveys to ATC intent to comply with the ATC instructions.
22	Pilot Maneuvers	Pilot	ATC Instructions, UA Performance Limitations	Change in UA Trajectory	Activity Pilot commands and the UA executes the instructed maneuver.
23	Encounter Resolved or RA Required?	DAA Equipment	Change in UA Trajectory, Changes to Air Traffic Picture, RA Logic for Class 2 DAA System, DAA Conflict Resolved		Decision Pilot monitors air traffic picture to determine if additional DWC maneuvering is required, RA is triggered, or passing clear of conflict.

#	Activity	Performer(s)	Information Input	Information Output	Activity Description
24	Pilot Maneuvers Without ATC Approval	Pilot	DAA Traffic Display, Selected Maneuver from #14	Change in UA Trajectory	Activity Pilot commands and the UA executes the instructed maneuver.
25	Pilot Notifies ATC of DWC Maneuver	Pilot	Two-way Comms with ATC, Maneuver from #24	Convey Pilot Initiation of Maneuver for Traffic	Activity Pilot notifies ATC that an immediate maneuver was required and has been initiated.
27	DWC Maneuver Type?	Pilot			Decision Depending on ATC instruction, Clearance, or non-instruction, the Pilot determines the method for returning to course.
28	Pilot Continues to Fly Amended Clearance	Pilot	ATC Amended Clearance		Activity Pilot follow amended clearance which ends the encounter.
29	Pilot Uses DAA Equipment to Decide When to End Maneuver	DAA Equipment	Intruder Tracks, Ownship State Data, Ownship Performance Data, DWC Definition		Activity The PIC will evaluate aircraft trajectories for determining that the encounter has been resolved and the maneuver can be completed.
31	Pilot Returns UA to Course 1	Pilot	DAA Air Traffic Display, Ownship State Data, Original Course	Change in UA Path to Return to Course	Activity Pilot uses training, experience, and judgment to determine course changes and returns to original course (could be a continuous evolution to enable the DWC and CA functions).
33	Notifies ATC of Return to Course	Pilot, ATC	Two-way Comms, Info from #31	Conveys to ATC that UA is Back on Course	Activity Pilot notifies ATC when back on course. Ends encounter.

#	Activity	Performer(s)	Information Input	Information Output	Activity Description
30	ATC Declares Traffic No Longer a Factor/Return to Course	ATC	ATC Automation, Previously Issued ATC Instructions	ATC Instruction	Activity ATC uses standard procedures, training and experience to determine that UA has cleared the conflicting traffic and provides instructions to return to course or for the UA to resume own navigation.
32	Pilot Responds to Clearance, "WILCO"	Pilot, ATC	Acceptability of Instructions, Established ATC Comms	Convey Pilot Understanding and Intent to Comply	Activity Pilot reads back clearance and conveys to ATC intention to comply with the ATC instructions.
34	Pilot Returns UA to Course 2	Pilot	ATC Instructions, DAA Air Traffic Display, Ownship State Data, Original Course	Change in UA Path to Return to Course	Activity Pilot uses training, experience, and judgment to comply with ATC instructions.
37	End DAA Timeline Continue to Start	-	-	-	Continue back to #1. Activity diagram is a continuous loop.
26	Pilot Requests Alternate or No DWC Maneuver	Pilot, ATC	Information from #20, Alternate Maneuver, Link Status (when DAA Lost Link)	Convey Alternate Maneuver (or No Maneuver) Need to ATC Waiting for ATC Response	Activity Pilot conveys to ATC the need to make an alternate maneuver or the inability to control the UA (lost CNPC link) or request for amended clearance or vector.
19	ATC Issues Alternate Maneuver	ATC	Information from #17, Two-way Comms with UAS PIC	ATC Clearance or Instruction	Activity ATC uses standard procedures, experience and ATC automation tools to separate UA from intruder aircraft.

#	Activity	Performer(s)	Information Input	Information Output	Activity Description
3	ATC: Is Action Needed?	ATC	ATC Surveillance of Air Traffic Picture, Current and Planned Intruder and UA Clearances and Instructions	Air Traffic Advisories ATC Instructions ATC Clearances No Action	Decision ATC uses standard procedures, experience and ATC automation tools to identify traffic conflicts.
4	ATC Issues Traffic Advisory	ATC	Information from #3, Two-way Comms with UAS PIC	Air Traffic Advisory	Activity ATC issues a traffic advisory to UAS PIC, workload permitting.
5	ATC Issues Clearance/Instructions to UA	ATC	Information from #3, Two-way Comms with UAS PIC	ATC Clearance or Instruction	Activity ATC uses standard procedures, experience and ATC automation tools to separate UAs from intruder aircraft.
6	ATC Issues Clearance/Instructions to Intruder	ATC	Information from #3, Two-way Comms with Intruder Aircraft	ATC Clearance or Instruction	Activity ATC uses standard procedures, experience and ATC automation tools to separate intruder aircraft from UAs.
7	ATC Issues Traffic Advisory to Intruder	ATC	Information from #3, Two-way Comms with Intruder Aircraft	Air Traffic Advisory	Activity ATC issues a traffic advisory to intruder aircraft (receiving IFR services or flight following service), workload permitting.
11	Pilot: Is Traffic Detected?	Pilot, DAA Equipment	Air Traffic Advisory, DAA Air Traffic Picture, Ownship State Data	Traffic Detected Traffic Not Detected	Decision Pilot attempts to identify the traffic called out by ATC.

#	Activity	Performer(s)	Information Input	Information Output	Activity Description
12	Pilot Acknowledges Traffic is Detected	Pilot	Information from #11, Two-way Comms	Acknowledges Traffic Detected	Activity Pilot associates traffic calls from ATC with DAA traffic display; acknowledges that traffic is detected. (this could occur during the same activity as Pilot requests deviation for DWC maneuver, starting at #16).
13	Pilot Informs ATC that Traffic is Not Detected	Pilot	Information from #11, Two-way Comms	Acknowledges Traffic Not Detected	Activity Pilot cannot associate traffic by ATC with any traffic on DAA traffic display; informs ATC that traffic is not detected.
35	Is ATC Clearance or Instruction Needed for Intruder?	ATC	ATC Surveillance of Air Traffic Picture, Current and Planned Intruder and UA Clearances and Instructions	ATC Instructions ATC Clearances No Action	Decision ATC uses standard procedures, experience and ATC automation tools to identify traffic conflicts identifying needed intruder maneuver. Ends encounter.
36	Perform RA	-	-	-	Continue to TCAS II activity diagram.

A.4.4 DAA Class 2 Activity Diagram

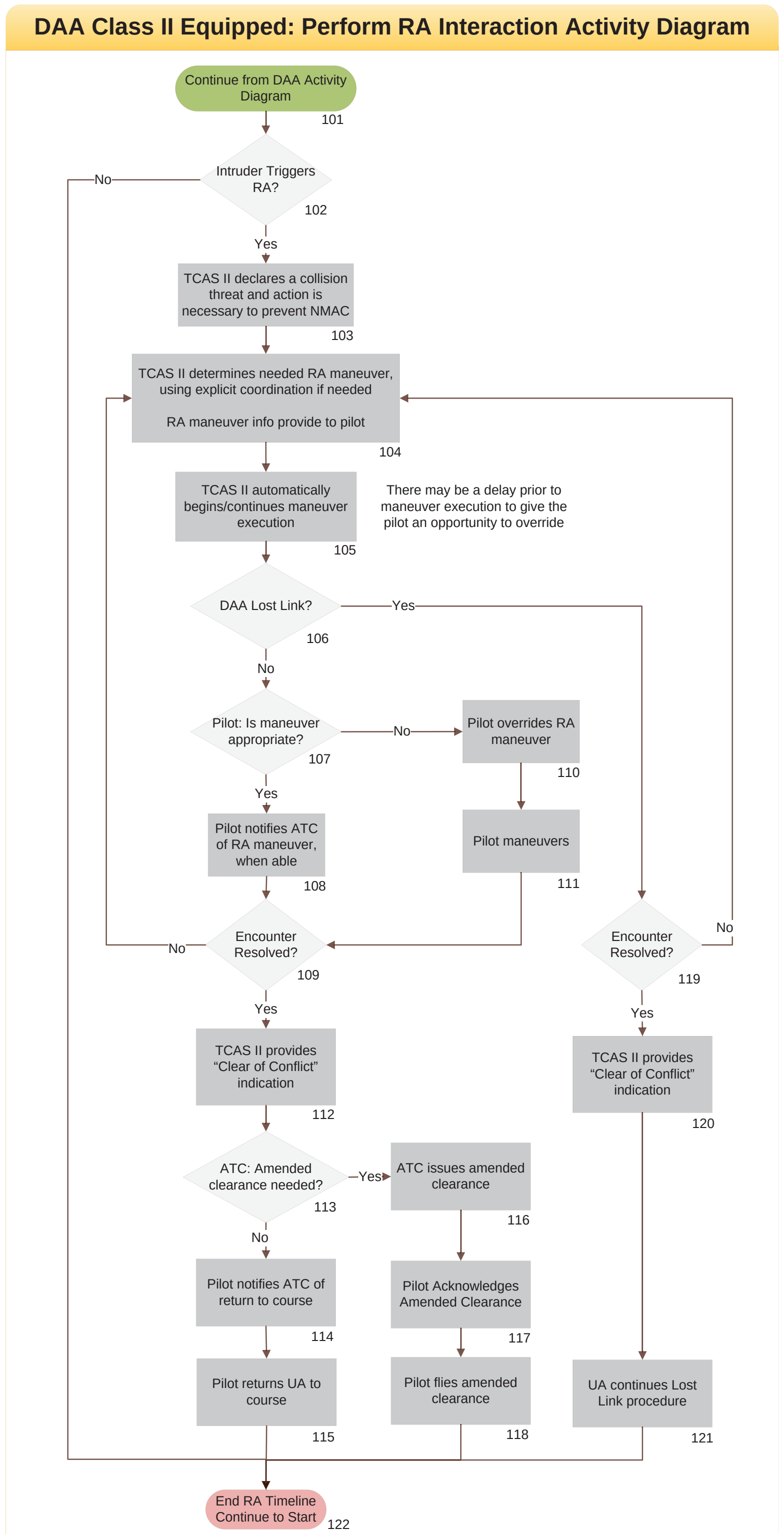


Figure A-11 Class 2 DAA – Automatic TCAS II Interaction Activity Diagram

Table A-4 Descriptions of Activities Outlined in Figure A-11

#	Activity	Performer(s)	Information Input	Information Output	Activity Description
101	Continue from DAA Activity Diagram	-	-	-	Continue from the DAA activity diagram.
102	Intruder Triggers RA?	TCAS II	Intruder Tracks, Ownship State Data, Ownship Performance Data, TCAS II Logic	RA Flag	Decision Determines if track triggers RA. If it has, it is declared a conflict. If it hasn't, continue surveillance.
103	TCAS II declares a collision threat and action is necessary to prevent a Near Mid-Air Collision (NMAC)	TCAS II	RA Flag		Activity Begin TCAS II Guidance.
104	TCAS II determines needed RA maneuver, using explicit coordination if necessary RA Maneuver Info Provided to Pilot	TCAS II	Intruder Tracks, Ownship State Data, Ownship Performance Data, TCAS Coordination Information	RA Maneuver to UA Control System(s) RA Alert to PIC RA Selected Maneuver to PIC	Activity Use state information to determine a maneuver, consistent with explicit TCAS coordination information (information exchanged between TCAS units), which will avoid an NMAC. Provide alert and maneuver information to the PIC.
123	Automatic RA Execution?	TCAS II	TCAS II Equipment Design and Approval		Decision Is the TCAS II system currently capable of automatic RA execution?
105	TCAS II Automatically Begins/Continues Maneuver Execution	TCAS II, UA Control System(s)	RA Maneuver	Change in UA Trajectory	Activity TCAS II automatically maneuvers the UA through the onboard control system(s). There may be a short delay prior to initial execution to allow the PIC to override prior to maneuver.

#	Activity	Performer(s)	Information Input	Information Output	Activity Description
106	DAA Lost Link?	N/A	Link Status Information		Decision Is the UA in a lost-link situation with respect to the DWC function? The DAA equipment may not need this information.
107	Pilot: Is Maneuver Appropriate?	Pilot	RA Maneuver, Current Air Traffic Picture	Acceptability of Maneuver	Decision Pilot uses the current air traffic picture to assess the acceptability of the CA maneuver. Pilot will need to take into account aircraft not being tracked by TCAS.
108	Pilot Notifies ATC of RA Maneuver, When Able	Pilot	Two-way Comms with ATC, Maneuver from #107	Convey DAA Initiation of Maneuver for Traffic	Activity Pilot notifies ATC that a maneuver was required and has been initiated.
110	Pilot Overrides RA Maneuver	Pilot	Current Air Traffic Picture	Alternative Maneuver	Activity Pilot inhibits or stops the automatic DAA RA maneuver (if applicable) and selects an alternate maneuver based on information not available to the TCAS II. The alternate maneuver choice could include no maneuver.
111	Pilot Maneuvers	Pilot	Alternate Maneuver Intruder Tracks, Ownship State Data, UA Performance Limitations	Change in UA Trajectory	Activity Pilot commands and the UA executes the original TCAS II or alternate maneuver. The alternate maneuver choice could include no maneuver.
109	Encounter Resolved?	DAA Equipment, TCAS II	Change in UA Trajectory, Changes to Air Traffic Picture, Collision Avoidance Threshold, DAA Conflict Resolved		Decision TCAS II monitors air traffic picture to determine if additional RA maneuvering is required.

#	Activity	Performer(s)	Information Input	Information Output	Activity Description
112	TCAS II provides “Clear of Conflict” indication	TCAS II	Intruder Tracks, Ownship State Data, Ownship Performance Data	DAA Conflict Resolved flag	Activity TCAS II will evaluate aircraft trajectories to determine that the encounter has been resolved. TCAS II will provide a Clear of Conflict indication. The display of DAA Conflict Resolved may only involve the removal of previously provided guidance.
113	ATC: Amended clearance needed?	ATC	ATC Surveillance of Air Traffic Picture, Current and Planned Intruder and UA Clearances and Instructions	ATC Clearances No Action	Decision ATC uses standard procedures, experience and ATC automation tools to decide whether to issue an amended clearance as a result of the RA maneuver (e.g., new assigned altitude).
114	Pilot notifies ATC of return to course	Pilot	Two-way comms, DAA Conflict Resolved flag, DAA Air Traffic Display, Ownship State Data, Original Course	Conveys to ATC that UA is Back On or Returning to Course	Activity Pilot notifies ATC when back on course or returning to course.
115	Pilot returns UA to course	Pilot	DAA Conflict Resolved flag, DAA Air Traffic Display, Ownship State Data, Original Course	Change in UA Path to Return to Course	Activity Pilot uses training, experience, and judgment to determines course changes and returns to original course .
116	ATC issues amended clearance	ATC	Information from #113, Two-way Comms with UAS PIC	ATC Clearance or Instruction	Activity ATC uses standard procedures, experience and ATC automation tools to separate UAs from nearby aircraft.
117	Pilot Acknowledges Amended Clearance	Pilot, ATC	Acceptability of Instructions, Established ATC Comms	Convey Pilot Understanding and Intent to Comply	Activity Pilot reads back clearance and conveys to ATC intention to comply with the ATC instructions.

#	Activity	Performer(s)	Information Input	Information Output	Activity Description
118	Pilot Flies Amended Clearance	Pilot	ATC Amended Clearance		Activity Pilot follows amended clearance, which ends the encounter.
119	Encounter Resolved?	DAA Equipment	Change in UA Trajectory, Changes to Air Traffic Picture, TCAS II Logic, DAA Conflict Resolved		Decision DAA equipment monitors the air traffic picture to determine if additional RA maneuvering is required or if aircraft are passing clear of conflict.
120	TCAS II "Clear of Conflict" indication	TCAS II	Intruder Tracks, Ownship State Data, Ownship Performance Data	DAA Conflict Resolved flag	Activity TCAS II evaluates aircraft trajectories to determine that the encounter has been resolved.
121	UA Continues Lost-link Procedure	UA Control System(s)	TCAS II Logic, Ownship State Data, Lost-link Procedure	Change in UA Path to Follow Lost-link Procedures	Activity After clear of conflict, the UA continues to follow the lost-link procedure.
122	End RA Timeline Continue to Start	-	-	-	Continue to the Start of the DAA activity diagram.

A.4.5 Roles and Responsibilities

A.4.5.1 Pilot and Flight Crew

The UAS PIC and any other required crewmembers (e.g., launch/recovery specialist, observers, or payload operators) will be trained in the use and features of the DAA equipment, as appropriate for their role. This includes understanding the DAA system's capabilities and limitations as well as understanding applicable UAS capabilities and limitations as a whole.

> **OR.11** The UAS PIC and other required crewmembers and ground support personnel shall be trained on the proper use, maintenance, phraseology, and theory of the DAA system and TCAS II system (when installed).

This OSED does not attempt to allocate responsibility for specific DAA functionality to individual members of the flight crew; instead, the OSED assumes a single UAS PIC operating a single unmanned aircraft, similarly to manned aircraft under 14 CFR §91.3. Pilot and crew training for a specific DAA system may allocate responsibilities differently. Handoffs of DAA operation from one crewmember to another will be conducted using appropriate procedures (see OR.7).

The UAS PIC is responsible for ensuring the UA maintains DWC of all aircraft in accordance with the ROW rules and applicable regulations. The UAS PIC is authorized to use the DAA system as an acceptable means of compliance with 14 CFR Part 91 while flying IFR in IMC or VMC (see OR.3 and OR.5).

The DAA equipment does not replace the UAS PIC and it does not combine or prioritize all the information the UAS PIC uses to safely aviate, navigate, and communicate. The UAS PIC uses information from the DAA equipment in conjunction with other instruments, airspace knowledge, and ATC instructions to make decisions about maneuvering the UA. The UAS PIC uses UAS specific-/DAA system-specific training and experience in maneuver selection and in overriding TCAS II RA maneuvers, if necessary.

The DWC alerts will be appropriately prioritized with other alerting systems in the CS in a fashion similar to the guidance in FAA Advisory Circular (AC) 25.1322-1, AC 23.23, and AC 23.1311-1C; system-specific guidance (e.g., TCAS, Ground Proximity Warning System (GPWS), Helicopter Terrain Awareness and Warning System (HTAWS), Terrain Awareness and Warning System (TAWS)); or any to-be-developed UAS-specific guidance. TCAS II RAs will take priority over DWC guidance, and the systems will be integrated such that conflicting information is not presented to the UAS PIC.

The UAS PIC will be trained in the capabilities and limitations of using the DAA system during all phases of flight (e.g., takeoff (once the DAA system is in use), departures, cruise, arrivals, approach and landing (until the DAA system is no longer in use)), and the PIC will not be authorized to use the system beyond its certified operating envelope. In general, this means the UAS PIC will follow ATC instructions and the instructions from ground/air observers or other systems that are authorized for use in any given phase of flight.

Pilots will also be trained on how to resolve conflicting sensor data through other means (e.g., ATC communications) or through avoiding false or split tracks if the data ambiguity cannot be resolved. If TCAS II is onboard, pilots will be trained on how to follow RAs and the limitations of the system, including what to do when intruders not tracked by TCAS conflict with an RA maneuver.

Pilots will inform ATC of a loss of DAA equipment functionality. The requirements in 14 CFR §91.187 should cover loss of DAA since they include reporting malfunctions with "navigational, approach, or communication equipment" and DAA equipment helps the UAS PIC navigate while avoiding other aircraft.

> **OR.12** The UAS PIC shall notify ATC as soon as practical when there is a loss of DAA functionality.

Whether or not the PIC or controller declares an emergency will be based on established procedures and the current situation (type of failure, airspace density, ability of ATC to provide separation, location of viable recovery point, etc.).

A.4.5.2 Air Traffic Controllers

All UAS operations using a certified Phase 1 DAA system will fly under IFR.[36] It is assumed ATC will provide the same separation services using the same separation standards to UAS as they provide to manned IFR aircraft. However, controllers should assume that pilots of DAA-equipped UAS are unable to accept visual separation, delegated separation, contact approach, or visual approach responsibilities. ATC services outside the scope of DAA operations (e.g., tower-provided separation during takeoff and landing) are not addressed in this OSED.

> **ASSUMP-OSED.13** ATC will provide the same separation service to UAS as they provide to manned IFR aircraft.

There may be some differences in communication phraseology associated with the UAS' lack of an onboard human operator to "see" or "visually acquire" nearby aircraft. In general, these terminology differences may require the introduction of appropriate phrases highlighting their use of an approved "detect" capability. ATC phraseology is discussed more in Paragraph A.4.6.

> **OR.13** Controllers shall be trained on DAA phraseology and functionality.

ATC will call out traffic advisories to UAS PICs the same as they would for pilots of manned aircraft—on a workload permitting basis. A subtle difference is that UAS will be authorized to use the DAA equipment, including the traffic display, to detect the traffic, analogous to manned aircraft having the traffic visually in sight out the window of the aircraft. The DAA equipment will assist the UAS PIC in predicting the developing conflict geometry and developing an avoidance strategy. The UAS PIC may query ATC regarding a potential conflict. If possible, the UAS PIC will coordinate with ATC any maneuvers to avoid a LoWC or regain DWC. This communication will be based on UAS PIC judgment and communication norms to avoid distracting ATC with traffic calls about traffic that is not a factor. While there may be an increase in traffic coordination communications, the impact of these communications is not expected to be any more

[36] The FAA UAS CONOPS and SC-228 TORs assume that UAS being integrated into the NAS file and fly IFR flight plans.

disruptive than manned aircraft pilots communicating to ATC about traffic observed visually or on traffic displays.

> **ASSUMP-OSED.14** The impact of UAS PIC-initiated traffic queries on ATC communications will be no more disruptive than manned aircraft pilots queries based on traffic visually observed or observed on traffic displays.

Per 14 CFR Part 91, §91.111a, §91.113, and §91.181 (once updated), the UAS PIC, when advised of the intruder by the DAA equipment, will be authorized to initiate maneuvers based on the capabilities of the DAA system and UA, with prior coordination with ATC if possible, else notifying ATC as soon as practical after maneuver initiation. This interaction implies a PIC-ATC dialogue similar in scope to one that would normally occur today for see-and-avoid. Normally, coordination with ATC will occur prior to an DWC maneuver. The UAS PIC should prioritize ATC clearances or instructions over DWC guidance, assuming those instructions do not lead to the violation of another rule (e.g., causing the UA to cross less than DWC or creating a collision hazard with other aircraft, obstacle, or terrain). However, TCAS II RAs supersede ATC clearance or instructions, as with TCAS II systems in today's NAS.

Similar to the ADS-B Cockpit Display of Traffic Information (CTDI), the DAA traffic display will provide the ability for early detection of developing traffic conflicts. This traffic awareness is expected to improve NAS safety and efficiency, but is not authorization to disregard ATC instructions and clearances. UAS PICs, like their counterparts flying manned aircraft, will be trained to use the DAA traffic display in ways that are comparable with operations at the time these MOPS were published. No changes to ATC procedures are expected with regard to the introduction of these traffic displays.

ATC will interact with UAS with the Class 2 DAA system in the same manner as manned aircraft with TCAS II systems. The TCAS II in Phase 1 will provide vertical resolutions identical to TCAS II RAs that are executed immediately by the UAS PIC or the UAS automatically. TCAS II RAs will take priority over ATC instructions. Pilots will report RA maneuvers, analogous to TCAS RA reporting, following existing ATC procedures.[37]

ATC services for UAs transitioning through Class G airspace are identical to the services provided to comparable manned aircraft, with controllers being responsible for separation as IFR aircraft enter and leave Class E airspace. The UAS is expected to fly the filed flight plan and to follow ATC-provided instructions. ATC will use procedural separation for IFR aircraft outside of radar coverage, including airports in Class G airspace, using one-in, one-out (blocking airspace) procedures when needed.

UA operating in Class G airspace will inform ATC as soon as feasible of any delays or deviations from their filed flight plan as required to maneuver for VFR traffic, or for any other reason (per FAA AIM 5-2-6). Timely communications requirements with ATC are identical for manned pilots and UAS PICs.

In the long term, ATC will not be limiting the density of UAS operations in a given airspace; UAS and manned IFR aircraft will compete for limited ATC services through

[37] FAA JO 7110.65W 2-1-27

the first-come, first-served and future best-equipped, best-served concepts in parallel with manned aircraft. The same ATC sector limitations that apply to manned IFR aircraft will apply to UAS aircraft.

If the DAA system functionally degrades or fails, the UAS PIC will inform ATC per 14 CFR §91.187. ATC and UAS PIC procedures for addressing this failure or degradation will need to be developed by the FAA. Declaration of an emergency for loss of DAA will not be mandatory but will be left up to the PIC and/or controller. During DAA lost-link conditions, the UAS cannot perform DAA, and therefore ATC will need to assist in maintaining separation between the UA and all VFR and IFR traffic in communication with the controller, just as with pilots of manned IFR aircraft who have lost communications with ATC. Again, declaration of an emergency for UAS lost link will not be mandatory but will be left up to the PIC and/or controller. It is expected that DAA failures and degradations will increase controller workload and therefore must have an appropriately small likelihood of occurrence.

ASSUMP-OSED.15 For Phase 1, there will be no automatic DWC maneuvers during UAS lost CNPC link.

A.4.5.3 Existing Manned Aircraft Crew

Manned aircraft crews should treat all UAS IFR operations with DAA no differently than other manned IFR operations. The introduction of these UAS into the NAS should be transparent to manned aviation.

VFR pilots will use the same right-of-way rules when encountering UAs as they would when encountering similar categories of manned aircraft. All pilots should use the same vigilance in seeing and avoiding UAs as they would use when encountering conflicting manned aircraft. The PIC will follow the same right-of-way rules as manned aircraft (adapted for UAS use), and will use vigilance to detect, avoid, and maintain DWC of all aircraft, at an acceptable safety threshold that is the same as or better than manned aircraft. The UAS PIC will follow 14 CFR §91.113 right-of-way regulations as applicable when performing maneuvers to maintain DWC per **OR.4**.

Some UAS may be smaller, larger, or lighter, and have greater speed variances than their manned counterparts. The introduction of UAS into the NAS may introduce different visibility, wake-turbulence, and encounter speed concerns, hence manned aircraft must follow best practices and continue to perform see-and-avoid against all traffic. No changes to manned aircraft right-of-way rules are expected. UA markings and lighting, including anti-collision lighting, are expected to follow the same certification criteria as manned aircraft, hence visual acquisition of UAs by crew of manned aircraft should be the same per given cross-section. UAS will be subject to the same transponder and ADS-B equipage rules as manned aircraft for the airspace in which they are flying.[38] A high percentage of DAA-equipped UAS are anticipated to be equipped with ADS-B Out prior to the January 1, 2020 mandate under 14 CFR §91.225 based on their anticipated operations.

[38] Section 4.2 of the FAA Integration of UAS into the NAS Concept of Operations v2.0 (28 Sept 2012) assumes that all UAS will be equipped with ADS-B Out, but this document does not.

A.4.6 Impact on Communications with ATC

Given that UAS PICs are not onboard their aircraft and are unable to look out the window using natural vision to see intruders, it may be necessary for the FAA to adopt new phraseology for UAS PICs and air traffic controllers for the purpose of traffic advisories. Whether the UAS PIC initiates a traffic call based on DAA equipment, or a controller initiates a traffic call based on observed sensor data, a change to a the PIC's standard response such as "traffic in sight" may be prudent, since the traffic is not actually in sight.

ATC personnel are used to hearing certain phrases such as "traffic in sight" or "negative contact"[39, 40] based on the knowledge that a pilot is visually searching for traffic. Other phrases common among ATC controllers are "traffic observed" and "traffic no longer observed." These "traffic observed" phrases have different meanings depending on the context in which they are used,[41] but as a rule, are used by controllers and are not used by pilots.

In order to avoid confusion and provide additional assistance to ATC, it is proposed that the phrases "traffic detected" and "negative contact" be used for traffic calls to and from UAS PICs, and were used in the development of the concept and scenarios within this document. The "traffic detected" phrase will provide a reminder to controllers and pilots on the same communication frequency that an aircraft is a UA that may have unique operating and performance characteristics. This would be of added benefit if there are no changes made to radar data tags or flight progress strips to indicate an unmanned status, especially in an environment where there is a mix of manned and unmanned traffic using tactical call signs.

UAS PICs and controllers will be trained on the new phraseology (see OR.11 and OR.13)

In NASA's Controller Acceptability Studies 1 and 2, these phrases were used exclusively by UAS PICs. During the out-briefs of all subjects, they were asked if the phrases were of value or if they seemed confusing. All subjects responded that they thought the new "traffic detected" phrase was appropriate as well as practical. Some added that they found the new phrase acted as a reminder of an aircraft's status as a UAS, similar to "Copter" or "Heavy."

A.5 Nominal Scenarios

The following fourteen scenarios describe the use of a certified Class 1 or Class 2 DAA system under conditions relevant to its expected use after completion of the Phase 1 MOPS. These scenarios are expected to help guide the development of the Phase 1 MOPS and assist in ensuring all aspects of the MOPS have been completed.

The nominal scenarios fall into the categories shown in Table A-5, based on the airspace classes in the left column. The Class 2 DAA system may operate in all airspaces assuming it has been approved as suitable and no operational limitations are in place.

[39] AIM Pilot/Controller Glossary
[40] AIM §4-4-17
[41] FAA JO 7110.65W, §2-1-21, §5-4-2, and §5-4-3

.

Table A-5 Nominal Scenario Breakdown

	UAS PIC Can't Determine if Intruder is Operating under IFR/VFR	Intruder is Known to UAS PIC as Operating under VFR	Intruder is Known to UAS PIC as Operating under IFR
Class A	N/A since all aircraft IFR		The DWC traffic display only acts to aid communications with ATC. Scenario A.5.6
Class B **Class C**	The DWC traffic display only acts to aid communications with ATC. Out of scope – no scenarios		
Class D	Attempt ATC coordination, maneuver to maintain DWC if necessary Scenarios A.5.12, A.5.13		
Class E	Attempt ATC coordination, maneuver if necessary to maintain DWC Scenarios A.5.3, A.5.10, A.5.14	Attempt ATC coordination, maneuver if necessary to maintain DWC Scenarios A.5.2, A.5.7, A.5.11	Attempt ATC coordination, maneuver if necessary to maintain DWC May delay maneuver if anticipating ATC instructions Scenarios A.5.1, A.5.8, A.5.9
Class G	N/A due to one-in, one-out procedures	Maneuver if necessary to maintain DWC Scenarios A.5.4, A.5.5	N/A due to one-in, one-out procedures

The point where alerts are issued to maintain DWC will normally be closer in than when the ATC controller acts to maintain radar separation minimums (e.g., 3 NM or 5 NM, 1000' vertically).[42] Therefore, it is unlikely that the DAA equipment will declare IFR traffic a threat, as ATC will already have applied IFR separation standards. However, if the DAA equipment did provide a DWC alert on an IFR intruder, the UAS PIC would try to contact ATC (Scenario A.5.3), else maneuver to maintain DWC and then contact the controller (Scenario A.6.1).

Analogous to a pilot of a manned aircraft, the UAS PIC will not be able to definitively determine if the intruder is operating under VFR or IFR. The UAS PIC may be able to infer the rules that the intruder is operating under through a number of factors including:

- Intruders squawking 1200 are operating under VFR and corporate Aircraft Flight Identifiers (IDs) (e.g., AA1731) are operating under IFR, if this information is available, but this is not expected to be a minimum display requirement

[42] This needs to be validated to ensure controller acceptability.

Note: *Not all DAA traffic displays will include items like transponder code and Flight ID. Discrete (non-1200) transponder codes are not a reliable indication of the aircraft being operated IFR with separation services provided by ATC since aircraft being provided VFR flight following are also given discrete squawk codes.*

- Non-cooperative traffic is assumed to be operating under VFR
- Aircraft level at cruise altitudes that are multiples of 1,000' above 3000' AGL (4000' MSL, 7000' MSL, etc.) are likely operating under IFR or receiving ATC services (e.g., VFR practice approaches)
- Aircraft operating at cruise altitudes that are multiples of 1,000' plus 500' (4500' MSL, 7500' MSL, etc.) are likely operating under VFR.

Therefore, while UAS PICs may infer an aircraft is operating under IFR and may delay contacting ATC or delay making a maneuver, UAS PICs must maintain their subjective well clear of all aircraft while using DAA to comply with 14 CFR §91.113 and 91.181. The UAS PIC is not required to make any inferences about the VFR or IFR status of intruders. Since the DWC definition is nominally inside ATC radar separation minima, the need for UAS DWC maneuvers will normally only occur against traffic that is not being separated by ATC. ATC is the "single separator" for IFR/IFR encounters, but the IFR DAA-equipped UA must maintain DWC of IFR aircraft to address the case when the separation service has been compromised.

The frequency of occurrence of DAA Corrective Alerts and DAA Warning Alerts against IFR intruders will be addressed in the Alerting performance metrics to ensure acceptability in the NAS. This is to ensure there will not be an unacceptable number of DAA Corrective Alerts where the Corrective Hazard Zone exceeds IFR separation standards; this could lead to the UAS PIC requesting amended clearance from ATC to inappropriately maneuver to avoid other IFR traffic. Amended clearance requests to ATC for maintaining DAA Well Clear from VFR traffic are not deemed to be a nuisance.

A.5.1 UA and Overtaking IFR Traffic Receiving IFR Separation Services from ATC

A UA is transitioning through Class E airspace on an IFR flight plan and is communicating with ATC via voice communications, consistent with the "Vertical Transit" or "Loiter for Surveillance"[43] scenarios in the FAA UAS CONOPS. A business jet (the intruder) operating under IFR begins to overtake the UA on the same airway, as depicted in Figure A-12 and Figure A-13, and the intruder is not yet predicted to cross the UA's well-clear boundary within the DWC alerting time. ATC is providing radar separation[44] between the IFR aircraft and issues instructions to the UAS PIC to avoid the passing intruder and to get the UA closer towards its destination. For example, "TURKEY 21, turn left heading zero-two-zero, vectors for spacing."[45] The UAS PIC acknowledges and follows the controller's instructions. The UAS PIC may consult the DAA traffic display for additional traffic situation awareness.

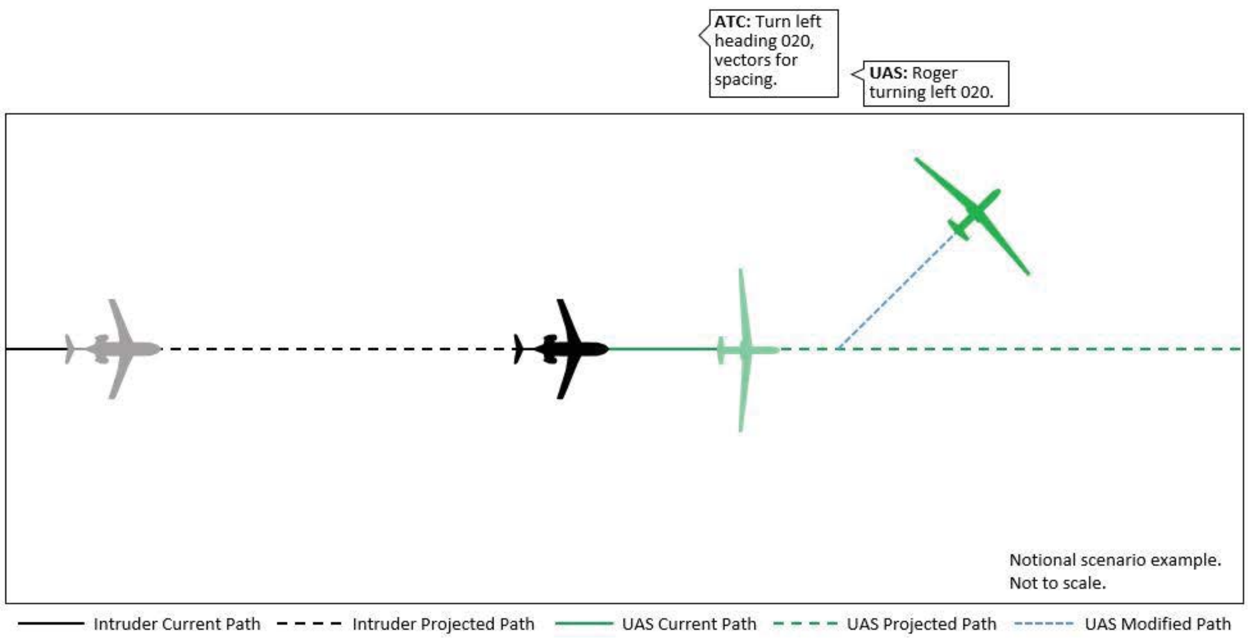


Figure A-12 **Scenario A.5.1 – UA and Overtaking IFR AC under ATC Control**

[43] The Loiter for Surveillance scenario is included to cover horizontal transit operations to or from an operational area.
[44] FAA JO 7110.65W §5-5-1
[45] FAA JO 7110.65W §2-1-21

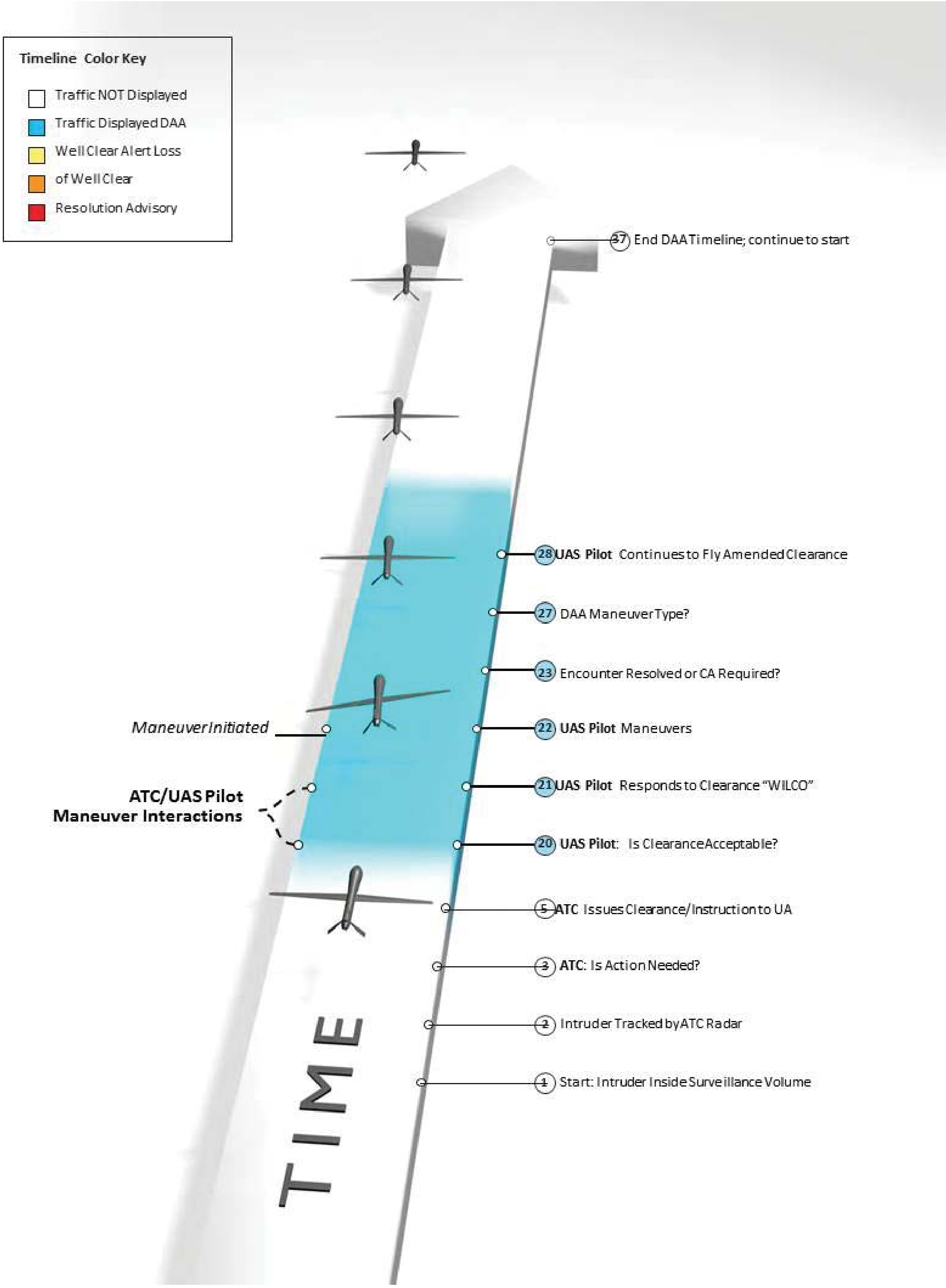


Figure A-13 **Scenario A.5.1 – Timeline for IFR Traffic Overtake**

A.5.2 ATC Calls Out Visual Flight Rules (VFR) Traffic to UAS PIC

A UA is climbing through 13,000' MSL, transitioning to Class A along a heading direct to a VHF Omnidirectional Range Radar (VOR), consistent with the "Vertical Transit" scenario in the FAA UAS CONOPS. ATC issues a traffic advisory[46] for a VFR parachute jump aircraft circling at 14,500' MSL, as depicted in Figure A-14 and Figure A-15; e.g., "NASA 21, traffic eleven o'clock, six miles, one four thousand five-hundred feet, circling Twin Otter." The DAA traffic display shows the traffic but does not indicate that the traffic is an DWC threat. The UAS PIC responds, "Traffic detected."

The Twin Otter is maneuvering and turns towards the UA after about a minute. The DAA traffic display then indicates the observed parachute jump aircraft is a DAA Corrective Alert since it is predicted to enter the Corrective Hazard Zone. The UAS PIC evaluates the situation, given the traffic display decision aids that support either a right or left turn, and requests a left turn to avoid the traffic: "Center, NASA 21 requesting a 30-degree left deviation for traffic." ATC replies with an offer for a right turn to maintain sector containment: "NASA 21, left turn would take you out of my sector, deviate right as necessary for traffic and report when clear." The UAS PIC evaluates that the instruction is acceptable, acknowledges ATC instruction: "NASA 21, Roger, turning right for traffic," complies, and reports when decision aids and pilot judgment indicate clear of traffic: "Center, NASA 21 is clear of the traffic, returning to course."[47] ATC instructs the UAS PIC to resume own navigation: "Roger NASA 21. Resume own navigation." The UAS PIC returns to course.

[46] FAA JO 7110.65W §2-1-21
[47] FAA JO 7110.65W §2-1-27 has details of returning to course phraseology after TCAS RAs.

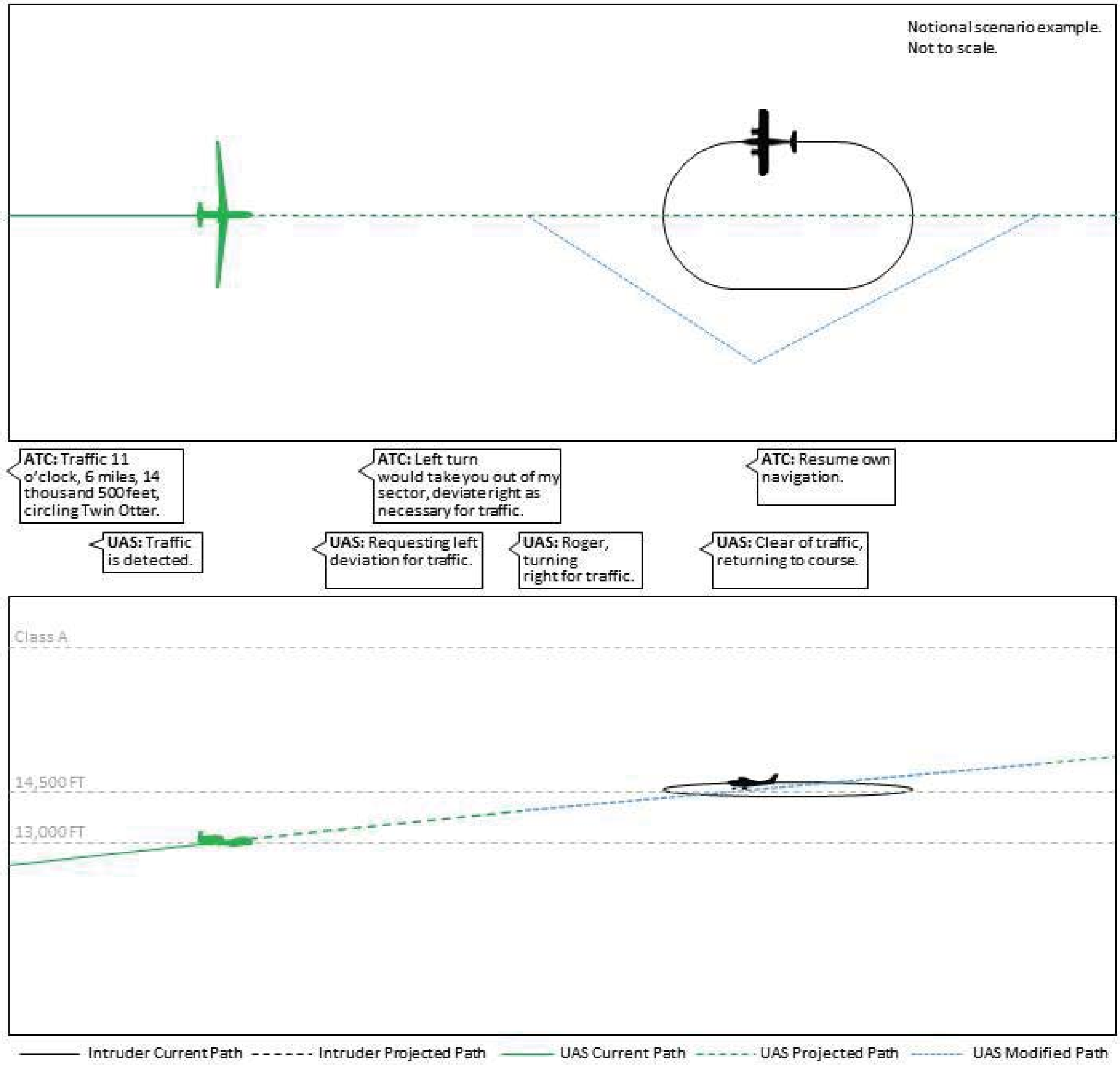


Figure A-14 **Scenario A.5.2 – ATC Calls Out VFR Traffic to UAS PIC**

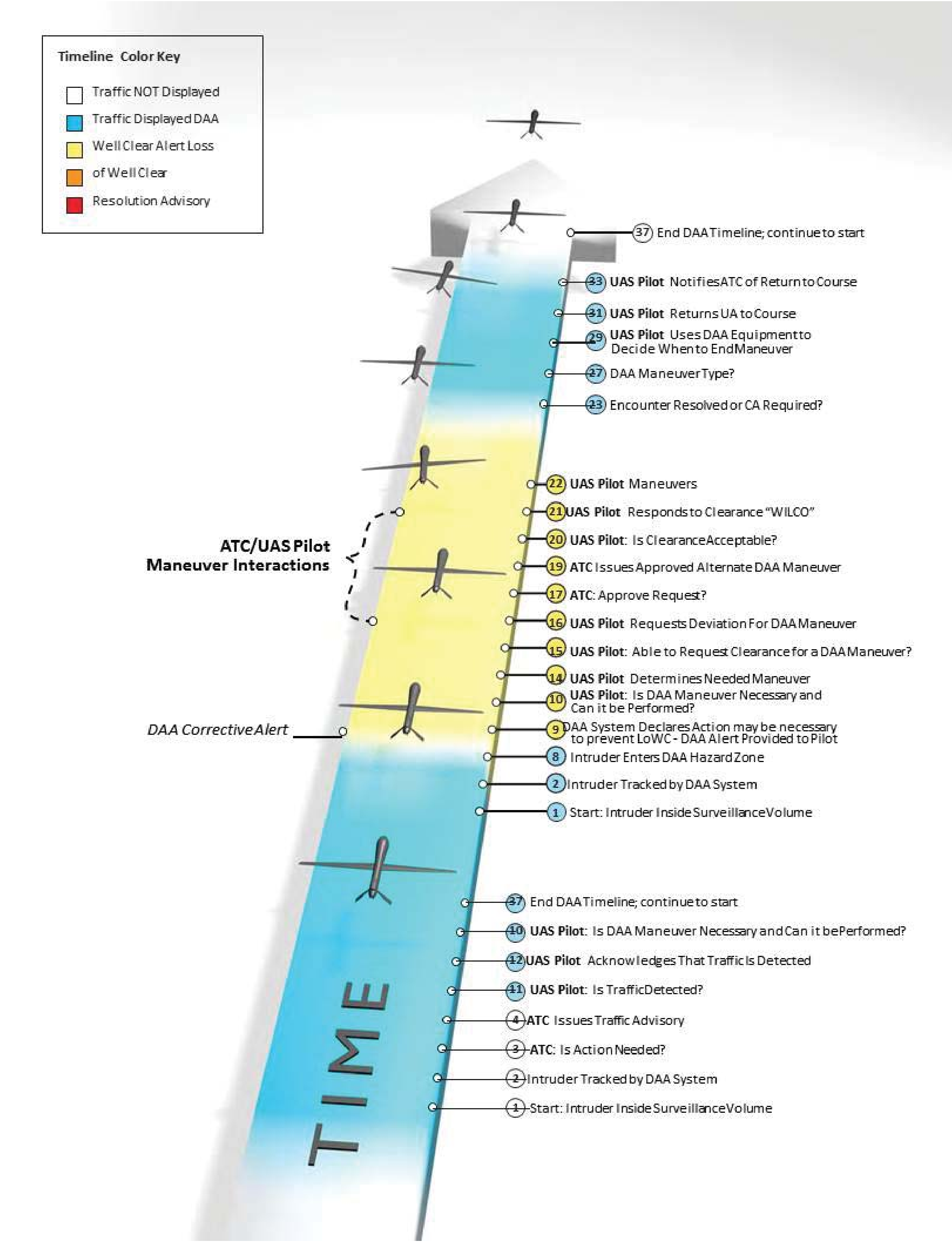


Figure A-15 **Scenario A.5.2 – Timeline for ATC Calls Out VFR Traffic to UAS PIC**

A.5.3 UAS PIC Calls Out VFR Traffic to ATC and Coordinates Maneuver

A UA is transitioning through Class E airspace on an IFR flight plan and is communicating with ATC via voice communications, consistent with the "Vertical Transit" or "Loiter for Surveillance" scenarios in the FAA UAS CONOPS. A twin engine airplane (the intruder) operating under VFR begins to converge on the UA from the front left quadrant. The controller has not yet provided a Traffic Advisory because of workload, frequency congestion, or the controller does not yet perceive the intruder to be a threat to the UA.

The UAS DAA equipment declares that the intruder is a threat and issues a corrective alert because it is predicted to cross the UA's well-clear boundary in the future.[48] The UAS PIC observes the intruder on the DAA traffic display and, based on pilot judgment, determines that a maneuver will be necessary in the near future to maintain DWC, and there is sufficient time to coordinate with ATC. The UAS PIC's decision to call ATC instead of beginning the maneuver and then informing ATC (Scenario A.6.1) is based on a number of factors, including:

- Ability to communicate with ATC, (e.g., no frequency congestion or imminent sector handoff),
- When operating in uncontrolled airspace (e.g., when authorized by ATC to enter Class G),
- Encounter geometry, aircraft trajectories and speeds,
- Desire for a clearance change to resolve conflict, (e.g., Direct-to a future waypoint, altitude change), and/or
- UAS PIC workload.

The decision to coordinate with ATC first or maneuver first is based on the maneuvering time required to maintain DWC, not to maintain an ATC separation standard.

The UAS PIC then calls ATC to request a maneuver with language such as, "Griffiss Approach, JOKER 2 requests a 30-degree right turn to avoid traffic at our eleven o'clock" (Scenario A.5.3.a, Figure A-16) or "Pensacola Approach, Navy 35 requesting lower altitude for traffic avoidance" (Scenario A.5.3.b, Figure A-17).

ATC then replies with instructions or an amended clearance based on the observed traffic situation and any strategic plans. For example the controller may respond with "JOKER 2, maneuver at pilot's discretion; advise when back on course" (Scenario A.5.3.a, Figure A-16) or "Navy 35, descend and maintain 4000" (Scenario A.5.3.b, Figure A-17). The controller may also issue instructions to the intruder if in communication, in which case no instructions or amended clearance would be given to the UAS PIC (this approach is not illustrated in this scenario). The UAS PIC follows any instructions or amended clearances issued by the controller until the encounter is resolved (see timeline in Figure A-18).

[48] This time to LoWC will need to be selected such that it normally provides time for ATC coordination but not too early that it becomes a nuisance to UAS pilots or ATC or frequently alerts on IFR intruders who are beyond ATC separation standards (3 NM, 5 NM, 1000'). Based on initial NASA Part Task 4 results, the nominal DAA alert time before well clear is expected to be somewhere in the range of 50-70 seconds.

The scenario is consistent with manned aircraft operations and existing controller phraseology. The main difference is that the UAS PIC may request a maneuver earlier than a pilot in a manned aircraft, using unaided vision only, would be able to see the intruder. This earlier awareness of the problem enables both the UAS PIC and ATC to resolve the situation in a safer and more strategic manner.

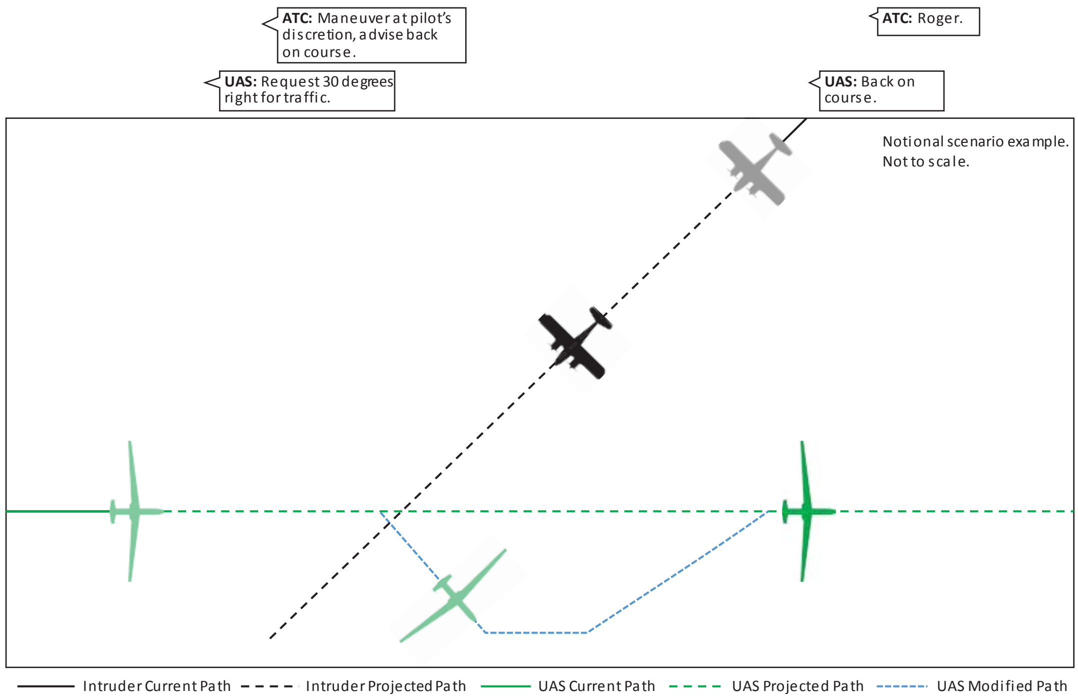


Figure A-16 **Scenario A.5.3.a – UAS PIC Calls Out Co-altitude VFR Traffic to ATC**

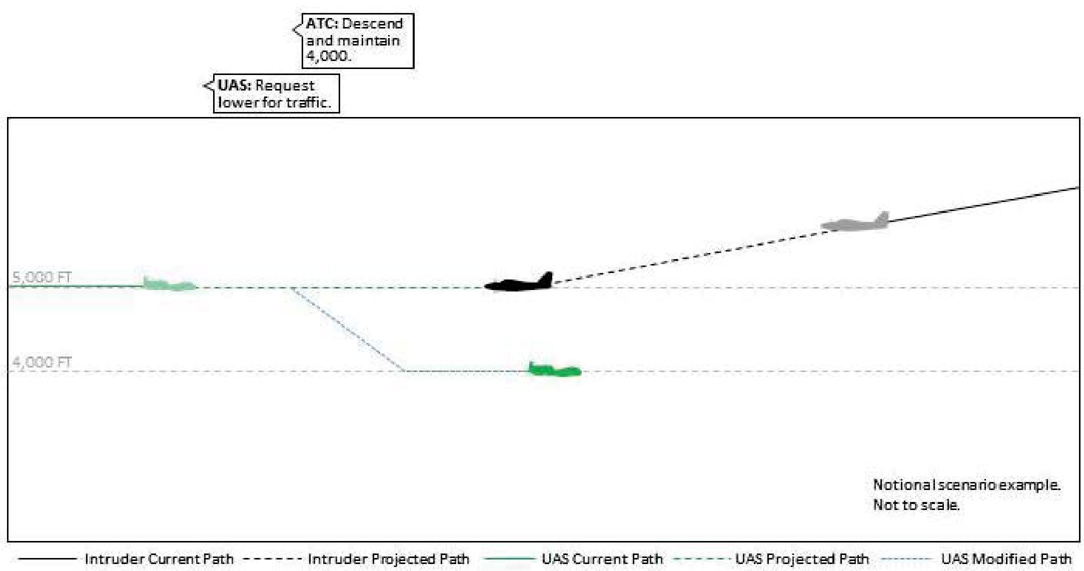


Figure A-17 **Scenario A.5.3.b – UAS PIC Calls Out Descending VFR Traffic to ATC**

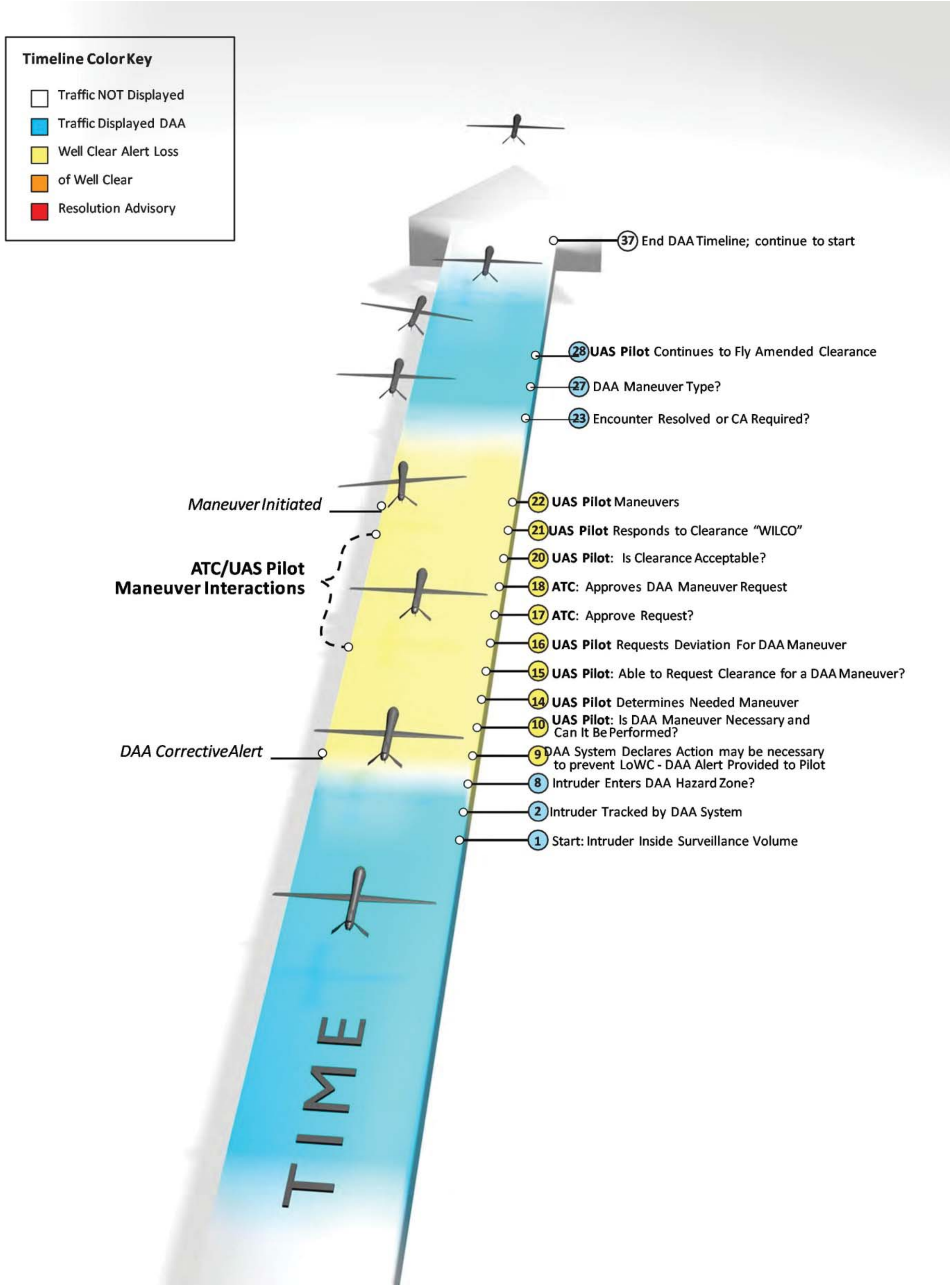


Figure A-18 Scenario A.5.3.a/b – Timeline for UAS PIC Calls Out VFR Traffic

A.5.4 UA Climbing IFR through Class G Airspace and Encounters VFR Traffic

A DAA-equipped UA is launched from a non-airport launch and recovery site in a high-altitude mountainous region, , as depicted in Figure A-19 and Figure A-20. Before departure, the UAS PIC requests activating a previously filed IFR flight plan in conjunction with a request for release from the presiding ATC authority, Salt Lake Center. The UAS PIC is given a clearance that begins upon entering controlled airspace pursuant to §4-3 of FAA Joint Order (JO) 7110.65W. The UAS PIC is responsible for separation from all other airspace traffic until the point at which the UA exits uncontrolled airspace on its flight plan.

Prior to launch a visual observer clears the immediate airspace around the launch zone and visually monitors the airspace until well clear separation responsibility transitions to the DAA equipment at 800' AGL. The UA climbs at 200' per minute (fpm) due to the high density altitude and UA performance limitations. The UAS PIC notifies ATC that the UA is only able to maintain a 200-fpm climb.[49]

After a minute, the DAA equipment issues a corrective alert for a non-cooperative helicopter 600' above and converging on the UA at 3 NM from the front. The intruder was not observed by the visual observer. The PIC turns the UA 30 degrees to the right to resolve the conflict, while continuing to climb. After the intruder is no longer a factor, the DAA system removes the alert.

Once the UA enters controlled airspace, establishes two-way radio communication, and is radar identified (in an ATC radar environment), ATC begins to apply standard Class E IFR separation between all IFR aircraft as found in the current version of 7110.65 Chapter 5 (Radar), or applicable portions of 7110.65 Chapter 6 (Non-radar).

[49] Per FAA AIM 5-3-3

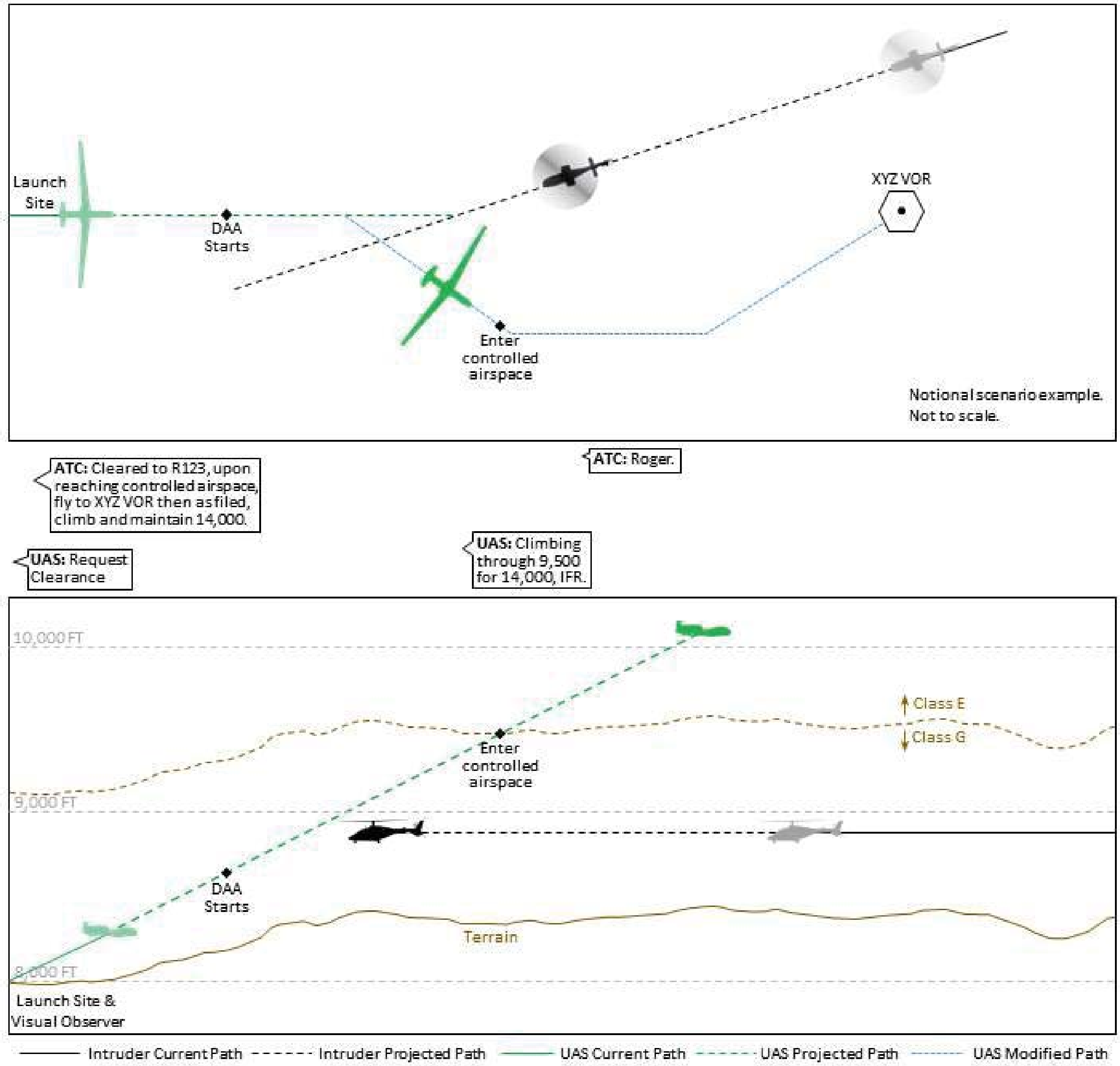


Figure A-19 Scenario A.5.4 – UA Climbing through Class G and Encounters VFR Traffic

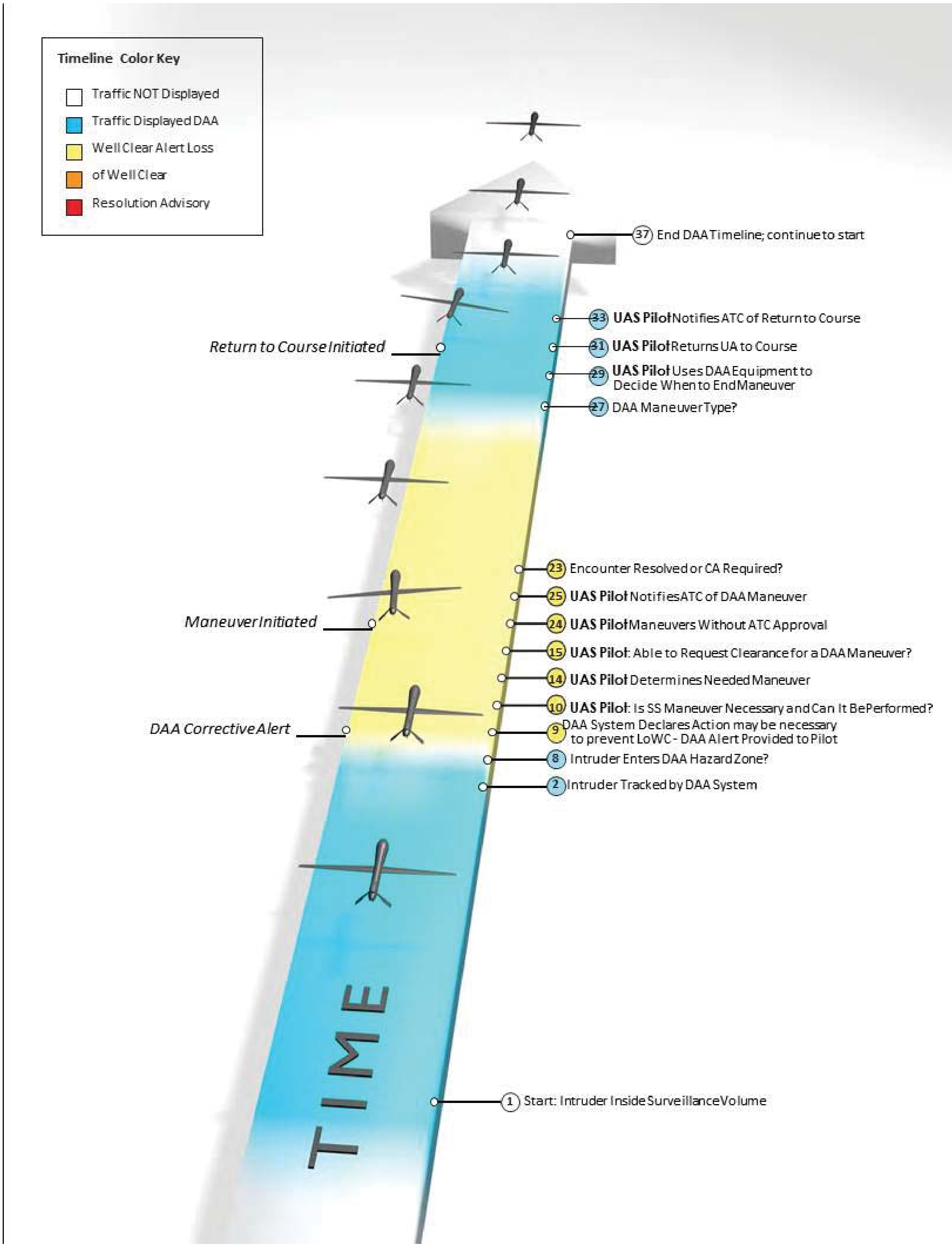


Figure A-20 **Scenario A.5.4 – Timeline for UA Climbing through Class G with VFR Traffic**

A.5.5 Un-towered Airport in Class G Airspace Involving One-In, One-Out Procedures

After completing a mission, a UA is returning to a public-use non-towered airport for landing, as depicted in Figure A-21 and Figure A-22. The UA is on an IFR flight plan and in two-way communications with ATC. While the UA is in Class E airspace, it is outside of ATC surveillance coverage. ATC is providing procedural separation between the UA and all other IFR traffic per FAA Order 7110.65 Chapter 6. ATC is also controlling an IFR Cessna 172 on approach to the same airport.

The airport has marginal VFR conditions with visibility of 4 NM and a 1400' ceiling.

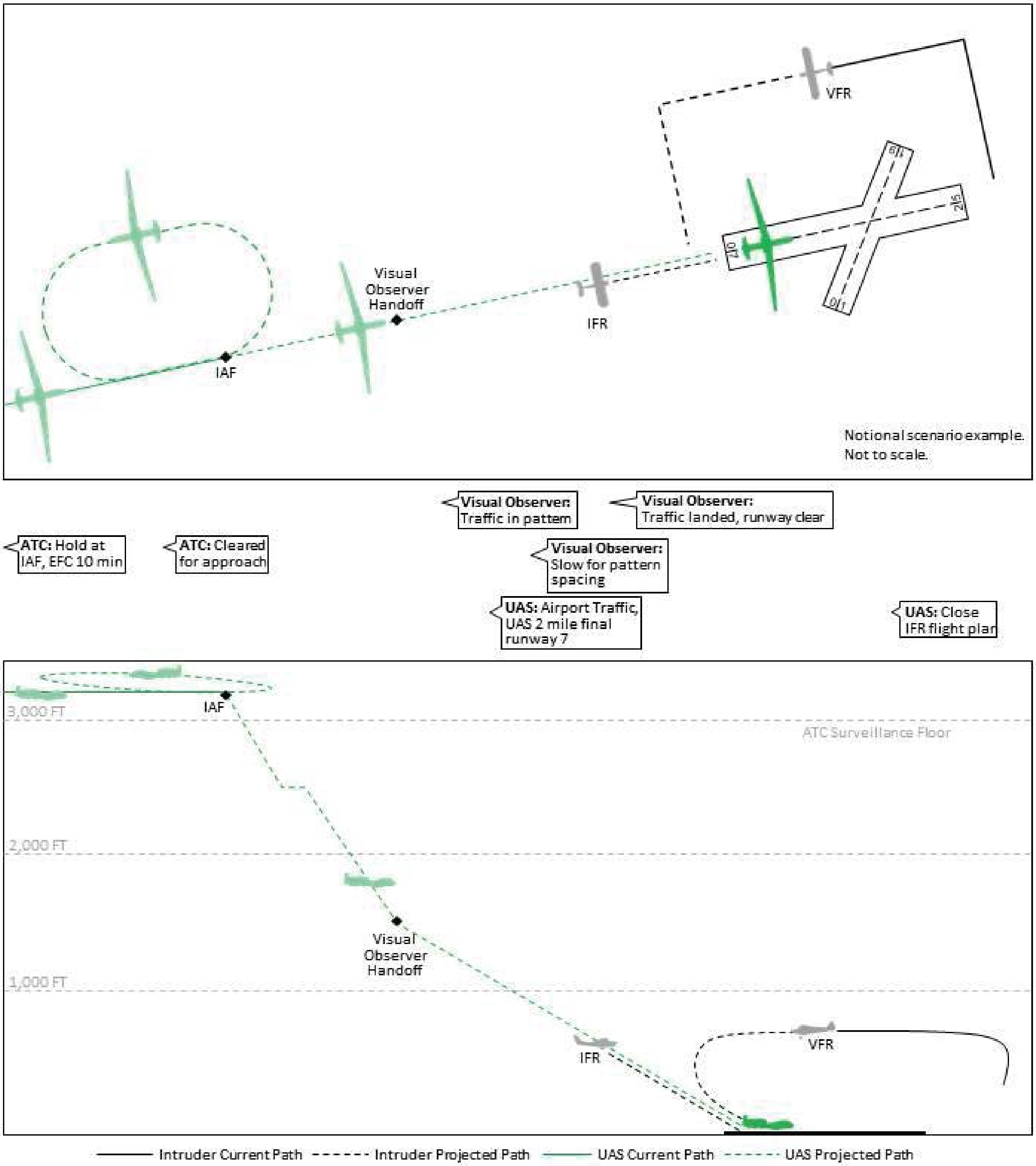
The UA is cleared direct to the Initial Approach Fix (IAF) for an Area Navigation (RNAV) Global Positioning System (GPS) approach to the airport. ATC instructs the UAS PIC to hold as published at the IAF with an Expect Further Clearance (EFC) time of ten minutes. ATC is waiting for the Cessna to land and report IFR cancelation to maintain separation in Class E airspace. The UAS PIC monitors the approach of the Cessna on the DAA traffic display for traffic situation awareness.

Once the Cessna lands and the pilot cancels the flight plan through the Remote Communications Outlet (RCO), ATC clears the UA for the approach. The PIC scans the DAA traffic display during the approach to ensure there are no other threatening aircraft. All intruders in Class G depicted on the DAA traffic display will be VFR aircraft (since IFR aircraft in Class G are separated procedurally using "one-in, one-out" procedures). The DAA equipment does not detect a non-cooperative Piper Cub conducting VFR takeoffs and landings in the airport traffic pattern, due to ground clutter rejection algorithms.

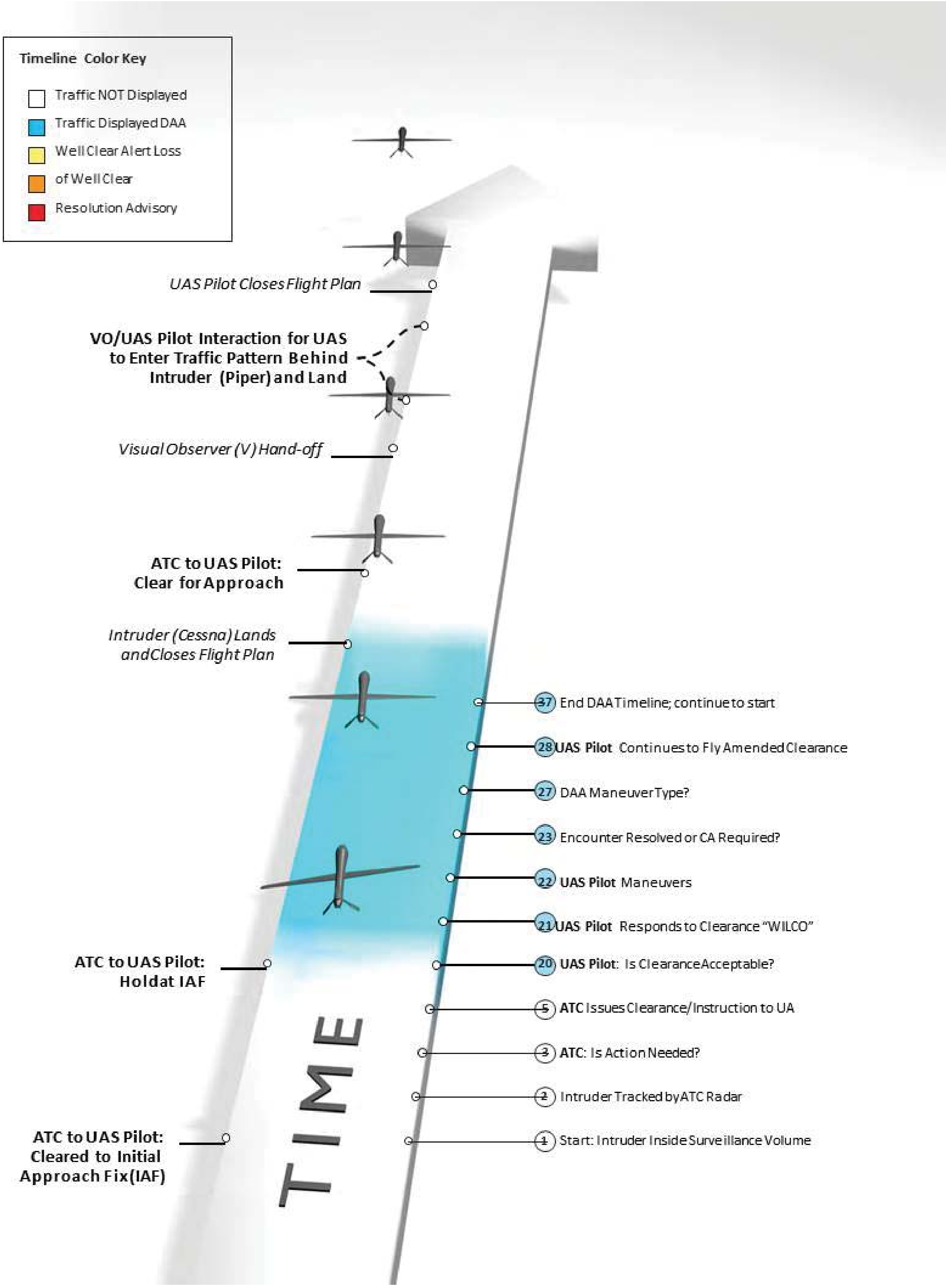
In this scenario, a visual observer is used at the recovery airport to separate the UA from other VFR traffic near the airport. This UA's operational specifications involve a positive handoff from the PIC using DAA for maintaining DWC to the visual observer upon the UA descending below 1,500' AGL within 5 NM of the airport.

If the Piper Cub had been equipped with a Mode C transponder or ADS-B Out, the UAS PIC would begin the approach knowing about the VFR traffic and would coordinate spacing with the visual observer.

Since the Piper Cub is non-cooperative, as the pilot descends through 2000' AGL the visual observer informs the pilot of the Piper Cub in the traffic pattern. At 1,500' AGL, the visual observer begins providing instructions to the UAS PIC to safely enter the traffic pattern behind the Cub. The UAS PIC provides position reports in the traffic pattern on the Common Traffic Advisory Frequency (CTAF). The Cub has no radio and doesn't issue position reports. The PIC lands the UA, exits the runway, and closes the IFR flight plan via the RCO.



<u>Figure A-21</u> **Scenario A.5.5 – Un-towered Class G Airport with One-In, One-Out**



<u>Figure A-22</u> **Scenario A.5.5 – Timeline for Un-towered Airport**

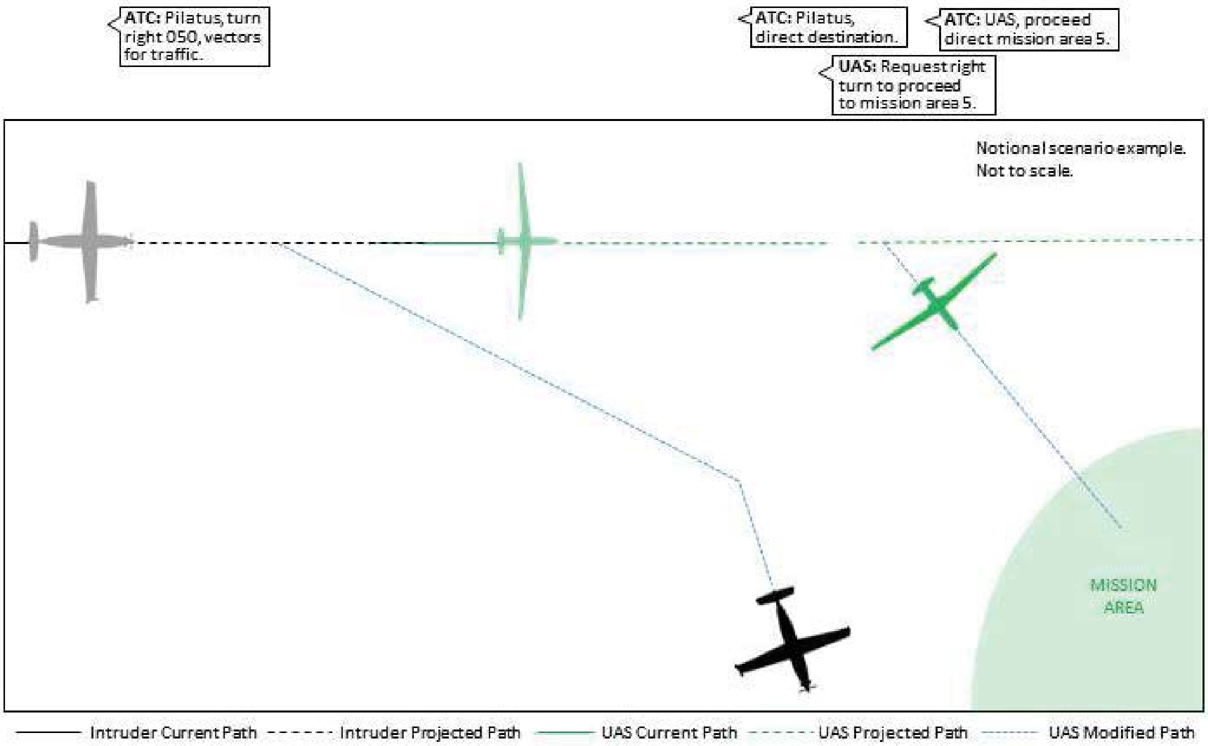
A.5.6 Operations in Class A; DAA System Supporting Enhanced Communications with ATC

DAA equipment may be used for traffic situational awareness and as an aid to communications with ATC in Class A, B, and C airspace, but not for maintaining DWC. This scenario demonstrates why DAA equipment can remain on in Class A airspace. The safety and efficacy of using DAA for the purpose of maintaining DWC in these airspaces, including departure and approach procedures, has not been established during DAA Phase 1 MOPS development.

A Turboprop UA is flying at FL250 along its filed flight plan on a common jet airway, similar to the "Point-to-Point" scenario in the FAA's UAS CONOPS. The UA is flying a true airspeed of 230-250 knots under IFR in VMC. A Pilatus PC-12 is overtaking the UA on the same jet airway, , as depicted in Figure A-23 and Figure A-24. ATC sees the situation evolving and vectors the PC-12 to the right of the UA. The UAS PIC may or may not overhear the ATC instructions given to the PC-12; however, the UAS PIC does observe the PC-12 on the DAA traffic display.

The UAS PIC has been considering an unplanned right turn off the jet airway to proceed to an updated mission area. The UAS PIC delays the request until the PC-12 has passed by or is sufficiently clear based on UAS PIC interpretation of traffic symbology on the traffic display (not based on DWC alerts or decision aids). The UAS PIC requests an amended clearance to turn right to proceed to the new mission area. ATC applies the separation standard, and clears the UA to proceed to the mission area when the separation is sufficient.

The UAS PIC will not perform DWC maneuvers in positively controlled Class A airspace (see OR.7; using DWC for maneuvers in Class A will be an operational limitation). However, the DAA equipment will be operational in Class A to provide traffic situation awareness. If the UA is equipped with the Class 2 DAA system, the TCAS II will be fully operational in Class A airspace; to include following TCAS II RAs.



<u>Figure A-23</u> **Scenario A.5.6 – DAA Supporting Enhanced Communications with ATC**

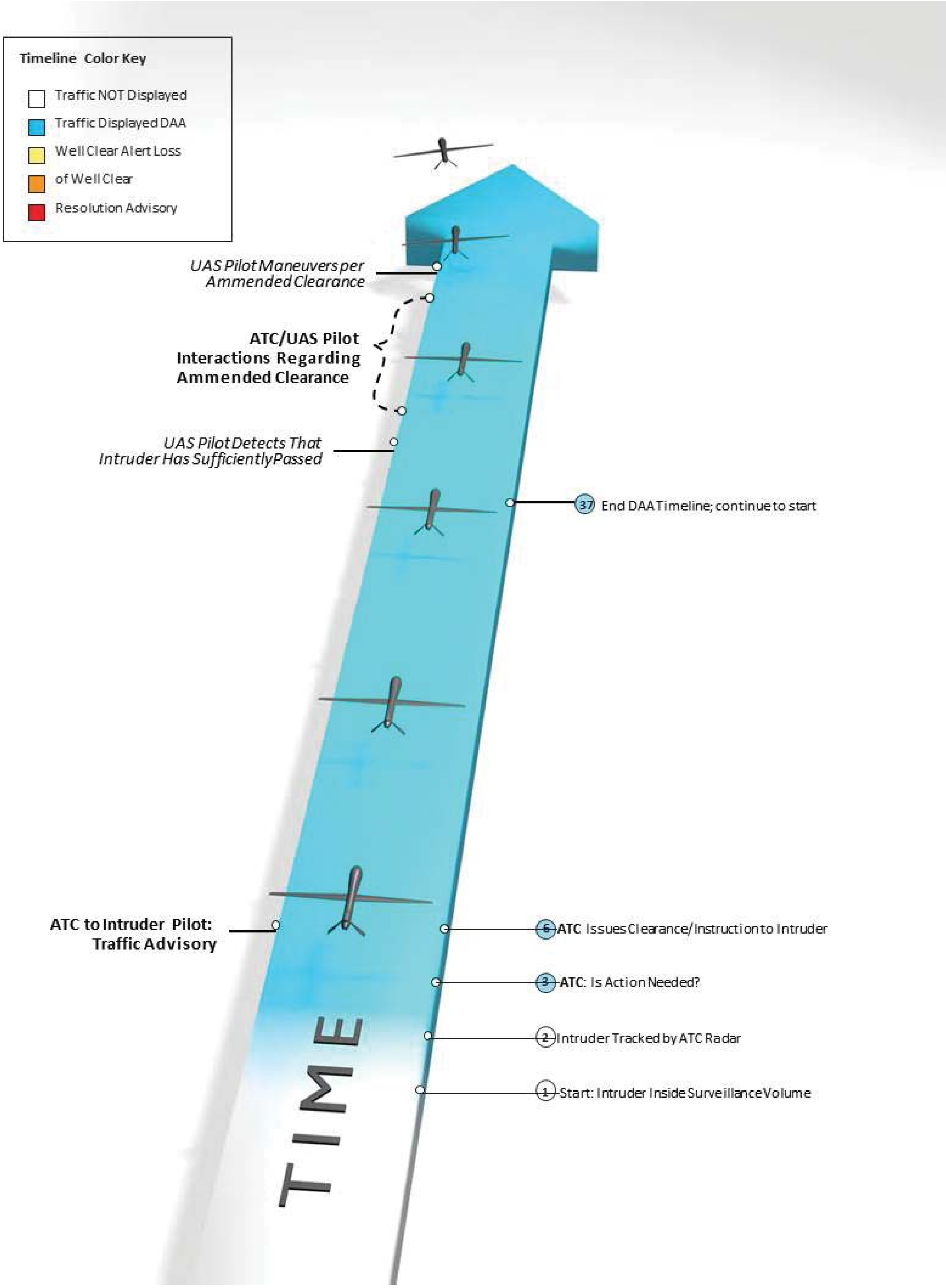


Figure A-24 **Scenario A.5.6 – Timeline for DAA Enhanced Communications with ATC**

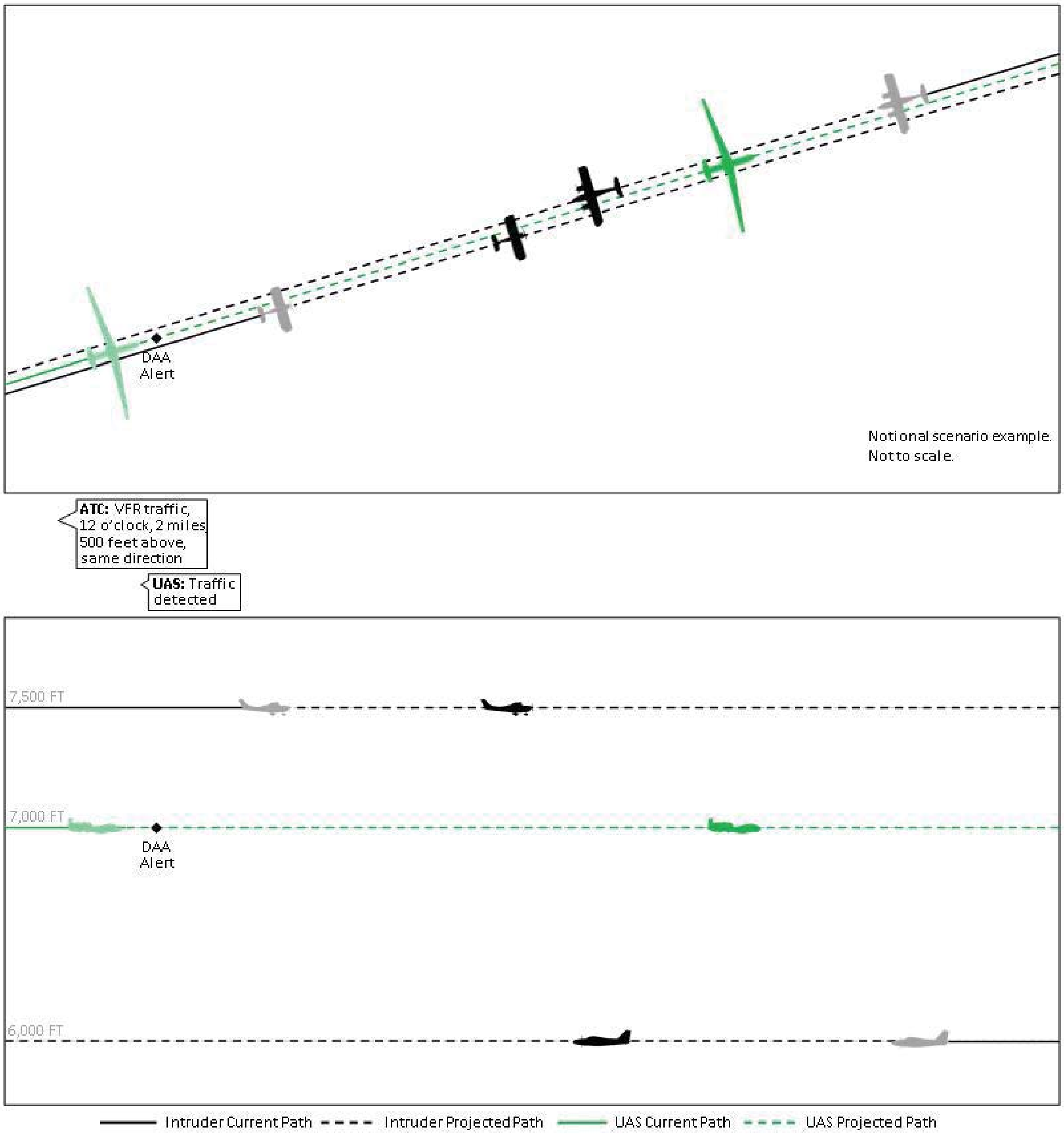
A.5.7 Class E VFR Intruder Separated Vertically by 500’

A piston engine UA, N374RP, is flying IFR northeast-bound along a victor airway at 7,000’ MSL in busy Northeast corridor airspace while in VMC. The sector controller is in communication with the UAS PIC and is also working multiple IFR piston aircraft on the same victor airway headed southwest at 6,000’ MSL. All IFR aircraft are separated using standard IFR separation.

The UA is overtaking a slower VFR intruder flying along the same victor airway at 7,500’ MSL, as depicted in Figure A-25 and Figure A-26. The VFR intruder is squawking 1200 and not communicating with ATC. The controller observes the overtake and issues a Traffic Advisory to the UAS PIC: “N374RP, McGuire Approach, VFR traffic twelve o’clock, two miles, seven thousand five hundred, same direction.” The controller does not give any instructions since the aircraft will be separated by the standard 500’ IFR/VFR vertical separation.

Simultaneously, the UAS PIC receives a preventive alert from the DAA equipment since the VFR intruder is predicted to be close to crossing the UA’s well-clear boundary (which has a 450’ vertical boundary). The UAS PIC assesses the situation, and since both aircraft are level, decides to continue at the same altitude since the intruder will not cross the UA’s well-clear boundary if both aircraft remain level. The UAS PIC replies to ATC, “Traffic detected, N374RP,” and does not request a maneuver.

The UA passes beneath the VFR traffic safely with 500’ vertical separation.



<u>Figure A-25</u> **Scenario A.5.7 – Class E VFR Intruder Separated Vertically by 500'**

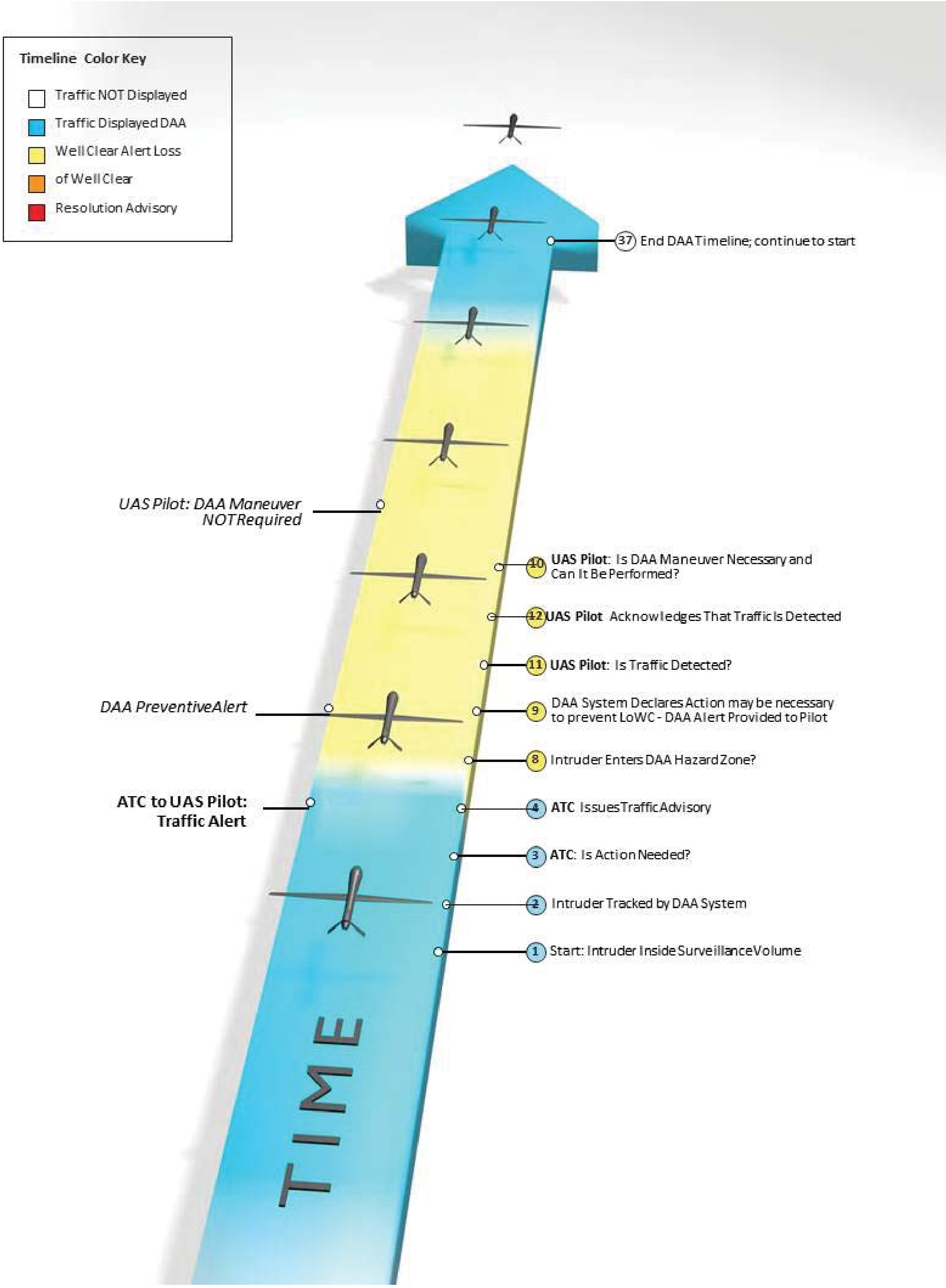


Figure A-26 Scenario A.5.7 – Timeline for Class E VFR Intruder Separated Vertically by 500’

A.5.8 ATC Issues Instructions to IFR Intruder

A UA is straight and level at 13,000’ MSL, transitioning to SUA along a heading direct to a fix inside a restricted area, consistent with the “Transit” scenario in the FAA UAS CONOPS. A conflict develops on the UAS DAA traffic display showing converging traffic at approximately two o’clock climbing through 10,200’ MSL at 10 NM, as depicted in Figure A-27 and Figure A-28. The DAA traffic display correctly issues a corrective alert for the detected traffic due to the predicted LoWC due to the intruder’s climb rate. The UAS PIC evaluates the situation given the traffic display decision aids which would allow a right or left turn and requests a right turn to avoid the traffic: “Center, NASA 21 requesting a 20-degree right deviation for climbing traffic.” ATC realizes that such a maneuver would cause the UA to enter an adjacent sector and replies, “NASA 21, maintain present course and stand by. Break, United 321 Heavy, maintain one-two thousand, traffic eleven o’clock, niner miles, one-three thousand, eastbound, unmanned aircraft.” The ATC controller has more information than is available to the UAS PIC or the DAA equipment. United 321 responds, “Maintain one-two thousand, looking for traffic, United 321 Heavy.” The UAS PIC overhears center’s instructions to the conflict traffic and, as United 321 Heavy levels off at 12,000’, the UAS DAA system indicates that the conflict is resolved.

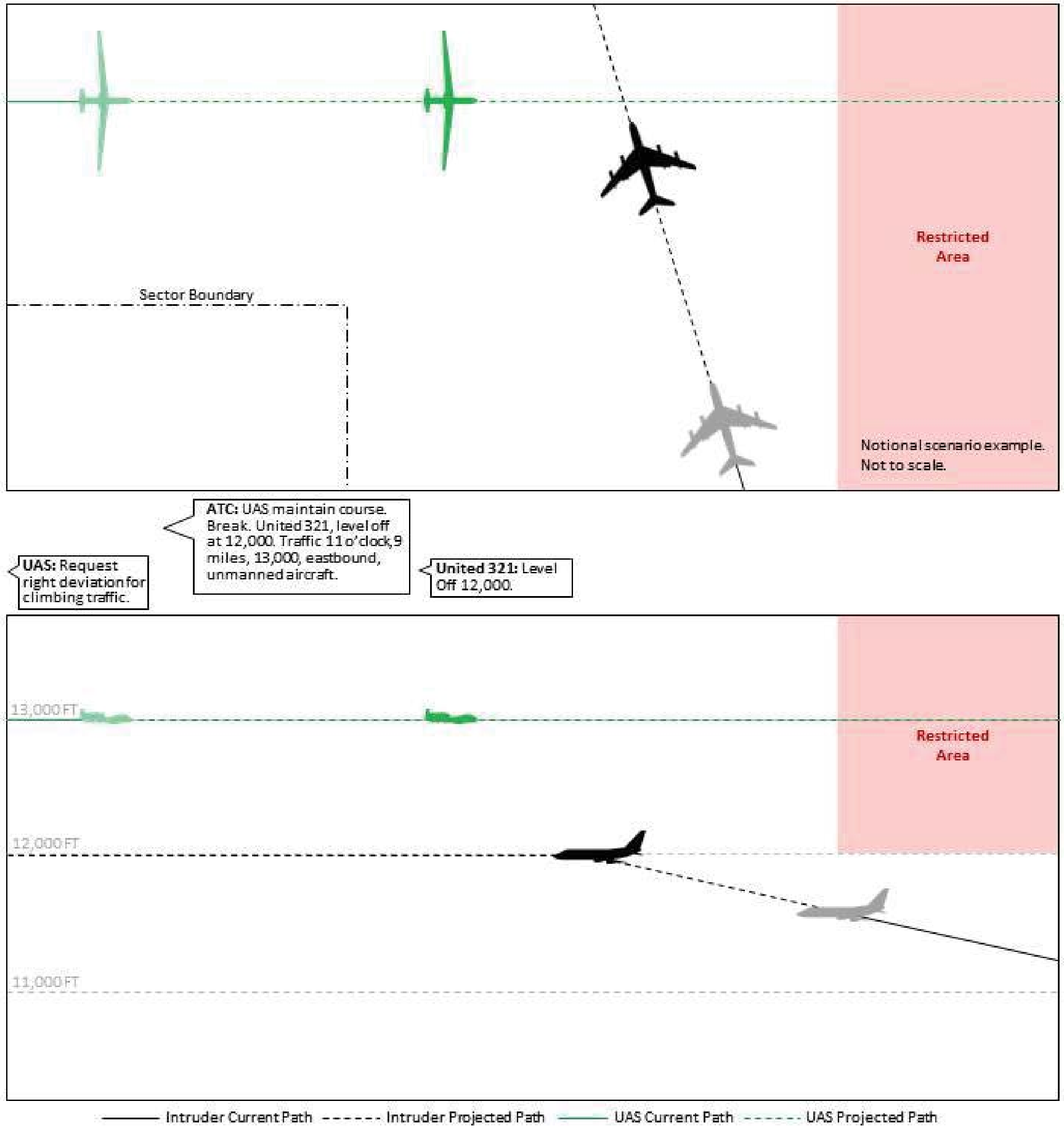


Figure A-27 Scenario A.5.8 – ATC Issues Instructions to IFR Intruder

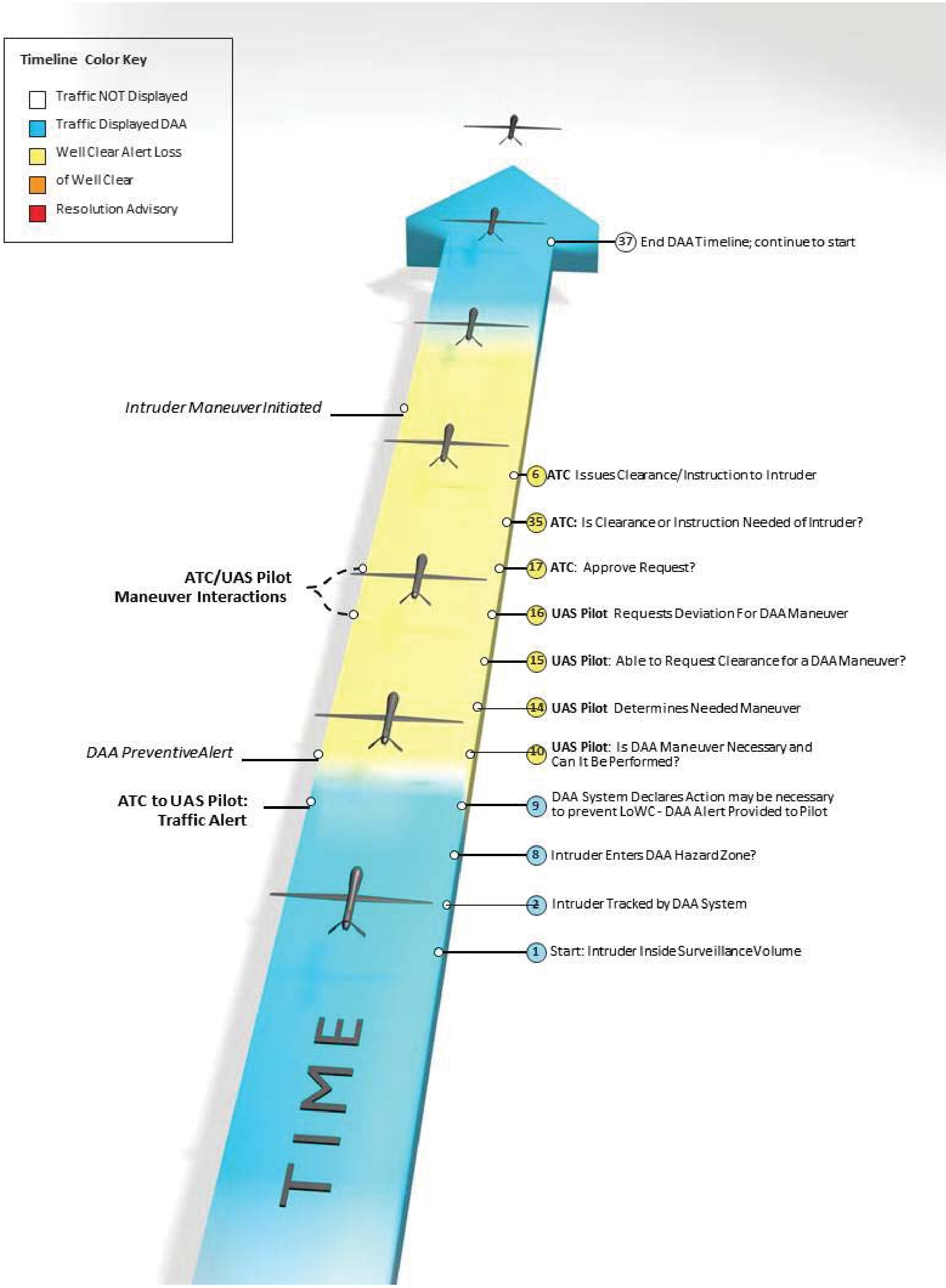


Figure A-28 Scenario A.5.8 – Timeline for ATC Issues Instructions to IFR Intruder

A.5.9 ATC Issues Alternate Maneuver Unacceptable to the UAS PIC

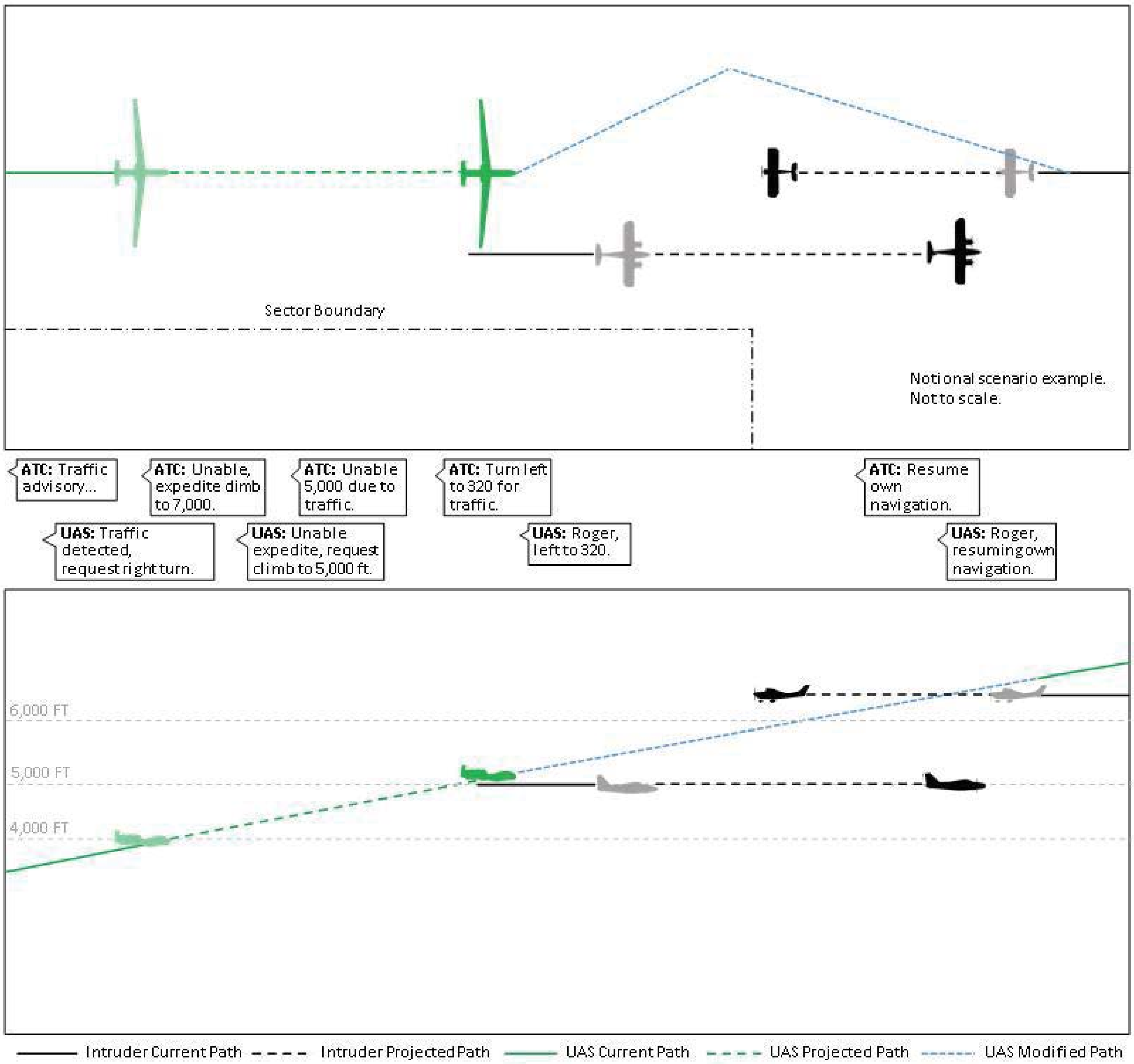
FREIGHT 44, a UA, is transitioning through Class E airspace on an IFR flight plan and is communicating with ATC via voice communications, consistent with the “Vertical Transit” or “Loiter for Surveillance” scenarios in the FAA UAS CONOPS. The UA has climb performance less than a typical manned aircraft of the same category.

FREIGHT 44 is northbound slowly climbing at 400 fpm through 4000’ on course following departure, as depicted in Figure A-29 and Figure A-30. The UAS PIC informs ATC that the UA is only able to maintain a 400-fpm climb rate of 400’ per minute.[50]

ATC observes slow-moving VFR traffic ahead of FREIGHT 44 on a head-on converging course level at 6500’ and issues a traffic advisory to the UAS PIC. The PIC advises ATC that the traffic is detected (on the UAS DAA display), and based on the DWC maneuver guidance requests a right turn to avoid the traffic. ATC advises that they are unable to issue a right turn due to FREIGHT 44 being in close proximity to a sector boundary and other traffic. ATC then offers FREIGHT 44 an expedited climb through 7000’. The UAS PIC advises ATC that he/she is unable to accept an expedited climb due to aircraft performance and requests to level at 5000’. ATC states unable 5000’ due to IFR traffic.

ATC then issues the PIC a vector to turn left and continue climb. The UAS PIC concurs and accepts the vector. After the UA clears the traffic, ATC advises traffic is no factor and issues instructions to FREIGHT 44 to resume on course.

[50] Per FAA AIM, §5-3-3



<u>Figure A-29</u> **Scenario A.5.9 – ATC Issues Alternate Maneuver Unacceptable to UAS PIC**

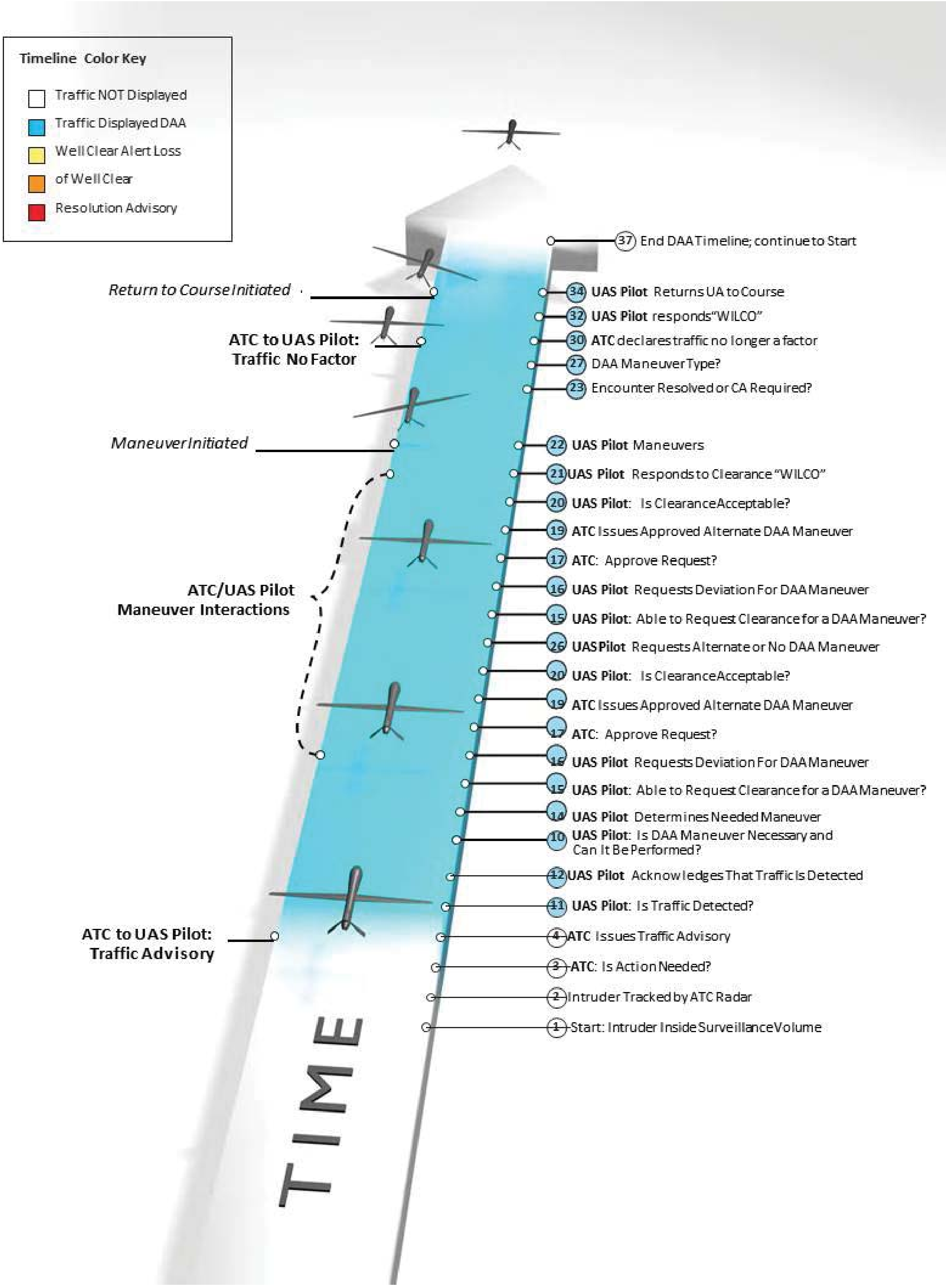


Figure A-30 **Scenario A.5.9 – Timeline for ATC Issues Maneuver Unacceptable to UAS PIC**

A.5.10 Intruder Maneuvers after DWC Maneuver Has Begun; Causes Change in DWC Maneuver

ACE 32, a UA, is transitioning through Class E airspace on an IFR flight plan and is communicating with ATC via voice communications, consistent with the "Vertical Transit" or "Loiter for Surveillance" scenarios in the FAA UAS CONOPS.

ACE 32 is descending at 500 fpm from a cruise altitude of 15,000' enroute to a landing zone, as depicted in Figure A-31 and Figure A-32. ACE 32 has been cleared to descend and maintain 5000'. While descending through 7000', the UAS PIC receives a corrective alert from the DAA system for an aircraft on a converging course level at 5,500'. The PIC observes the intruder is to the front and left of the UA converging at a 30- to 45-degree angle. Even though the UA has right of way per 14 CFR §91.113, the PIC is not sure if the other aircraft will see the UA and maneuver to avoid, so the UAS PIC decides to maneuver. Since the projected encounter is still about 1.5 minutes out, the PIC calls ATC and requests a left turn to pass beside the intruder: "Burlington Approach, ACE 32 requests deviation left for traffic below." ATC evaluates the situation and, given there is no other traffic to the left, approves the request: "ACE 32, Burlington Approach, proceed as requested." The PIC of ACE 32 acknowledges and, while continuing the descent, maneuvers the aircraft left so that the intruder will pass to the right.

After about one and a half minutes, the PIC of ACE 32 observes the intruder turning right and converging again. The corrective alert has not cleared. Due to the more urgent situation, the PIC levels off the UA at 6,300' to allow the intruder to pass underneath. After the level-off is complete, ACE 32 notifies ATC of the level-off due to traffic: "Burlington Approach, ACE 32 just leveled off due to traffic, will continue descent to five thousand when able." ATC then acknowledges: "ACE 32, acknowledge advisory for traffic." When clear of traffic, the PIC informs ATC of intent to continue: "Burlington Approach, ACE 32 continuing descent to five thousand."

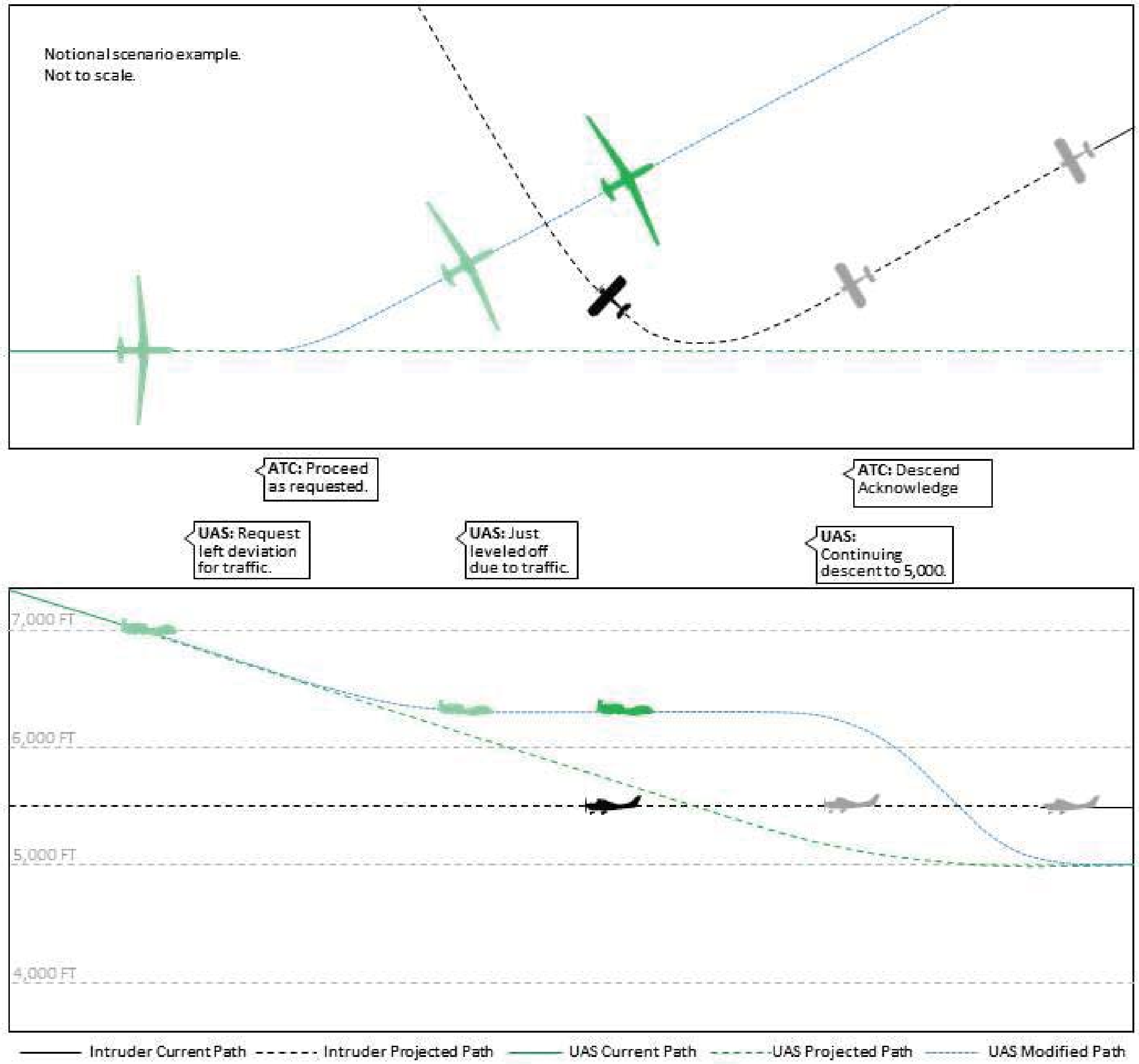


Figure A-31 **Scenario A.5.10 – Change in DWC Maneuver due to Intruder Maneuver**

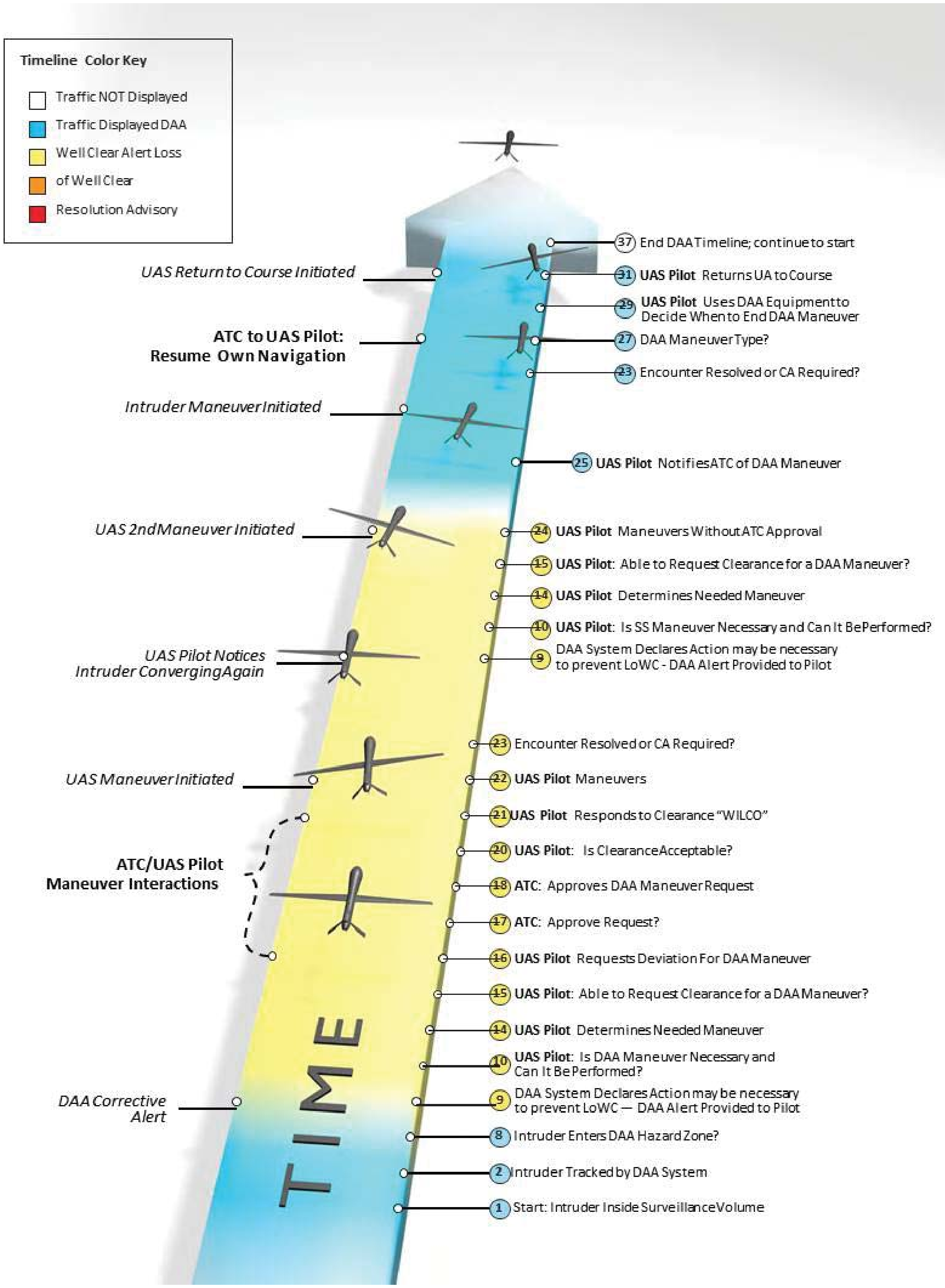


Figure A-32 **Scenario A.5.10 – Timeline for Change in DWC Maneuver**

A.5.11 Controller Instructs Intruder

HAWK 40, a UA, is transitioning through Class E airspace on an IFR flight plan and is communicating via voice communications with ATC, who is providing standard IFR separation services, consistent with the "Vertical Transit" scenarios in the FAA UAS CONOPS.

HAWK 40 is eastbound (heading 90°) climbing through Class E airspace at 3000 fpm on course following departure, as depicted in Figure A-33 and Figure A-34. HAWK 40 will transit through Class E airspace for about 5 minutes flying at 140 knots. N123, a Cessna 172 flying VFR and receiving flight following service, is traveling southwest (heading 220°) at 110 knots and level at 10,500' MSL.

HAWK 40, now crossing 5000', displays the Cessna as traffic on its traffic display; however, the traffic is not indicated as a factor, as it is not yet predicted to cross into the DAA Corrective Hazard Zone.

HAWK 40 and N123 are now about 7 NM separated but on a converging course. ATC issues a traffic advisory to N123 indicating traffic at one o'clock, seven miles, eastbound climbing through 5000'. N123 responds, "Negative contact." ATC also issues a traffic advisory to the UAS PIC, who reports, "Traffic detected." N123 reports traffic in sight, and informs ATC that it will turn right to heading 270° to avoid traffic.

HAWK 40 hears the traffic call and the intent of N123 to make a turn. The UAS PIC monitors, using the DAA system, as the conflicting traffic makes a right turn. The UA and VFR traffic pass about 1.5 NM separated and approximately the same altitude at the CPA.

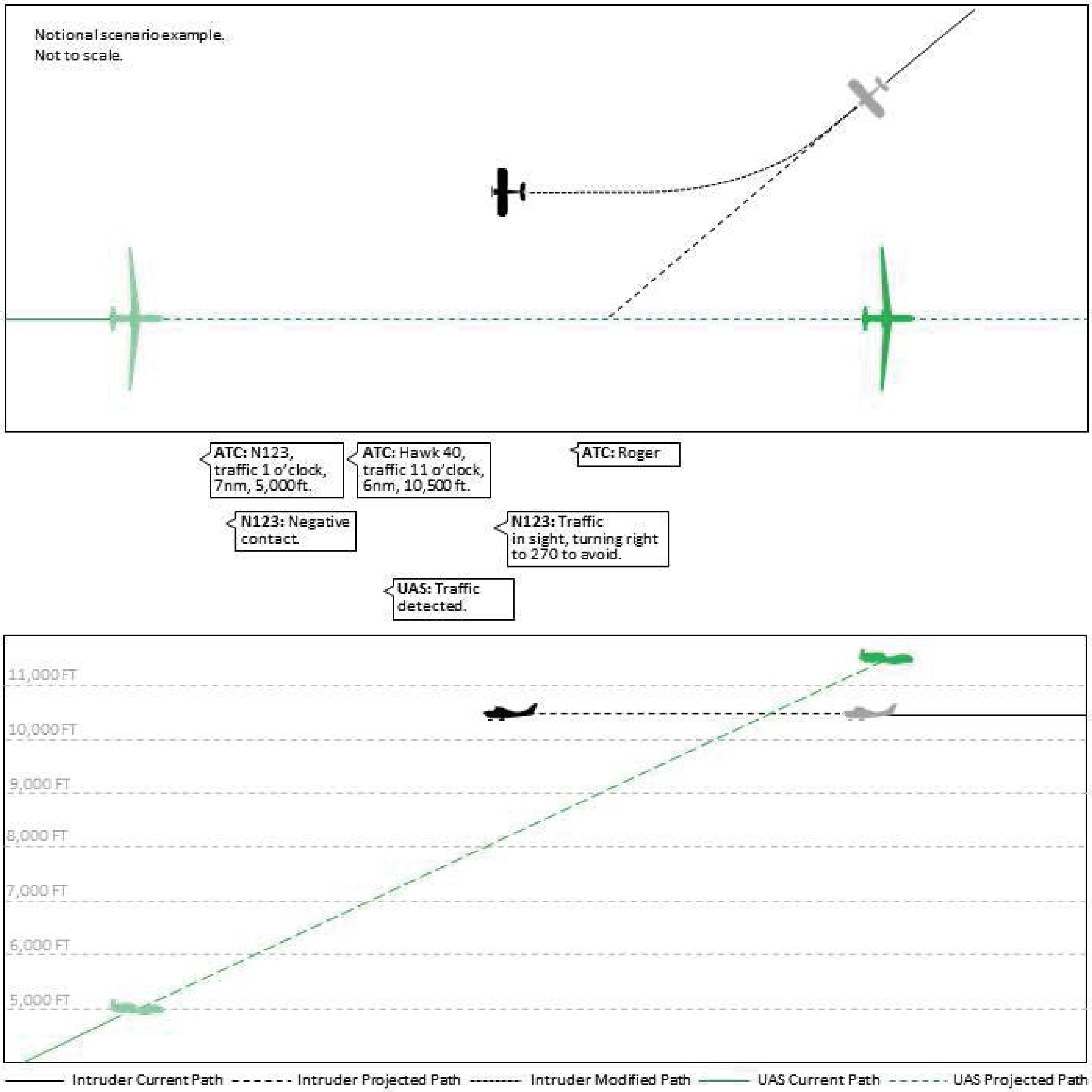


Figure A-33 Scenario A.5.11 – Controller Instructs Intruder

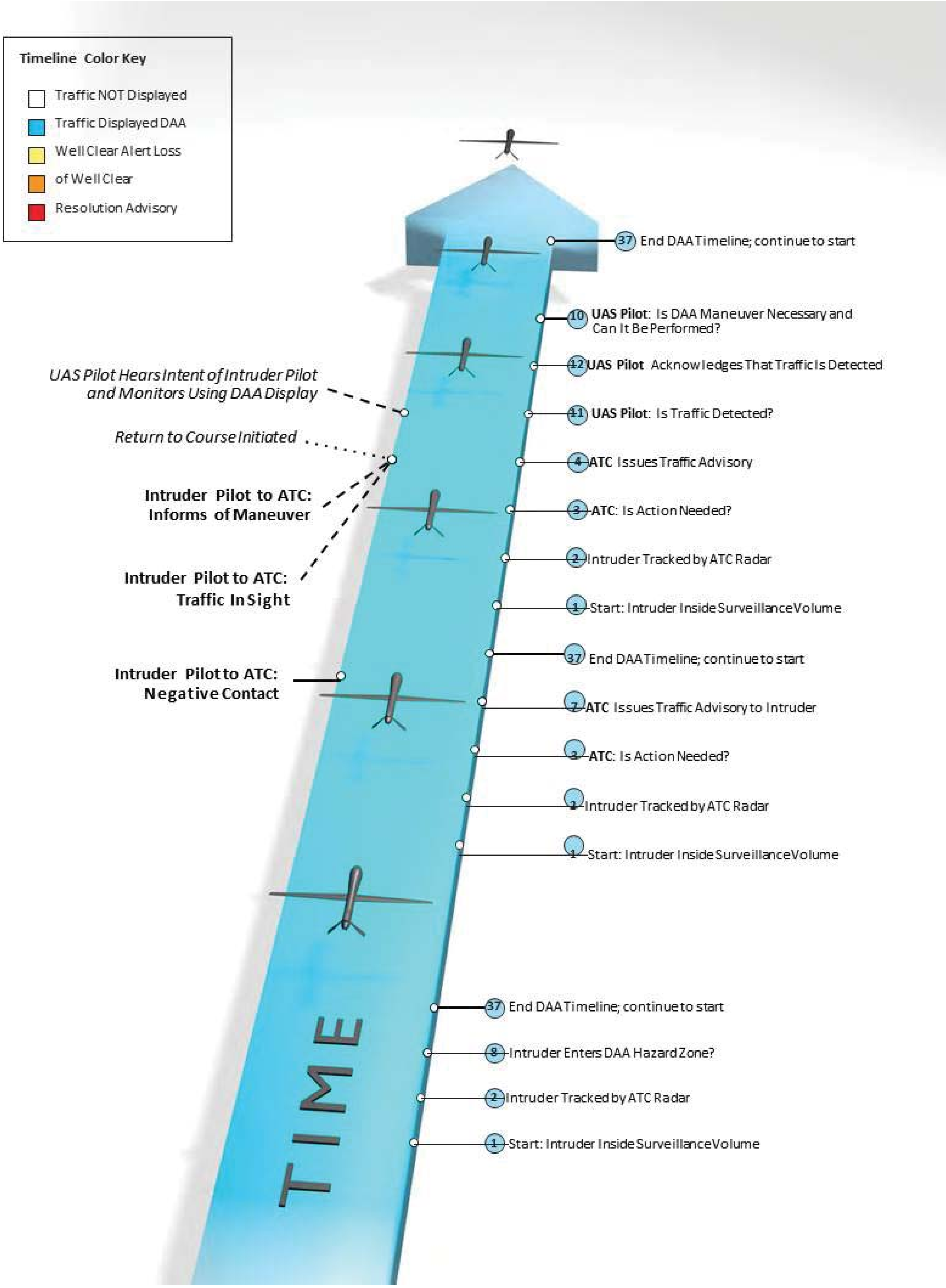


Figure A-34 **Scenario A.5.11 – Timeline for Controller Instructs Intruder**

A.5.12 UA Departing Class D with VFR Intruder

SCOOBY 2, a UA, is departing ABC airport, which is under the outer shelf of Class B airspace, as depicted in Figure A-35 and Figure A-36. ABC airport is within Class D airspace with a control tower. SCOOBY 2 is on an IFR flight plan and is communicating with ATC via voice communications, consistent with the “Vertical Transit” or “Loiter for Surveillance” scenarios in the FAA UAS CONOPS.

SCOOBY 2 departs Runway (RWY) 36 climbing to 3000’ on the runway heading. The aircraft is then given a frequency change to the radar departure controller, while still in the Class D airspace. SCOOBY 2 is radar identified by ATC, instructed to maintain 3000’, and instructed to continue on the Standard Instrument Departure (SID) previously issued by the tower controller. The SID instructs aircraft to begin a right turn southwest-bound to the next fix when the aircraft is leaving 2000’. Leaving 2000’, SCOOBY 2 begins a right turn on course.

As SCOOBY 2 begins the turn, the PIC receives a DAA preventive alert on the display. Traffic is ahead and to the right at 2500’ and the traffic display indicates a possible loss of DWC. The PIC queries ATC about the traffic and is told to stand by. The radar controller calls the tower and inquires about the traffic. Radar is advised the traffic is VFR, will remain at or below 2500’ and that the traffic has the UA in sight.

ATC then advises SCOOBY 2 of the VFR aircraft’s altitude restriction and visual acquisition. SCOOBY 2 acknowledges with “Traffic detected,” and levels at 3000’. No maneuver is made to further avoid the traffic. SCOOBY 2 passes within 5000’ horizontally and 500’ vertically. The DAA preventive alert then clears.

After clearing other IFR traffic in the vicinity, SCOOBY 2 is issued a higher altitude and climbs on course.

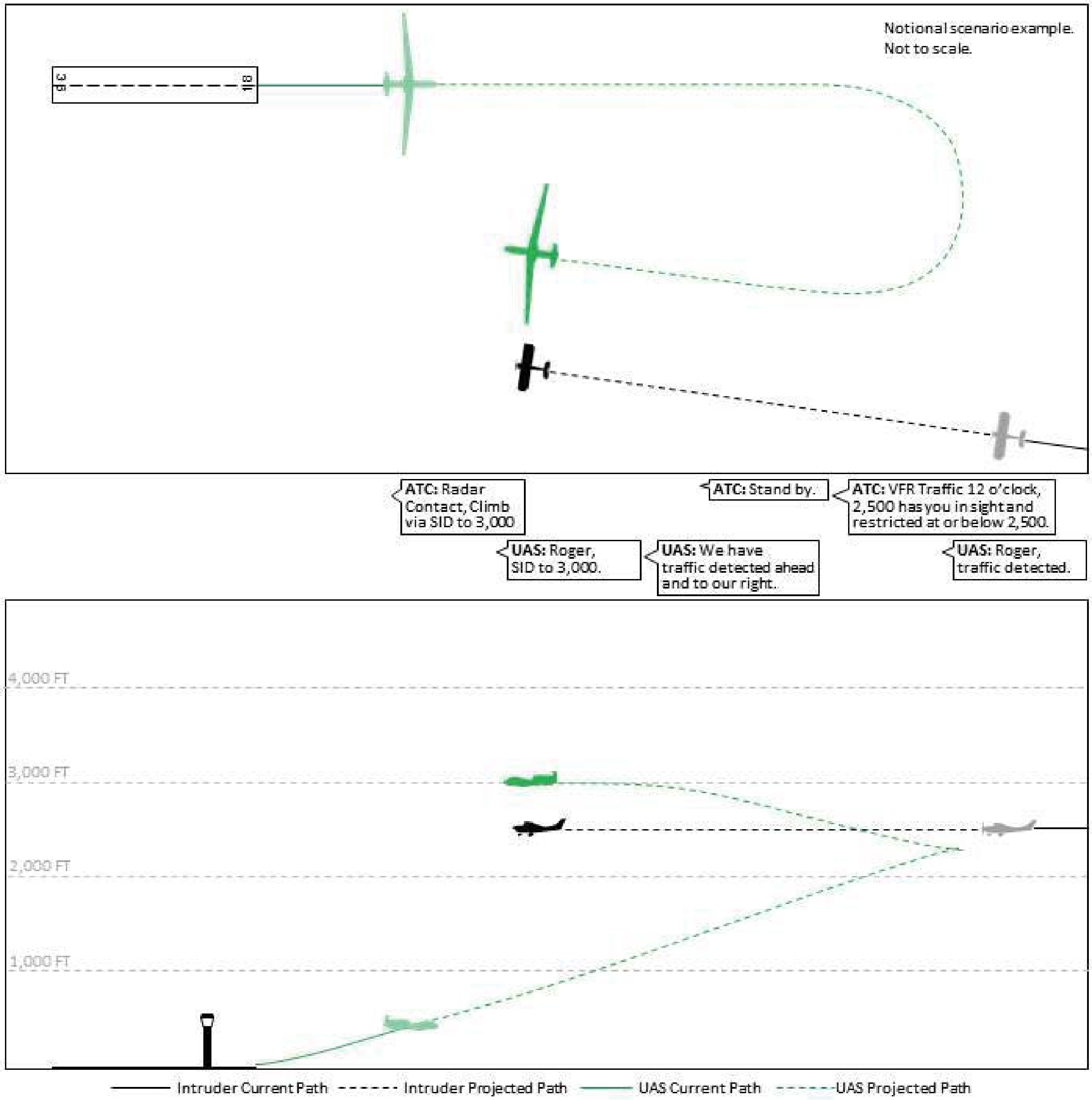


Figure A-35 **Scenario A.5.12 – UA Departs Class D with VFR Intruder**

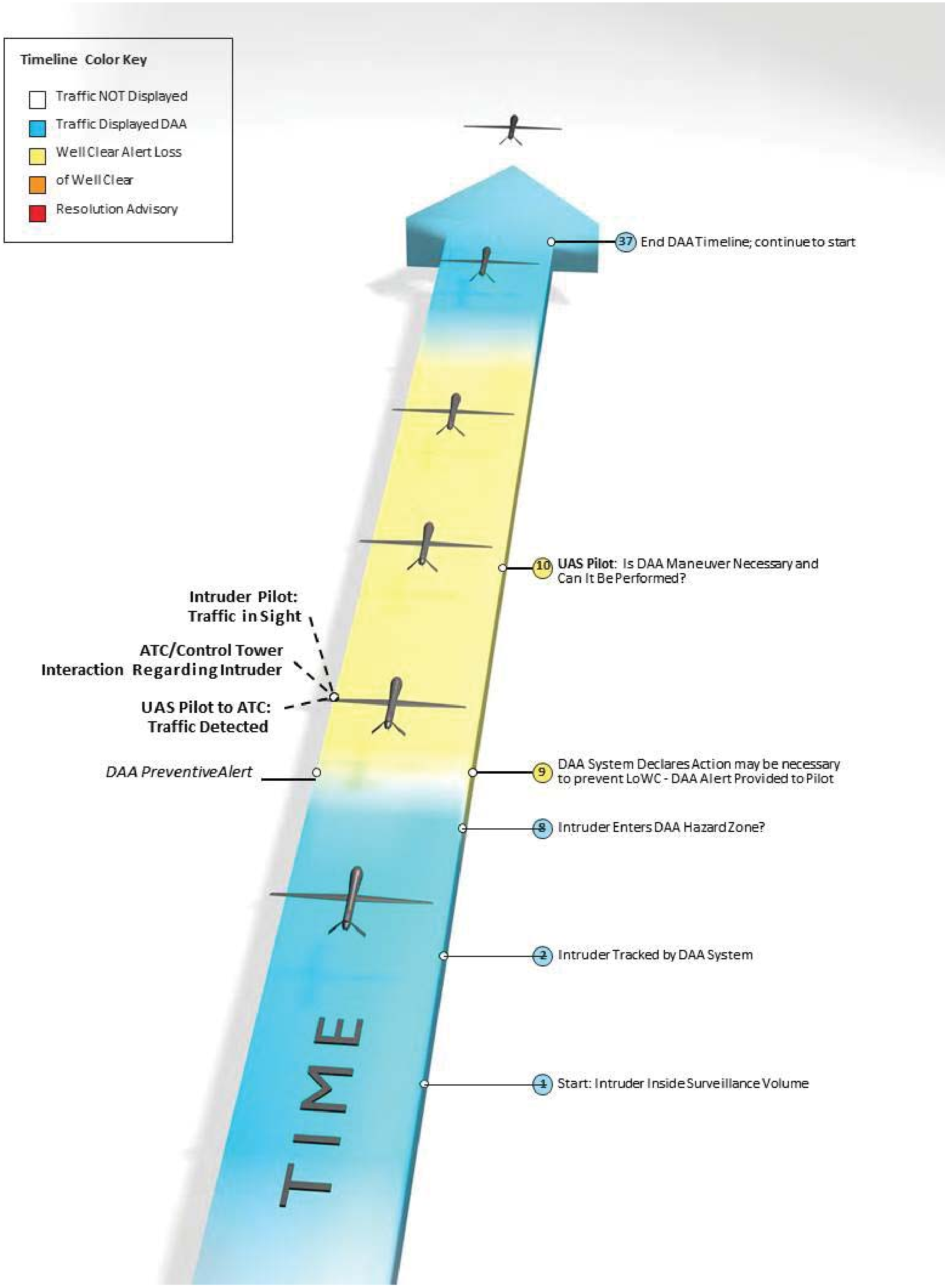


Figure A-36 **Scenario A.5.12 – Timeline for UA Departs Class D with VFR Intruder**

A.5.13 UA Arrival with GPS Approach in Class D with VFR Intruder

TOPCAT 1, a UA, is an IFR arrival to XYZ airport, which is under the outer shelf of Class B airspace, as depicted in Figure A-37 and Figure A-38. XYZ airport is within Class D airspace with a control tower. TOPCAT 1 is on an IFR flight plan and is communicating with ATC via voice communications, consistent with the “Vertical Transit” or “Loiter for Surveillance” scenarios in the FAA UAS CONOPS.

TOPCAT 1 is working with Approach Control and is on a vector for a GPS RWY 18 approach to XYZ. TOPCAT 1 is on a heading of 360° for a left downwind entry and is level at 4000’. As TOPCAT 1 passes the airport, ATC points out the UA to the tower. ATC then issues an altitude of 2300’, and TOPCAT 1 descends into the Class D airspace. TOPCAT 1 is then vectored to the final approach course and cleared for the approach. Following the clearance, TOPCAT 1 is instructed to contact the tower.

TOPCAT 1 has just turned an eight-mile final when he/she calls the tower. A few moments later, the TOPCAT 1 PIC observes unknown traffic on the display as a corrective alert maneuvering near the final approach fix 3 NM ahead. The display indicates the traffic is at 2500’, within a half mile of course, and that a maneuver is required to maintain DWC. TOPCAT 1 advises the tower that unknown traffic has been detected straight ahead and a maneuver may be needed to avoid it.

The tower instructs TOPCAT 1 to continue the approach and that the VFR traffic will be moved to remain clear of TOPCAT 1’s final. Following an exchange of traffic information, the VFR aircraft turns westbound away from TOPCAT 1’s final and is no longer predicted to cross the DWC boundary, so the corrective alert clears. TOPCAT 1 passes the traffic at nearly the same altitude with 4500’ horizontal separation.

TOPCAT 1 continues the approach and lands.

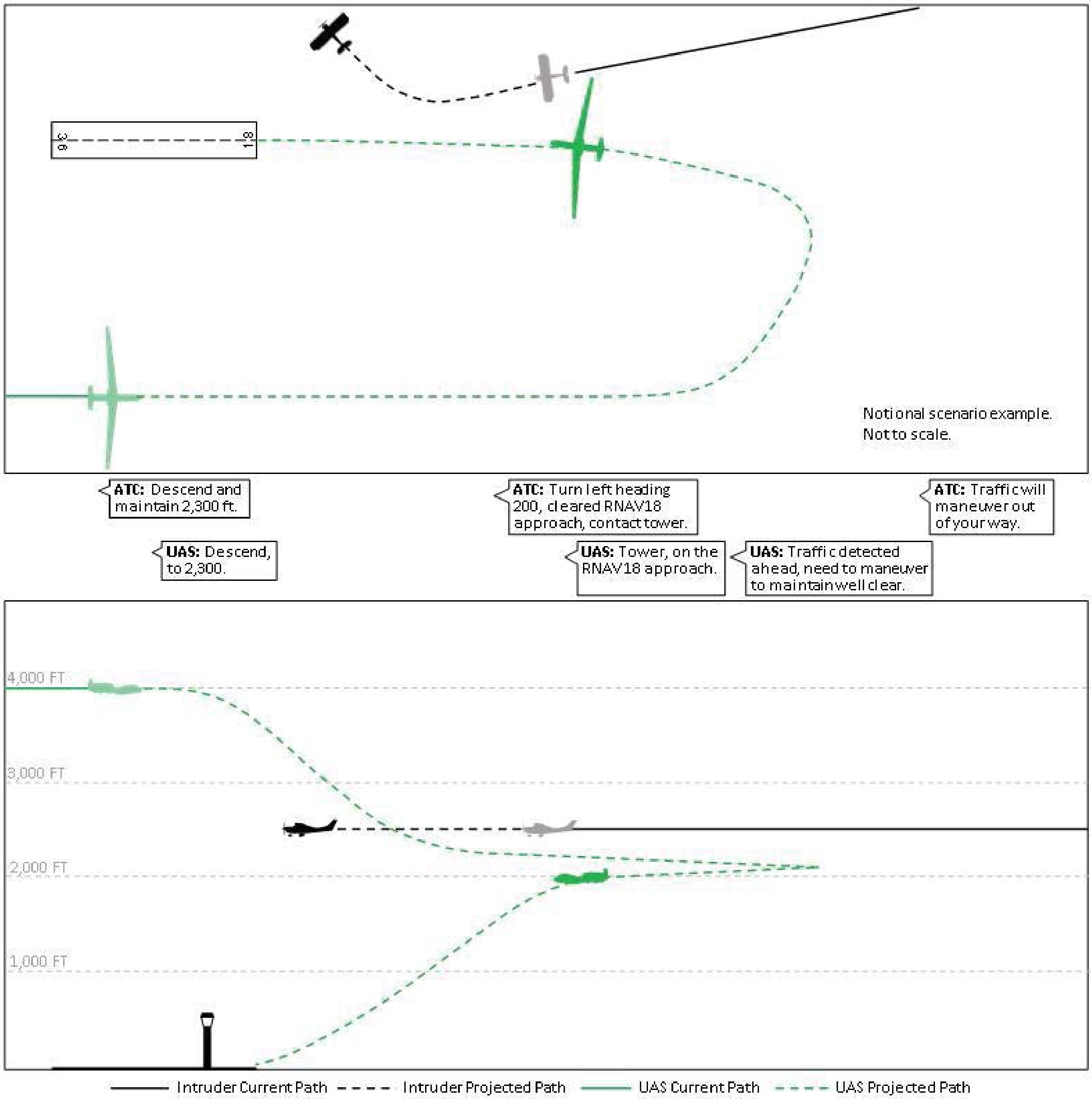


Figure A-37 **Scenario A.5.13 – UA Arrival with GPS Approach in Class D with VFR Intruder**

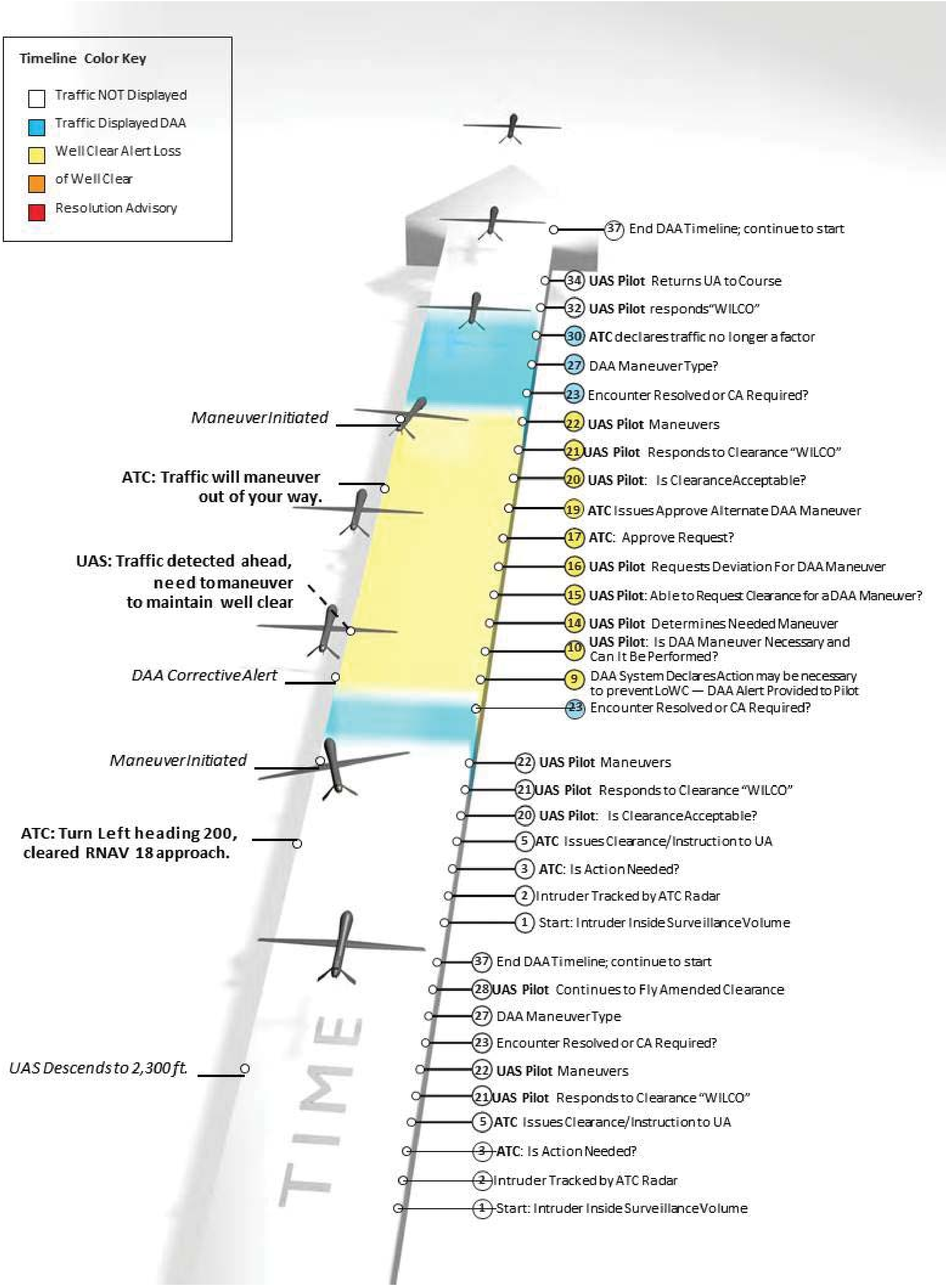


Figure A-38 Scenario A.5.13 – Timeline for UA GPS Approach in Class D with VFR Intruder

A.5.14 Intruder Visually Separates from UA

SABRE41, a civil commercial UA (Global Hawk), is on an IFR flight plan and is communicating with ATC via voice communications, consistent with the "Vertical Transit" or "Loiter for Surveillance" scenarios in the FAA UAS CONOPS. SABRE41 is an IFR arrival to XYZ airport, a civil/military joint use facility, as shown in Figure A-39 and Figure A-40. XYZ lies within Class C airspace and has an operational control tower. ABC Approach is providing radar ATC services to SABRE 41.

SABRE41 is west-northwest of XYZ airport and proceeding eastbound direct to the BUCKY intersection, the IAF for the RNAV GPS RWY 24 approach. SABRE 41 is level at 8000' in VMC. At this time, DAISY85, a flight of two F15s, is departing XYZ westbound on an IFR flight plan. DAISY85 checks in with ABC Departure Control and is issued a clearance to climb to 5000' and a right turn heading 300°, vectors on course.

ABC Approach descends SABRE41 to 6000', on course to the BUCKY Intersection. The ABC controller then issues traffic to SABRE41: "Traffic one o'clock, one-zero miles, opposite direction, flight of two F15s at five thousand." The PIC of SABRE41 advises "Negative contact." The ABC controller then initiates another traffic call: "DAISY85, traffic eleven o'clock, eight miles, opposite direction, a Global Hawk out of eight thousand for six thousand." DAISY85 advises "Looking for traffic." A moment later, DAISY85 reports the UA in sight, and requests a climb.

The controller then advises: "SABRE41, traffic twelve o'clock, four miles, northwest bound, flight of two F15s have you in sight and will climb off your left side." SABRE41 now observes the traffic on the DAA display and reports "Traffic detected." The controller then instructs DAISY85: "Maintain visual separation from the Global Hawk, climb and maintain one-one thousand." DAISY85 acknowledges the clearance and begins a climb.

DAISY85 climbs off SABRE41's left side, passing within 2000' laterally (inside the quantitative DWC definition). SABRE41's DAA system issues a corrective alert as the F15s climb towards the UA, but the UAS PIC ignores the guidance since she knows the F15s are visually separating from the UA and are subjectively well clear.

Both flights then continue on their assigned routes.

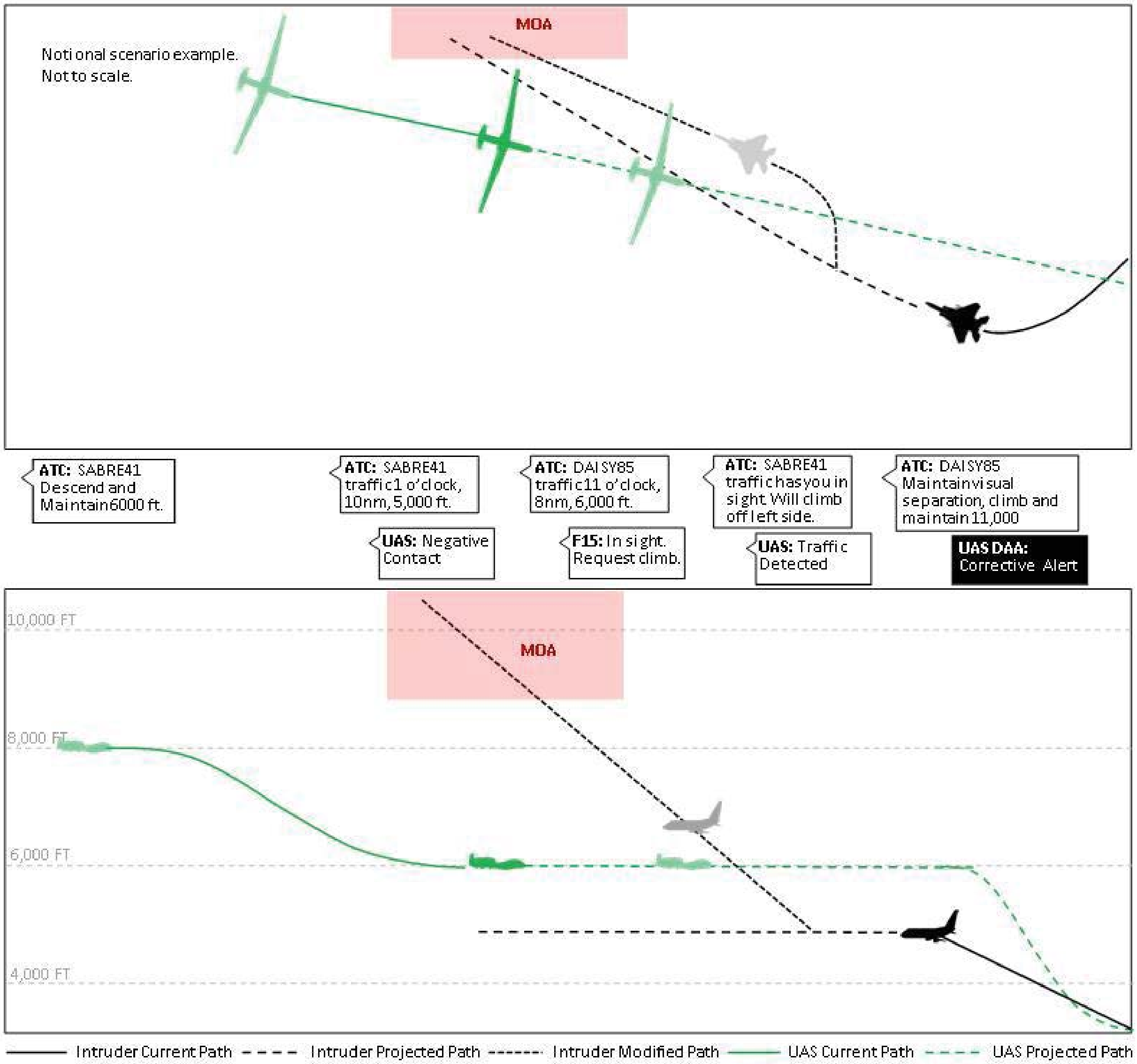


Figure A-39 **Scenario A.5.14 – Intruder Visually Separates from UA**

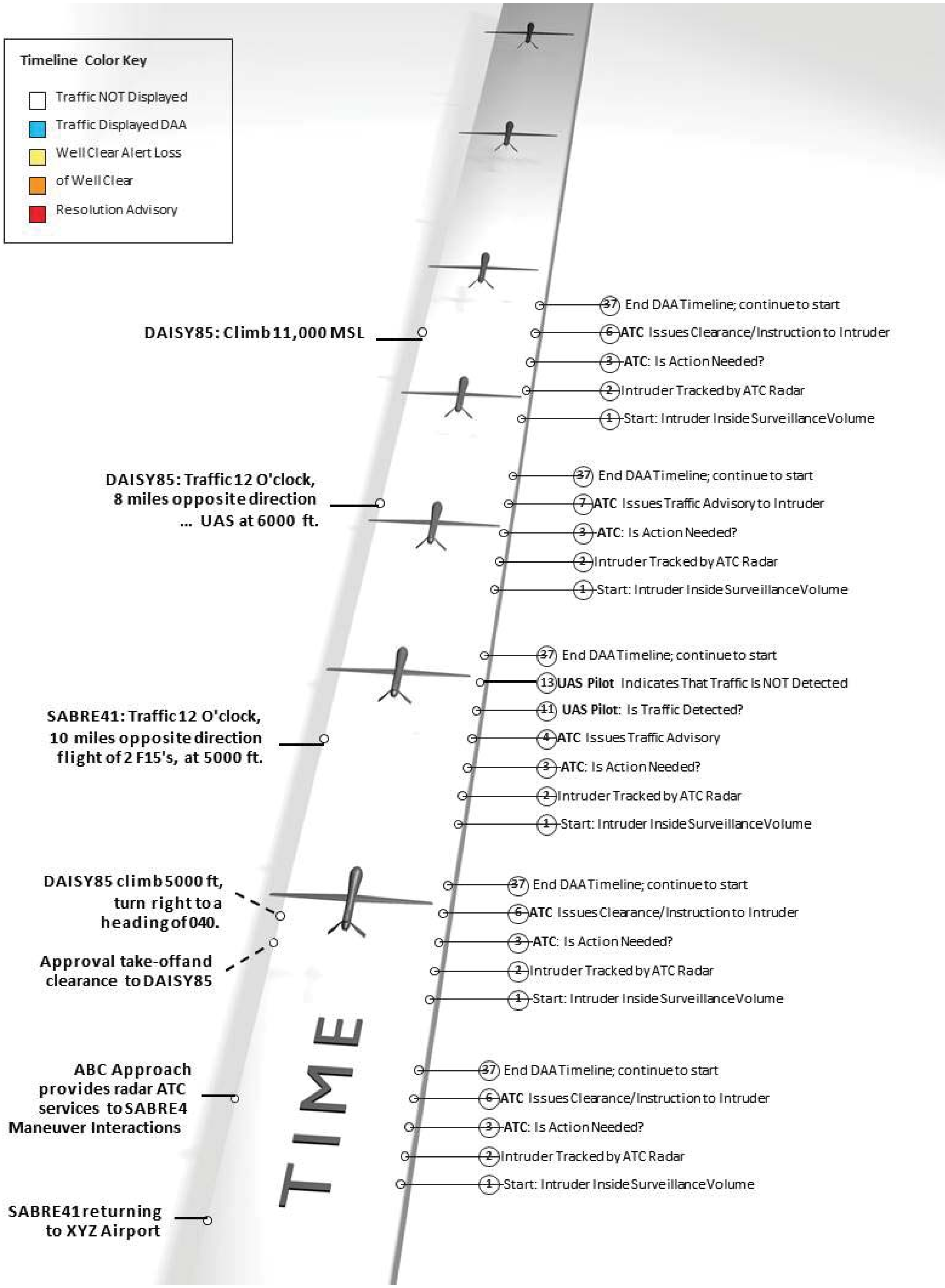


Figure A-40 Scenario A.5.14 – Timeline for Intruder Visually Separates from UA

A.6 Off-Nominal Scenarios

These off-nominal scenarios are ones that have a lower likelihood than the nominal scenarios, but are still expected to happen. They are not necessarily emergencies. The determination of an emergency condition is left up to the PIC and ATC.

Table A-6 Off-Nominal Scenario Breakdown

	Class 1 DAA System	Class 2 DAA System
Loss of Well Clear	DAA provides "regain well clear" alerting and guidance Scenario A.6.1, A.6.8	DAA provides Resolution Advisory; Pilot on the loop execution Scenario A.6.2
Loss of ATC Comm	UA Pilot will attempt to reestablish the communications link; UA will Squawk 7600; ATC will clear airspace around UA In the event of intruder, DAA Warning alert and guidance Scenario A.6.4; A.6.5	UA Pilot will attempt to reestablish the communications link; UA will Squawk 7600; ATC will clear airspace around UA In the event of intruder, DAA provides Resolution Advisory; Pilot on the loop execution Scenario A.6.2
Loss of CNPC Link	UA Pilot will attempt to reestablish CNPC link; UA will Squawk 7400; ATC will clear airspace around UA In the event of intruder, DAA will have no functionality Scenario A.6.3, A.6.5	UA Pilot will attempt to reestablish CNPC link; UA will Squawk 7400; ATC will clear airspace around UA In the event of intruder, DAA automatically executes Resolution Advisory Scenario A.6.7
Loss of DAA	UA Pilot will Inform ATC of DAA Failure; ATC will clear airspace around UA In the event of intruder, DAA will have no functionality; however, ATC can provide UAS PIC (or intruder) with vectors where able Scenario A.6.6	

A.6.1 UA Encounters VFR Traffic and Maneuvers Prior to ATC Approval

NASA 21, a UA, is transitioning through Class E airspace on an IFR flight plan and is communicating with ATC via voice communications, consistent with the "Vertical Transit" or "Loiter for Surveillance" scenarios in the FAA UAS CONOPS. A VFR single-engine airplane (the intruder) begins to close on the UA, as depicted in Figure A-41 and Figure A-42. The controller does not provide a Traffic Advisory (FAA JO 7110.65W §2-1-21) because of workload, frequency congestion, or the intruder is not displayed on the ATC radar display (e.g., non-cooperative traffic).

The UAS DAA equipment declares that the intruder is a DAA corrective alert because it will imminently cross the UA's well-clear boundary.[51] The UAS PIC observes the intruder on the DAA traffic display and determines if a maneuver is necessary and the timeframe in which the maneuver must be performed.

At some point after the declaration, the intruder turns to a DAA warning alert and the UAS PIC decides that a maneuver is necessary and there is insufficient time to request a maneuver from ATC. (The UAS PIC coordinating with ATC prior to maneuvering is covered by Scenario A.5.3.) This decision to maneuver without ATC coordination first is based on a number of factors, including:

- Inability to communicate with ATC due to frequency congestion or controller handoff at a sector boundary
- No communication with ATC
- Operations in uncontrolled (Class G) airspace
- Encounter geometry
- Aircraft speeds
- A late-detected intruder that is about to or has already crossed the UA's well-clear boundary ("Late-detected intruders" are those that, due to surveillance limitations, are not detected at the edge of the normal surveillance volume), and/or
- UAS PIC workload.

Note: *UAs equipped with Class 1 DAA will provide DAA maneuver guidance to maintain DWC of all intruders and will continue to provide DAA maneuver guidance when the intruder passes the DAA Well Clear boundary, in an attempt to regain DWC. UAs equipped with Class 2 DAA will provide an RA against altitude transponding intruders and will provide DAA maneuver guidance to maintain DWC of all others.*

The UAS PIC then maneuvers to maintain DWC of the intruder traffic. The choice of maneuver (right/left turn, climb/descent, speed change, or a combination) would be dependent on the geometry, aircraft performance, and right-of-way rules. As pilot workload permits and as soon as practical, the UAS PIC informs ATC of the maneuver; for example, "Grand Forks Approach, NASA 21 just turned right to avoid traffic; now

[51] Based on initial NASA Part Task 4 results, the nominal DAA alert time before DWC is expected to be somewhere in the range of 50-70 seconds.

returning to course" or "Boston Center, HAWK 37 is climbing to avoid traffic." ATC may issue alternate instructions, for example changing the assigned altitude, issuing a vector, or clearing the UA to a different waypoint, or ATC may just acknowledge the pilot's report. The PIC maneuvers the UA until the encounter is resolved then proceeds per the last ATC clearance or instruction received.

The maneuver prior to communication with ATC in this scenario is based on the UAS PIC's responsibilities and actions under 14 CFR §91.113 and §91.181. The UAS PIC is responsible for avoiding other aircraft and following right-of-way rules per §91.113 and §91.181, which allow the UAS PIC to maneuver to maintain DWC of other aircraft without additional ATC authorization. While UAS PICs will attempt to coordinate with ATC prior to a maneuver (Scenario A.5.3), this may not always occur prior to the need for the UAS PIC to maneuver the UA.

The ATC interaction for this scenario is the same as for manned aircraft. The only difference is that the UAS PIC is authorized to maneuver based on the DAA traffic display if ATC coordination cannot be achieved. Manned aircraft pilots cannot maneuver based on a traffic display alone with any CDTI applications developed to date. There is nothing inherent in manned operations that would preclude such an application in the future, but manned aircraft pilots can maneuver based on visual acquisition if ATC coordination cannot be achieved.[52]

[52] Future ADS-B In applications may allow aircraft to maneuver based solely on a traffic display.

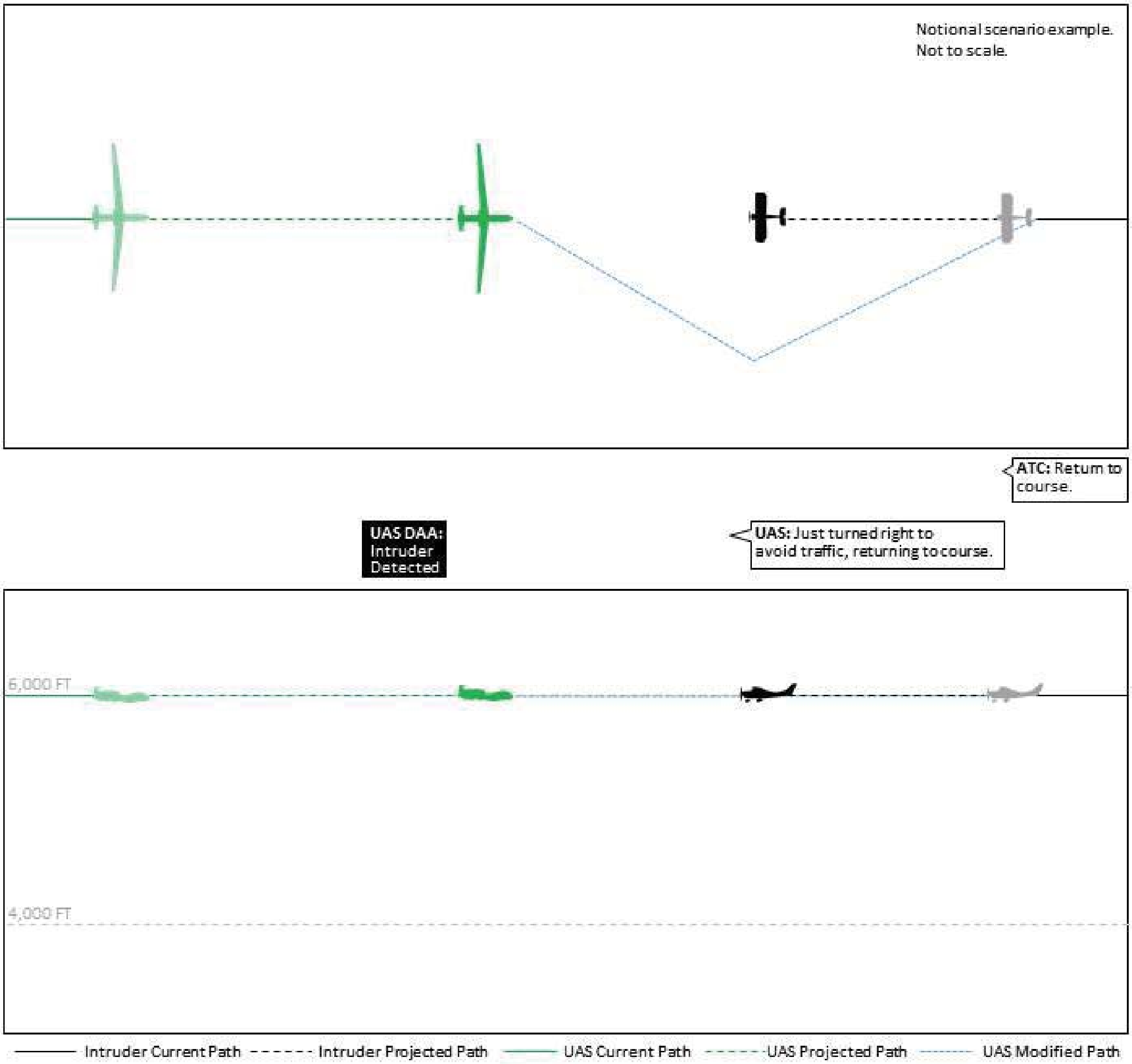


Figure A-41 **Scenario A.6.1 – UA Maneuvers against VFR Intruder before Contacting ATC**

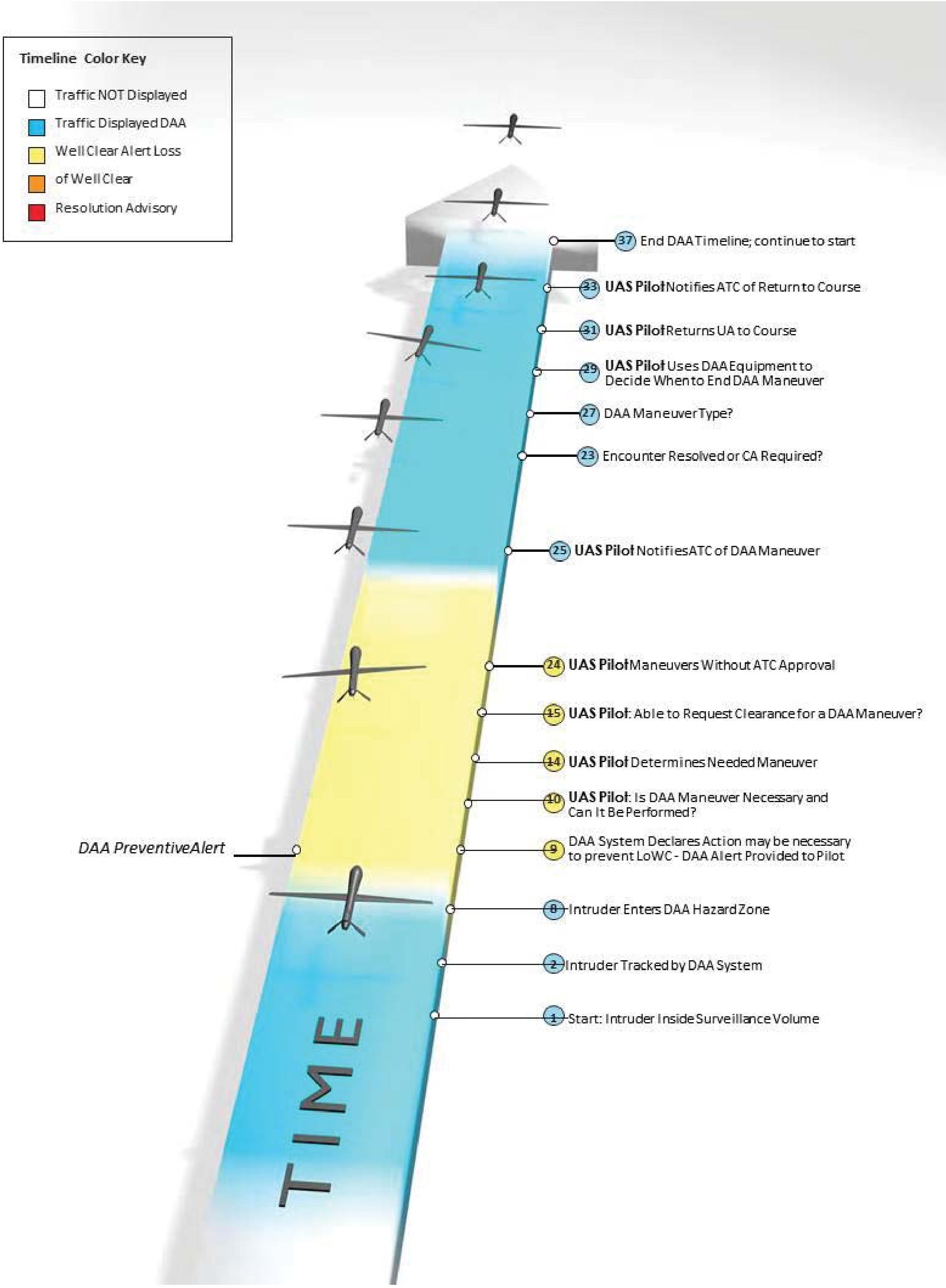


Figure A-42 **Scenario A.6.1 – Timeline for UA Maneuvers Prior to ATC Approval**

A.6.2 TCAS II RA

Unmanned aircraft operating in Class E and G airspace may encounter conflicting traffic that may quickly develop into an imminent collision threat. The Class 2 DAA system will include a TCAS II to improve safety in this event.[53] However, it is important to recognize the intended function of TCAS II is collision avoidance, not maintaining well clear of other aircraft.

A UA is flying level at 8,000' through Class E airspace when the Class 2 DAA system tracks an intruder with a predicted loss of DWC and initiates a corrective alert. The intruder is in front and to the right of the UA and descending, as depicted in Figure A-43 and Figure A-44. The PIC requests from ATC an amended clearance to maneuver to maintain DWC, for example, "Traffic detected, two o'clock, request right turn." ATC responds, "Stand by."

Due to some geometries, the situation may quickly change to one where the TCAS II system issues an RA such as, "Climb, Climb." When a UA is equipped with the Class 2 DAA system, the UAS PIC will execute the TCAS RA in accordance with TCAS II procedures and design, in this example, by climbing. TCAS coordination will be conducted if the intruder is also equipped with TCAS RA functionality. Automatic execution of the RA by onboard systems may be performed. RAs issued as part of the TCAS II system will take precedence over ATC instructions; authority to execute the RA is authorized in accordance with 14 CFR §91.123. Under the Phase 1 MOPS there are no provisions for a new collision avoidance function unique to DAA systems. The Phase 1 MOPS will only include requirements for the Class 2 DAA system which integrates the TCAS II avoidance systems.

The PIC's DAA decision aids will indicate the RA for PIC commands or notify the PIC of activation of the automated RA maneuver when it occurs (if equipped). Prior to the RA, the UAS PIC should have been made aware of the traffic as being an DWC alert. In most cases, the UAS PIC will have discussed the developing conflict with ATC, and presumably the encounter did not pose a conflict, or the conflict has evolved differently than expected (e.g., the intruder suddenly maneuvers). In the case where ATC is in communications with the conflicting traffic, the controller may inform the UAS PIC of the opposing traffic's intent.

The UAS PIC will follow RA guidance over ATC instructions due to the explicitly coordinated nature of TCAS-compatible RAs, unless overridden by the PIC. As with TCAS operations on manned aircraft, the UAS PIC will inform ATC of the RA as soon as practical, e.g., "TCAS climb." DAA RA guidance may be executed automatically in normal link operations, with UAS PIC override authority. Automatic execution of a RA may be needed due to latencies inherent in having the UAS PIC geographically separated from his or her aircraft. The Class 2 DAA system may optionally enable automatic execution of RA maneuvers when the UAS PIC cannot command the UA due to a lost CNPC data link (see Scenario A.6.7).

[53] Studies are underway to determine the suitability of TCAS II on UAS. Only air vehicles deemed suitable will be equipped with TCAS II.

After the TCAS "Clear of Conflict" indication, the PIC will continue on course and return to assigned altitude unless otherwise instructed by ATC. In the depicted scenario, ATC instructs the UAS PIC to climb and maintain 10,000'.

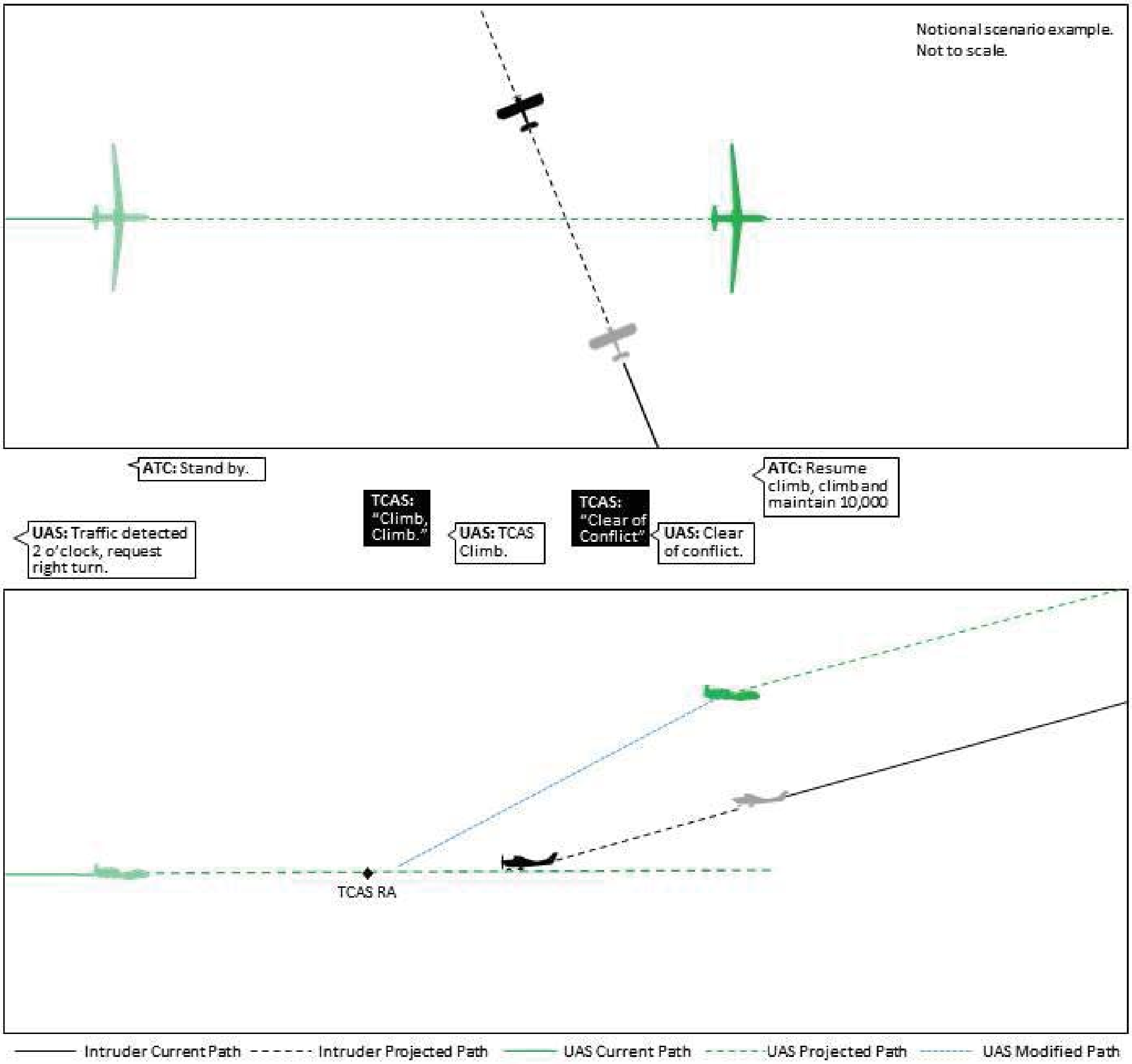


Figure A-43 **Scenario A.6.2 – TCAS II RA Scenario**

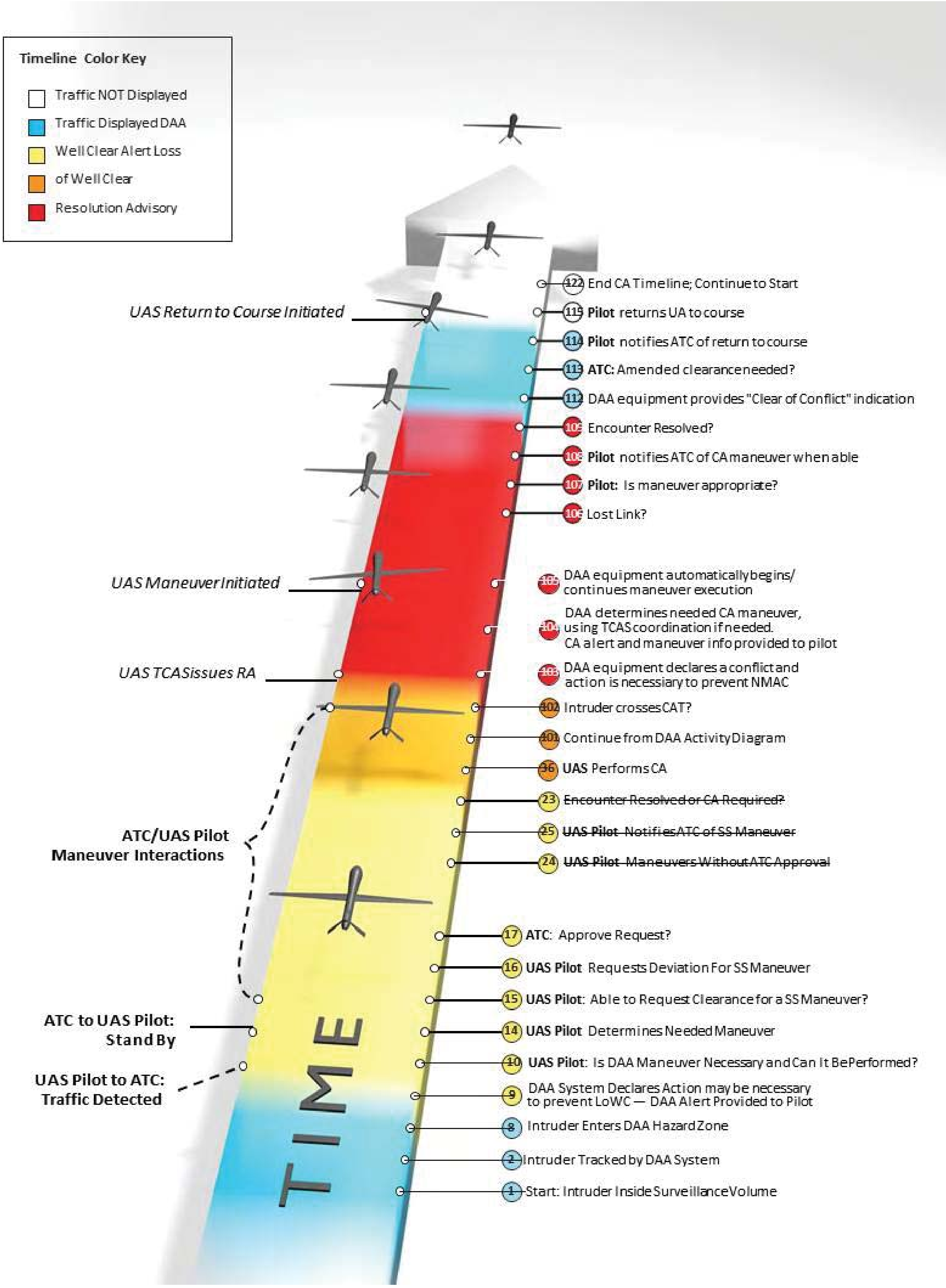


Figure A-44 Scenario A.6.2 – Timeline for TCAS II RA Scenario

A.6.3 PIC Loses CNPC Link with UA

Loss of CNPC data link means the PIC has no active control over the UA flight.

The UA will execute its pre-programmed lost-link protocol after a predetermined length of time when the CNPC data link is lost; the protocol is assumed to be predictable and well behaved. The lost-link protocol typically includes automatically setting the beacon code to a code to indicate a lost link. An alternate communication method with ATC will be pre-arranged if needed. This scenario is agnostic of what type of ATC communication is used when the CNPC data link is operable and inoperable (direct VHF/UHF voice, voice relay, or land line voice) Standardizing lost-link behavior across all UAS is outside the scope of this DAA MOPS.

When the CNPC data link is re-established, the PIC would return the beacon code to the original assigned code.

For this scenario, the UAS does not automatically execute DWC maneuver guidance. Automatic execution of TCAS II RAs is considered optional functionality and is addressed in Scenario A.6.7.

A UA, Predator 567HK, is transiting through Class E airspace on an IFR flight plan at 8,000', consistent with the "Vertical Transit" or "Loiter for Surveillance" scenarios in the FAA UAS CONOPS.

While enroute, the UAS PIC monitors the health and status of the UAS, including the status of the CNPC data link and DAA systems. As the UA continues along its flight plan, the UAS PIC may need to update the UA's lost-link programmed procedure.

At a point along the route, the UA loses its CNPC data link (and any secondary CNPC data links) , as shown in Figure A-45 and Figure A-46. The PIC will have an indication that the link has been lost and will start following the lost-link checklist, which includes normal attempts to regain the link. After following the lost-link checklist, the UAS PIC is unsuccessful at re-establishing the CNPC data link, and the PIC notifies ATC of the current condition (possibly via an alternate means such as a landline): "Albuquerque Center, Predator 567HK, experiencing CNPC link failure."

Logic onboard the UA also recognizes the loss of the CNPC data link and begins executing lost-link protocols, including setting the beacon code to the lost-link code. The En Route ATC controller recognizes the potential emergency condition when he/she sees the change of UAS beacon code. ATC responds via the alternate means, "Predator 567HK, Center, I show you squawking seven-four-zero-zero, level at eight thousand, do you need to declare an emergency?"

The controller assesses the immediate threat to any other traffic; no immediate conflicts exist at this time.

Continued attempts by the UAS PIC to regain CNPC data link are unsuccessful: "Albuquerque, 567HK, I have an emergency, loss of control link, aircraft is 22 miles due west of Los Alamos, eight thousand feet, level, heading three-five-zero; aircraft will continue twelve miles before turning right to lost-link hold point."

The deceleration of an emergency or not for lost link will be based on PIC and ATC judgment and procedures. ATC will provide separation from IFR aircraft along the confirmed route, and normal separation minima and advisory services to cooperating VFR aircraft.

A single-engine airplane (the intruder) flying VFR at 7500’ begins to converge on the UA from the rear. ATC advises the UAS PIC of the approaching traffic conflict and inquires if the PIC has possibly regained control of the UA: “Predator 567HK, Albuquerque Center, VFR traffic at one o’clock altitude unverified indicating 7500’. Have you regained control link?” The UAS PIC responds, “Albuquerque, 567HK, no contact, no control link with UA, proceeding to lost-link hold point.” ATC attempts to communicate with the intruder by broadcasting on 121.5 MHz and all frequencies available, but is unsuccessful. The intruder observes the UA and maintains altitude and passes with a CPA of 500’ vertical and 1000’ horizontal separation.

The UA enters a holding pattern at its designated lost-link location where it remains until the link is regained. After performing troubleshooting steps, the PIC regains control of the UA, checks downlinked health and status information, and contracts ATC; “Center, Predator 567HK, have control link with UA, request return to course.” ATC advises “567HK, approve return to course, squawk three-three-five-eight, maintain eight thousand, heading three-five-zero when able.” The UAS PIC changes the squawk code to 3358.

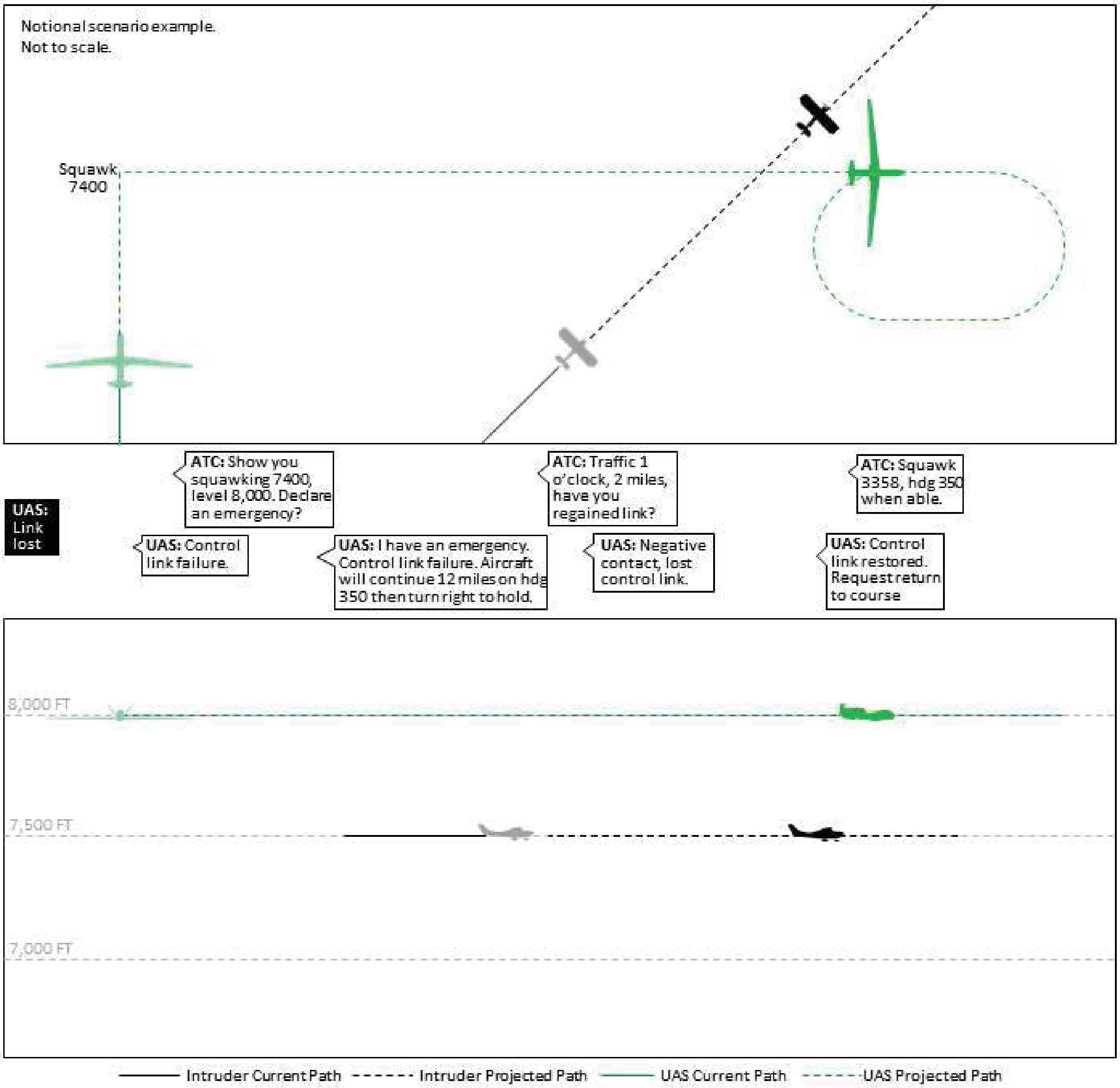


Figure A-45 Scenario A.6.3 – PIC Loses CNPC Link with UA

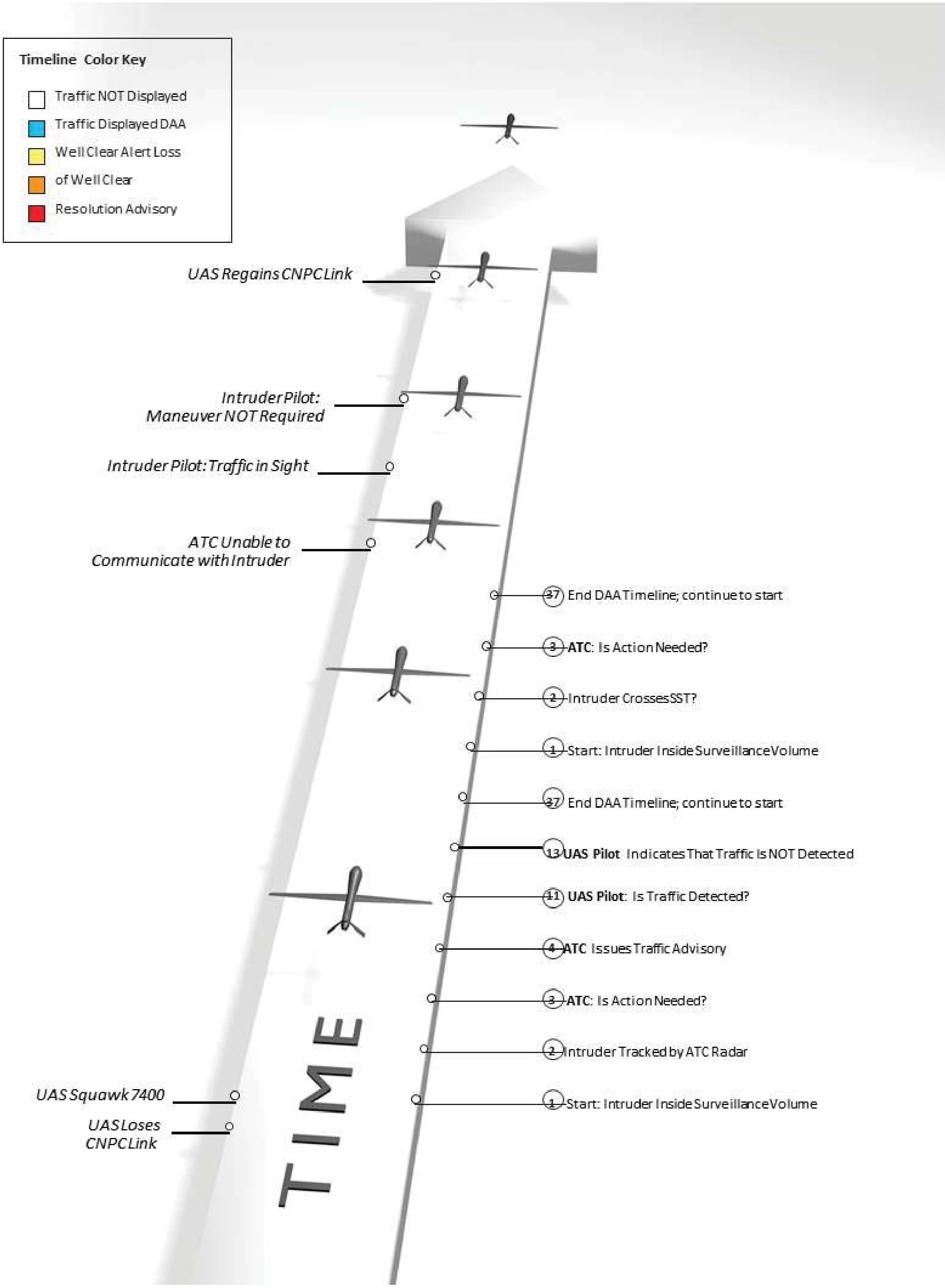


Figure A-46 **Scenario A.6.3 – Timeline for PIC Loses CNPC Link with UA**

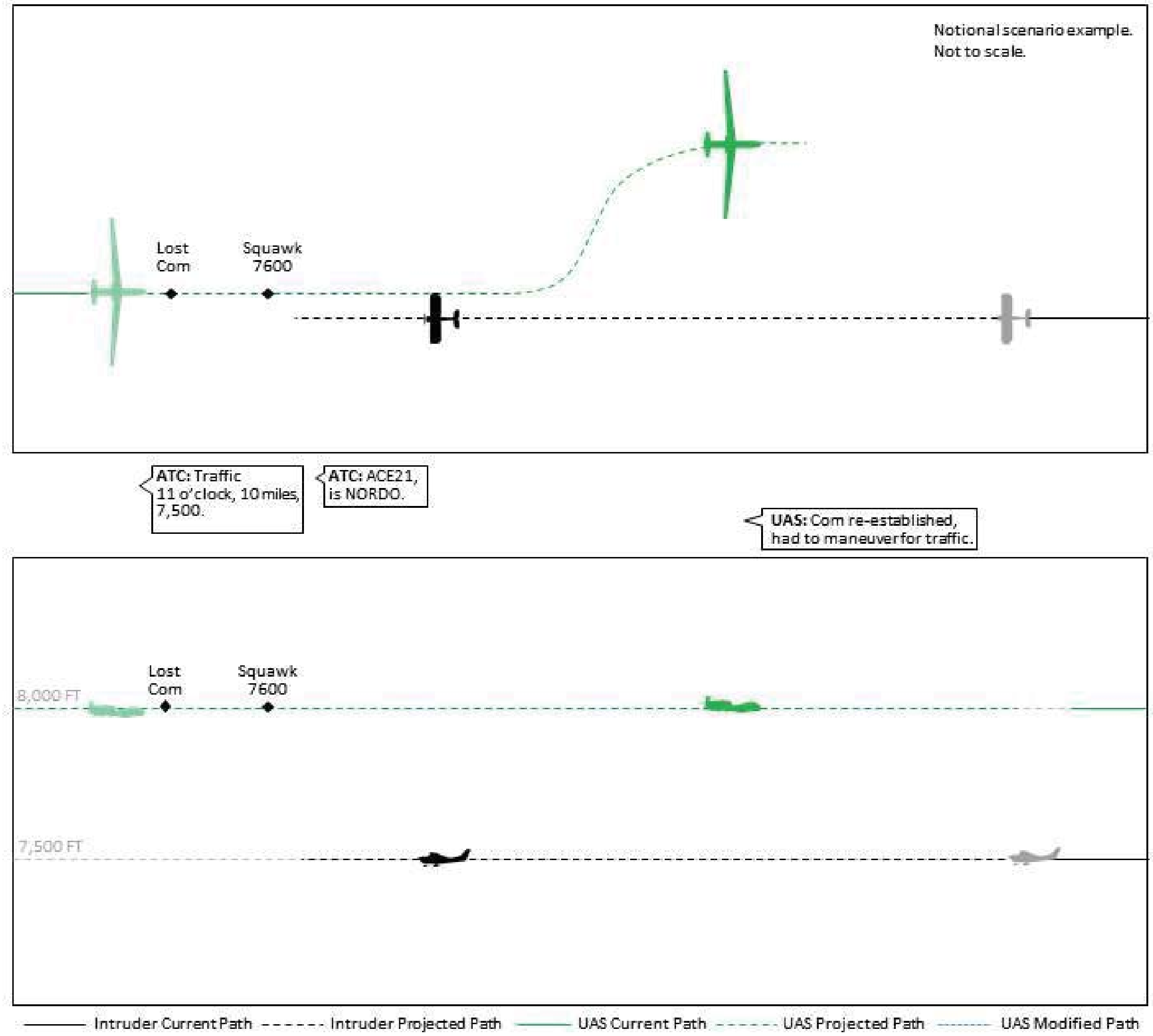
A.6.4 PIC Loses Communications with ATC (Lost ATC Comms but Not Lost CNPC Link)

ACE 21, a UA, is transitioning through Class E airspace on an IFR flight plan and is communicating with ATC via voice communications, consistent with the "Vertical Transit" or "Loiter for Surveillance" scenarios in the FAA UAS CONOPS.

ACE 21 is westbound at 8,000', as depicted in Figure A-47 and Figure A-48. During the flight, the PIC observes that he/she is no longer in communication with ATC and hears no other communications on the ATC frequency. A failure indication may be presented to the PIC if the fault is with the onboard radio. Assuming radio failure, and in accordance with directives and checklists, the PIC attempts various means of re-establishing communications. These actions include previous sector frequencies, Navigational Aid (NAVAID) voice, ATC emergency frequencies, and land-line communication. When these attempts fail, the PIC resets the aircraft's transponder to squawk 7600 (No Radio). The PIC then determines that the appropriate course of action is to continue on to his/her destination. At this time, the PIC observes on the DAA display that an intruder may be approaching.

During this time, ATC observes that ACE 21 has VFR traffic at eleven o'clock and 10 NM eastbound (opposite direction) at 7,500'. ATC calls out the traffic to ACE 21 but receives no acknowledgement. After a second unanswered call to ACE 21, ATC then attempts to communicate via other means such as the emergency frequencies, previous sectors, transponder, etc. ATC then observes ACE 21 squawking 7600. The sector controller then advises the Front Line Manager of the situation, as well as the next sector on the UAs' flight plan. The controller also flags the flight plan by placing NORDO-(No Radio) in the remarks section.

Traffic continues to close on ACE 21 and DAA issues a preventive alert. The UAS PIC observes the approaching traffic and determines that the UA may or may not maintain DWC due to the altitude separation near the UA's well-clear boundary. The PIC then receives a corrective alert. Approaching the UA's well-clear boundary, the UAS PIC initiates a right turn for traffic avoidance to provide an additional subjective buffer over the 450'vertical DWC definition. ACE 21 passes DWC on the left of the traffic at one mile horizontally and 500' vertically. After passing the traffic, ACE 21 returns to course. ATC observes ACE 21 maneuver around the traffic and concludes that the PIC still maintains control of the aircraft. At this time, the PIC is able to establish communications with the ATC facility (likely the ATC supervisor) via alternate means (e.g., landline telephone). The PIC advises that aircraft control was retained and that it was necessary to maneuver around traffic. ATC then continues services via the alternate communications method.



<u>Figure A-47</u> **Scenario A.6.4 – PIC Loses Communications with ATC**

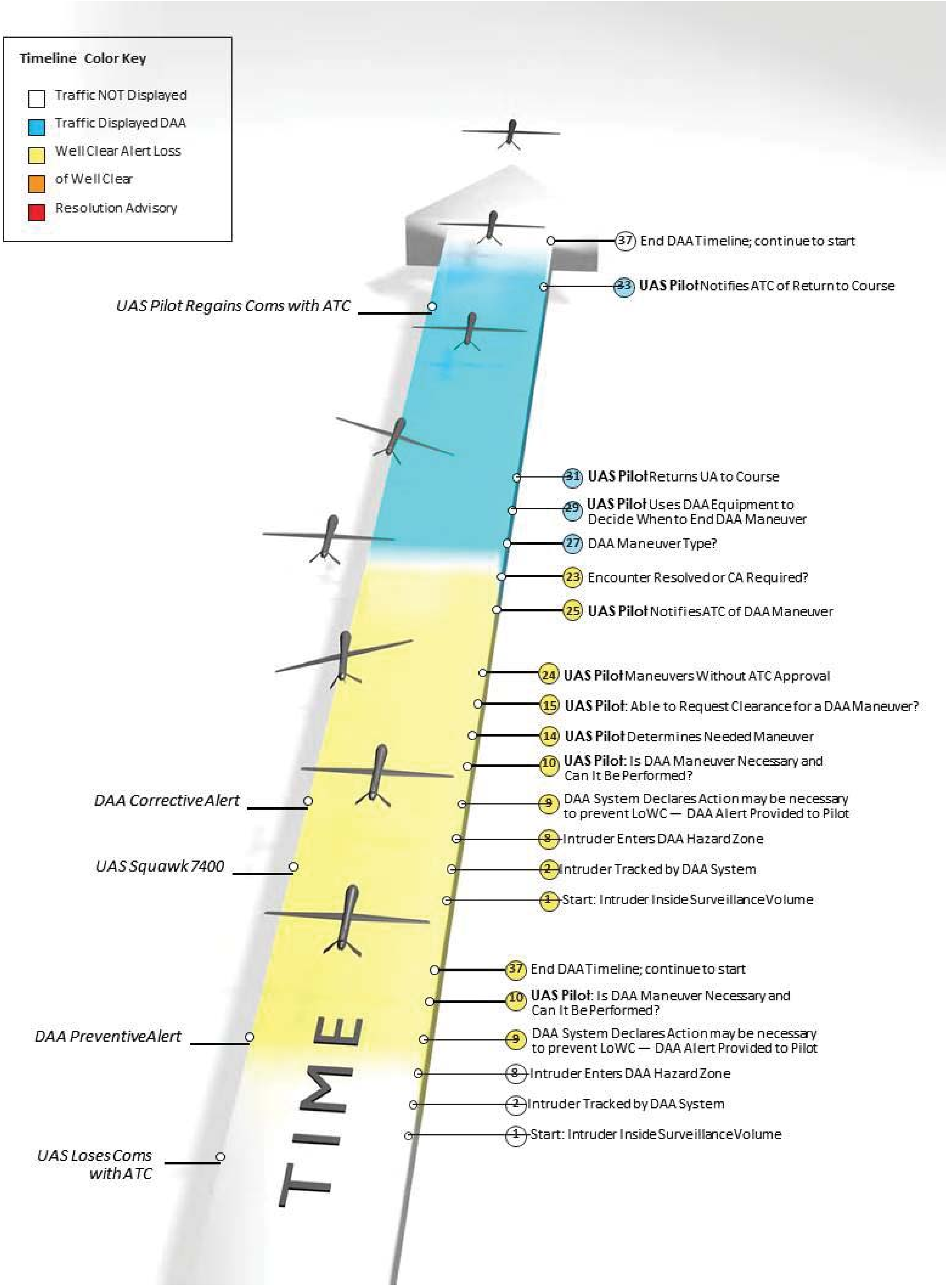


Figure A-48 Scenario A.6.4 – Timeline for PIC Loses Communications with ATC

A.6.5 PIC Can't Control the UA and Can't Communicate with ATC or the Intruder

A UA is transitioning through Class E airspace on an IFR flight plan and is communicating with ATC via voice communications, consistent with the "Vertical Transit" or "Loiter for Surveillance" scenarios in the FAA UAS CONOPS.

The UA experiences a lost CNPC link, as depicted in Figure A-49 and Figure A-50. The PIC notices that the CNPC link has been lost and starts following the lost-link checklist, which includes normal attempts to regain the link. The PIC's attempt to regain link is unsuccessful and the PIC attempts to notify ATC of the emergency condition. The PIC's attempt to communicate with ATC through the normal channel is unsuccessful due to the communications failure. The PIC attempts to communicate with ATC through a pre-planned alternate method, but establishing this link may take a few minutes.

Simultaneously, after a specified amount of time, the UAS automatically recognizes a loss of the CNPC data link and executes lost-link protocols, including automatically setting the beacon code to the lost-link code (e.g., 7400).

ATC recognizes the emergency condition and assesses the immediate threat of other traffic. ATC is unable to communicate with the UAS PIC to confirm UAS lost CNPC link.

The UA maintains altitude at 8000' per the pre-set lost-link protocol. The lost-link protocol will be known by the UAS PIC and ATC in advance (see **OR.9**).

ATC will provide separation from IFR aircraft along the pre-set but unconfirmed route, providing normal separation minima and advisory services to cooperating VFR aircraft.

A single-engine airplane (the intruder) flying VFR at 7500' is on a converging course with the UA.

ATC is unable to advise the UA of the approaching traffic conflict. ATC attempts to communicate with the intruder by broadcasting on 121.5 MHz and all frequencies available, but is unsuccessful. The intruder observes the UA and maintains altitude and passes the CPA with 500' vertical separation and abeam horizontal separation of 1000'. Both aircraft maintain well clear in this situation by following normal IFR/VFR altitude rules.

Eventually, the UAS PIC is able to establish communications with ATC through an alternate means (e.g., land-line telephone). The UAS PIC confirms with ATC the expected UA's lost-link procedure.

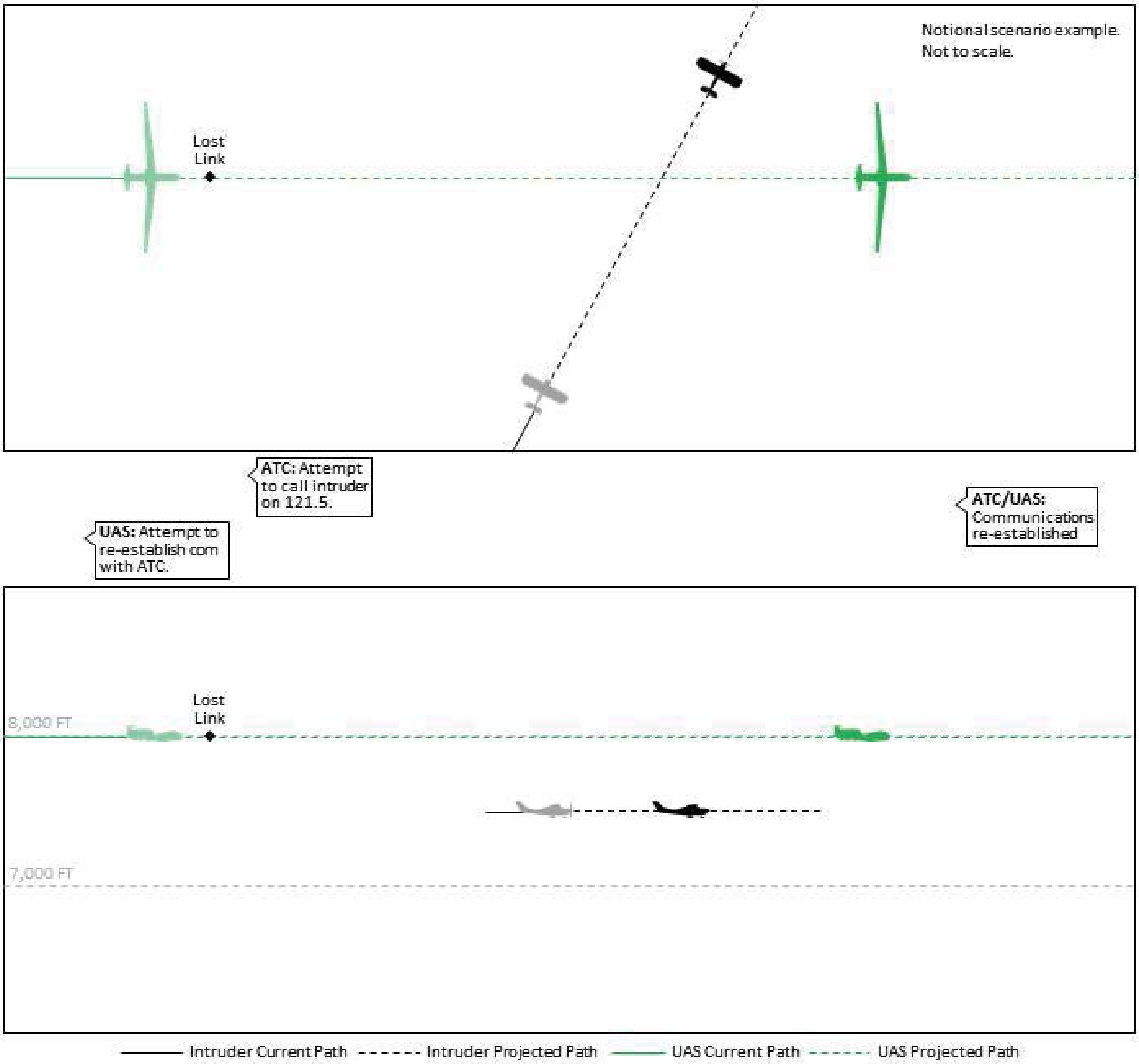


Figure A-49 **Scenario A.6.5 – PIC Can't Control UA and Lost ATC Comms**

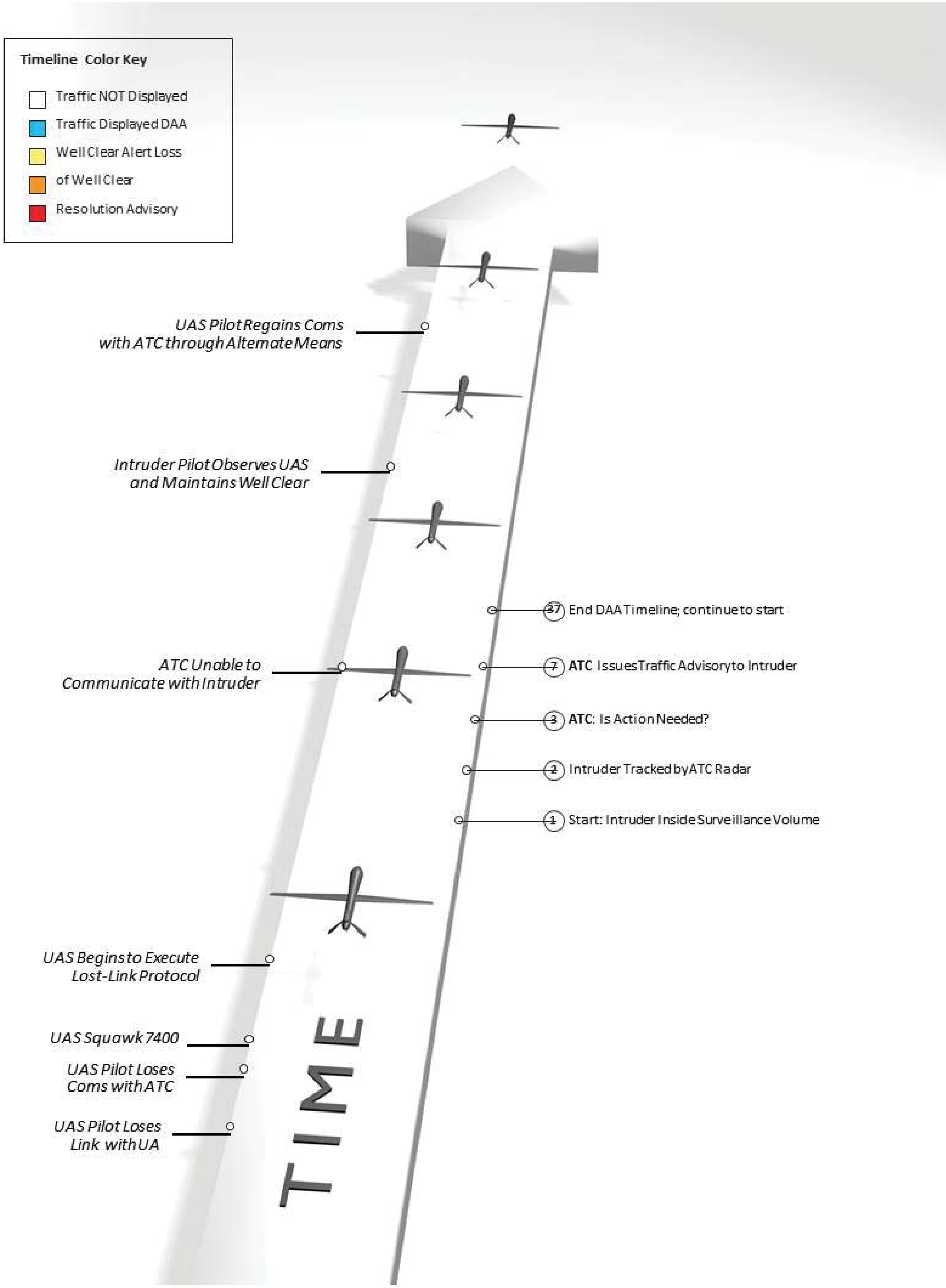


Figure A-50 **Scenario A.6.5 – Timeline for PIC Can't Control UA and Lost ATC Comms**

A.6.6 DAA Equipment Failure

This scenario addresses a complete DAA equipment failure as a worst case scenario; therefore degradations of the DAA system are not covered.

A UA is transitioning from Class A through Class E airspace on an IFR flight plan and is communicating with ATC via voice communications, consistent with the "Vertical Transit" or "Loiter for Surveillance" scenarios in the FAA UAS CONOPS. During this transition, there is a failure of the DAA system. A visual indication appears on the traffic display and there is an aural alert presented to the PIC that is uniquely associated with a DAA system failure, as shown in Figure A-51 and Figure A-52. The PIC also receives a message on the display indicating the type of failure that has occurred (e.g., loss of sensor, sensor overheat, loss of display, unknown).

The PIC acknowledges the failure with a clearly specified control action (e.g., mouse click, button press) and performs the initial DAA failure checklist steps.

The PIC then notifies ATC of the failure of the DAA system, when practical, per **OR.12**. ATC asks the PIC if he or she wishes to declare an emergency. The PIC will declare an emergency or not based on established procedures and the current situation (type of failure, airspace density, ability of ATC to provide separation, location of viable recovery point, etc.). The PIC will attempt to recover the DAA system and/or diagnose the failure more exactly by performing the full DAA failure checklist steps. Results from the checklist might lead the PIC to declare an emergency or not, and the PIC may request a destination change to an alternate or diversion airport.

After notifying ATC of the failure, ATC notifies the UAS PIC of the presence of a VFR intruder and provides vectors to maintain separation. The UAS PIC acknowledges and initiates these vectors. The UAS PIC also requests ATC to notify when it is permissible to return to course. Once back on course, the UA completes transition though Class E airspace into the original destination or an alternate destination airport area and completes the flight.

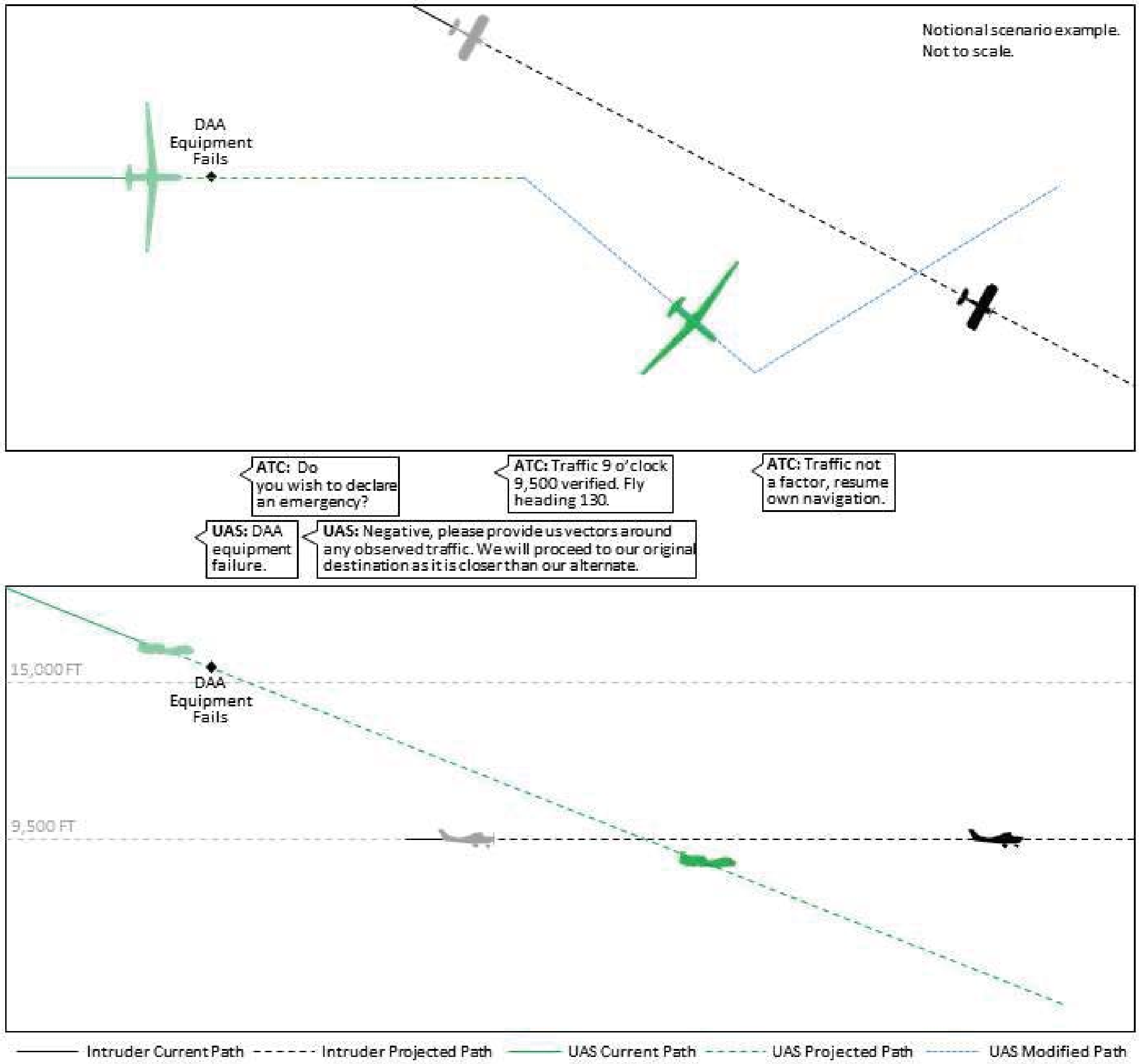


Figure A-51 **Scenario A.6.6 – DAA Equipment Failure**

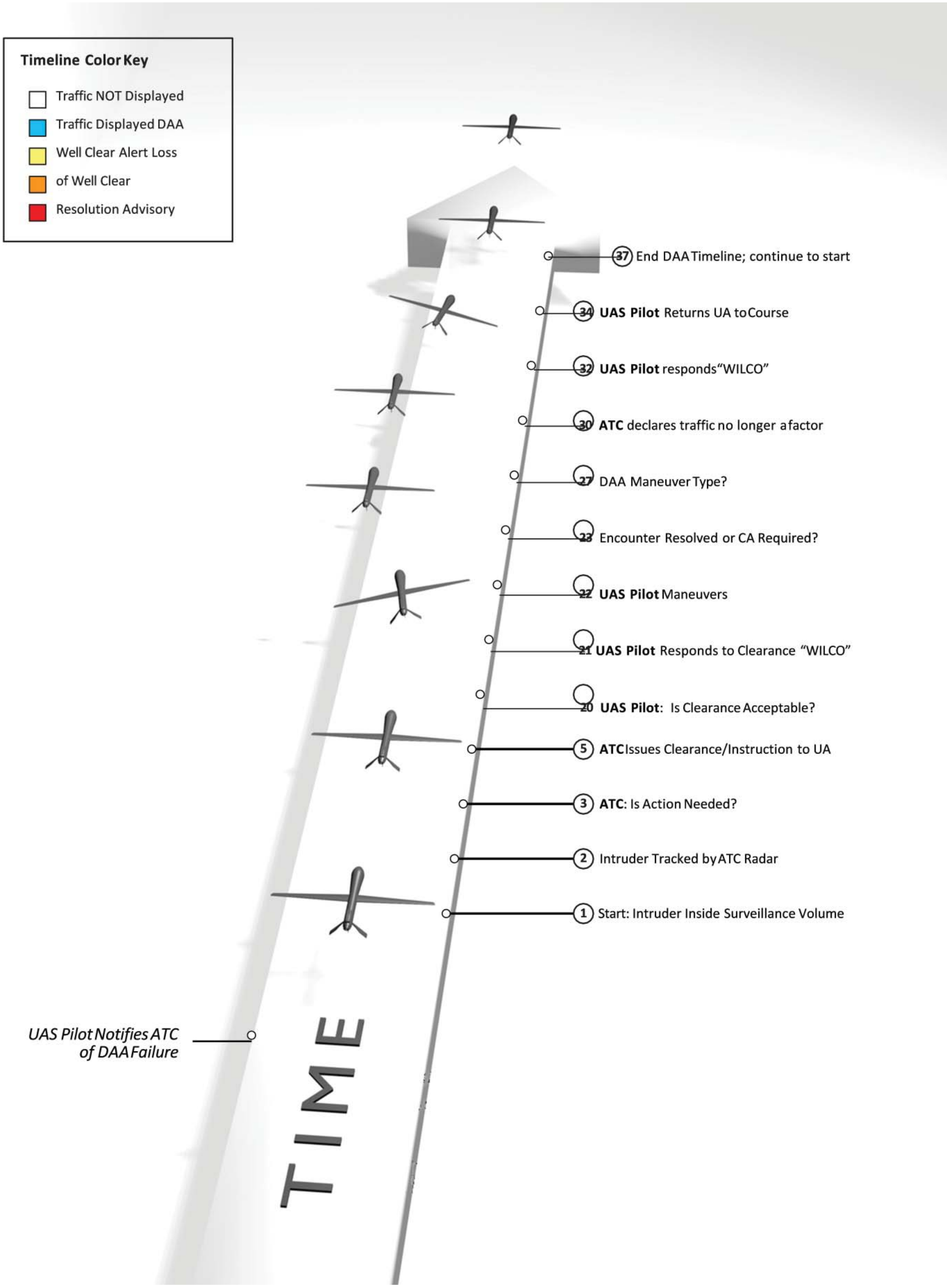


Figure A-52 Scenario A.6.6 – Timeline for DAA Equipment Failure

A.6.7 Automatic Execution of RA during Lost CNPC Link, Vertical Maneuver

Loss of the CNPC data link means the PIC has no active control over the UA's flight. For this scenario, the DAA system design includes the Class 2 DAA system and includes the option to automatically execute TCAS II RA maneuver commands. Automatic execution is expected to operate when lost CNPC link occurs

The UAS will execute its pre-programmed lost-link protocol after a predetermined length of time after the CNPC data link is lost; the protocol is assumed to be predictable, and well behaved. The lost-link protocol typically includes automatically setting the beacon code to the lost-link code. However, standardizing lost-link behavior across all UAS is outside the scope of this DAA MOPS.

When the CNPC data link is re-established, the PIC would return the beacon code to the original assigned code.

Shadow 12, a UA, is transiting through Class E airspace on an IFR flight plan, consistent with the "Vertical Transit" or "Loiter for Surveillance" scenarios in the FAA UAS CONOPS. The UAS PIC is communicating with ATC using comms routed through the UA. While enroute, the UAS PIC monitors the health and status of the UAS, including the status of the CNPC data link and DAA systems.

At a point along the route, the UA loses its CNPC data link, which includes the PIC's link to ATC; the PIC will have an indication that both the CNPC data link and VHF comms link have been lost, as shown in Figure A-53 and Figure A-54. The UAS PIC starts following the lost-link checklist, including normal attempts to regain the link, as well as attempts to establish alternate ATC comms. After following the lost-link checklist, the UAS PIC is unsuccessful at re-establishing the CNPC data link, but is able to establish communications with ATC using a landline. The PIC notifies ATC of the situation; "Cleveland Center, Shadow 12, experiencing control link failure."

Logic onboard the UA also recognizes the loss of the CNPC data link and begins executing lost-link protocols, including setting the beacon code to the lost-link code. The En Route ATC controller recognizes the potential emergency condition when he/she sees the UAS change of beacon code. ATC responds "Shadow 12, Cleveland Center, I show you squawking seven-four-zero-zero, level at eight thousand, do you need to declare an emergency?"

While the UAS PIC is not able to command the UA, the PIC is able to monitor the UA position. The UAS PIC informs ATC of the lost-link protocol, and ATC will keep all IFR aircraft separated.

An intruding aircraft is flying VFR climbing through 7000' ahead and flying in the same direction as the UA; the UA will overtake in about two minutes. ATC advises the UAS PIC of the approaching traffic conflict and inquires if the PIC has possibly regained CNPC link with the UA: "Shadow 12, Center, slower VFR traffic at eleven o'clock, indicating seven thousand unverified and climbing, have you regained control link?" The UAS PIC responds "Center, Shadow 12, negative contact, no control link with the UA." ATC attempts to communicate with the intruder by broadcasting on 121.5 and all frequencies available, but is unsuccessful.

The UAS PIC does not regain the CNPC link, while the two aircraft converge. However, the UAS has a DAA system that includes a TCAS II system with automatic execution of

RAs. At about 25 seconds to CPA, the TCAS II issues a descend RA requiring the UA to descend at 1500 feet per minute (fpm) to avoid collision. The UAS automatically executes the required maneuver. ATC observes the maneuver and informs the UAS PIC that the VFR aircraft appeared to pass 700' above the UA.

In this scenario the UAS has lost CNPC link, and the UAS pilot does not have the ability to override the automatic execution of the RA.

After becoming clear of the conflict, the UA returns to its pre-programmed lost-link procedure; in this example, the UA climbs back to 8,000'. The UA enters a hold pattern at its designated lost-link location where it remains until the link is regained. The UA will continue to execute RA maneuvers if required.

After performing troubleshooting steps, the PIC regains CNCP link with the UA and contacts ATC: "Center, Shadow 12, have control link, request return to course." ATC advises, "Shadow 12, approve return to course, squawk three-three-one-one, maintain eight thousand, heading two-five-zero when able."

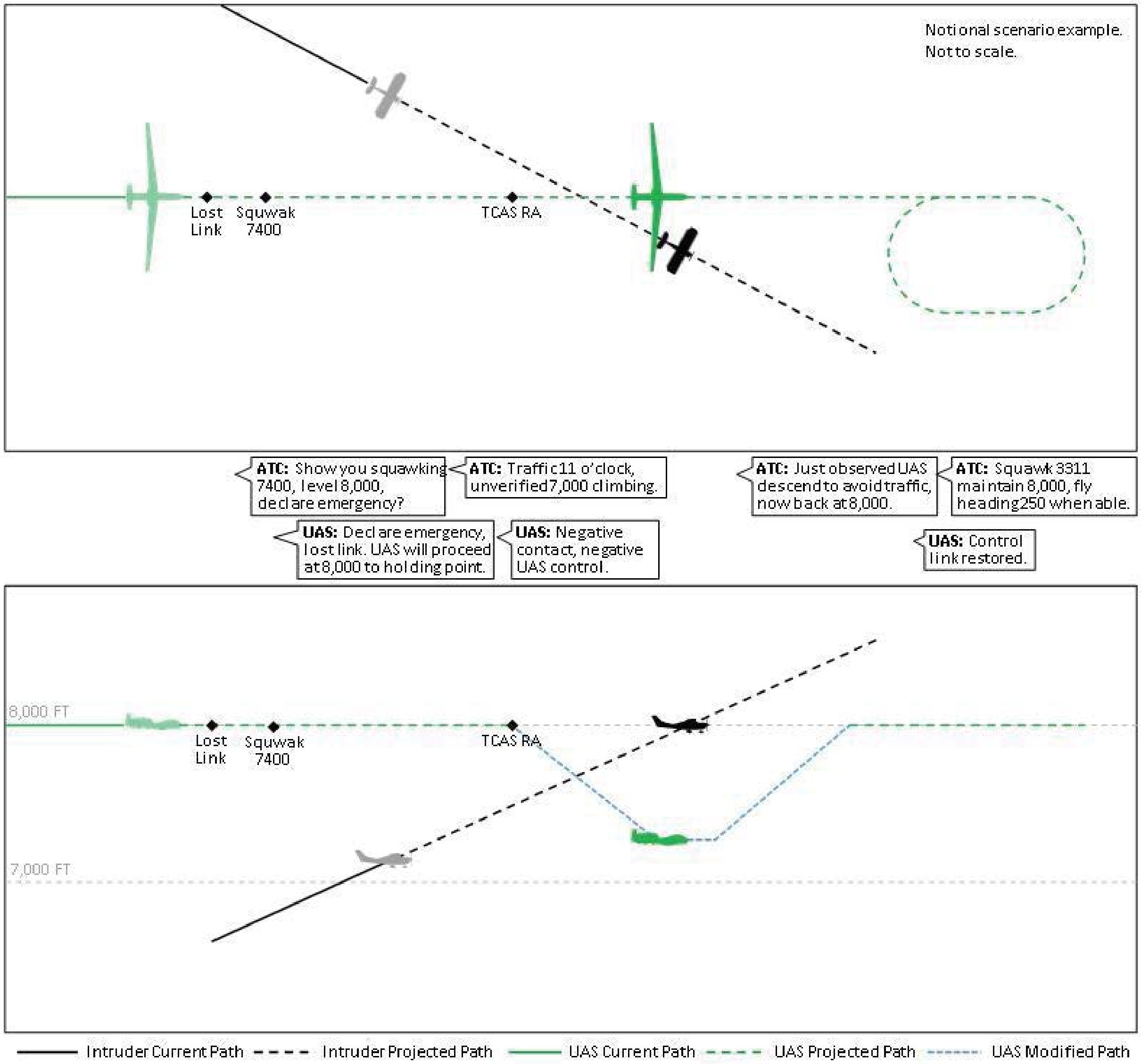


Figure A-53 **Scenario A.6.7 – Automatic CA Vertical Maneuver during Lost CNPC Link**

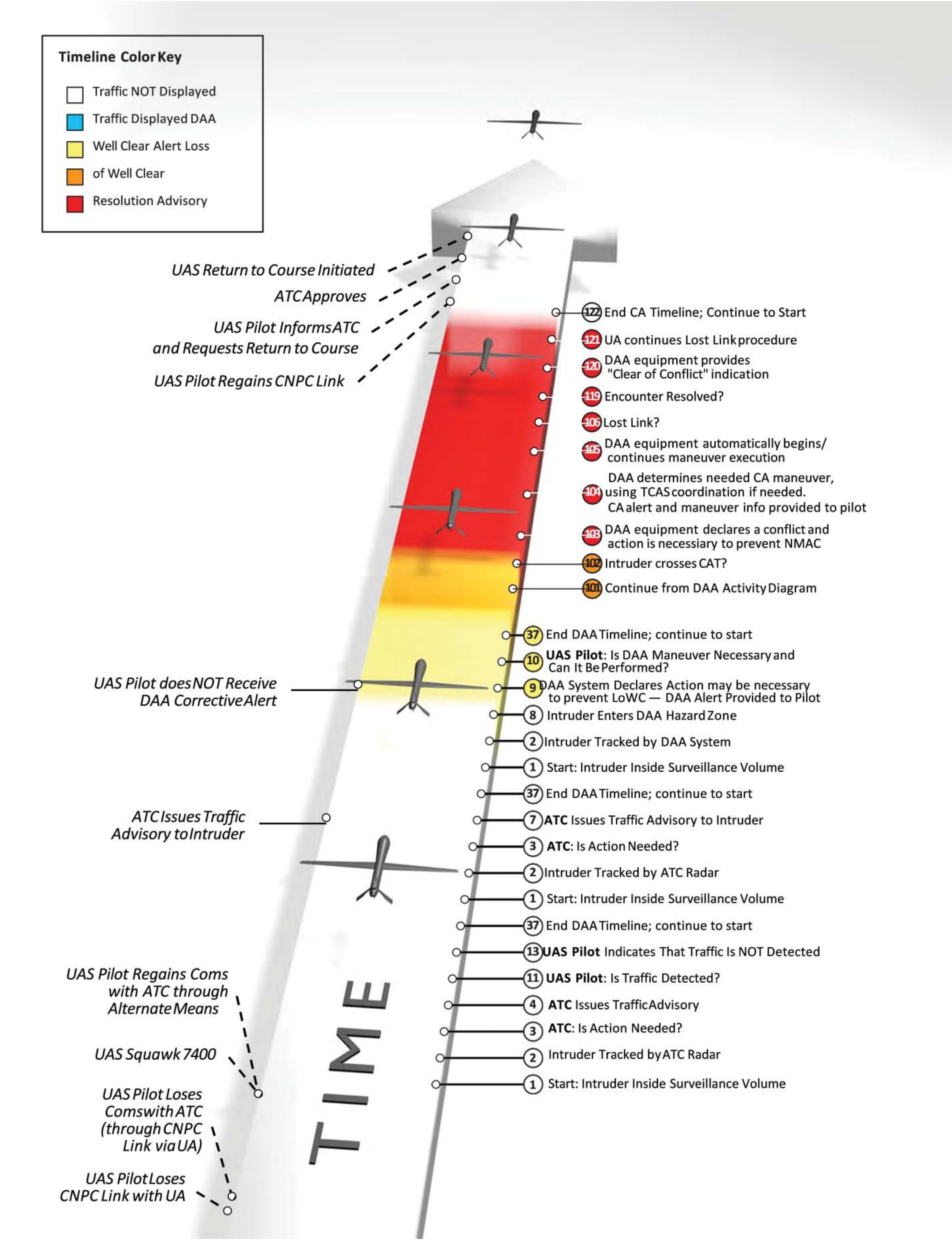


Figure A-54 **Scenario A.6.7 – Timeline for CA Vertical Maneuver during Lost CNPC Link**

A.6.8 UA Maneuvers to Regain DWC

SURVEY 32, a civilian UA about the size of a Cessna Caravan, is transiting at 6,000’ MSL enroute to its operational area on an IFR flight plan, as depicted in Figure A-55 and Figure A-56. The UA is equipped with a Class 1 DAA system (no TCAS II). The UAS PIC is in two-way communications with ATC.

The UAS PIC observes on the DAA traffic display an intruder at 6,500’ about 7 NM away, flying in the opposite direction. The UAS PIC estimates the intruder will pass about half a nautical mile to the right.

ATC provides a traffic advisory to the PIC: “SURVEY 32, Traffic one o’clock, five miles, opposite direction, altitude indicates six thousand five hundred, type unknown.” The UAS PIC associated the called traffic with the observed traffic on the DAA traffic display and responds, “Traffic Detected, SURVEY 32.”

About ten seconds later, the DAA equipment provides a preventive alert to the PIC indicating that the intruder is predicted to be close to, but not within, the UA’s well-clear boundary due to the 500’ vertical separation. The PIC then increases the scan of the DAA traffic display to monitor the intruder.

When the intruder is about one mile away from the UA, it begins to descend. About five seconds later, the DAA system provides a corrective alert to the PIC indicating that the intruder is predicted to cross the DWC boundary. This alert brings the pilot’s attention back to the DAA traffic display. Before the PIC has a chance to determine maneuver or call ATC, the intruder becomes a warning alert then crosses the DWC boundary. The PIC continues to monitor the traffic display and with the help of the DWC maneuver guidance decides to make a left turn to avoid the traffic. Due to the urgency of the situation, the PIC elects to begin the maneuver prior to contacting ATC.

The PIC maneuvers the UA to the left and successfully regains DWC. During the left turn, the PIC contacts ATC: “Boston Center, SURVEY 32 had to turn left to avoid the opposite direction traffic.” ATC responds, “SURVEY 32, roger, resume on course when able.”

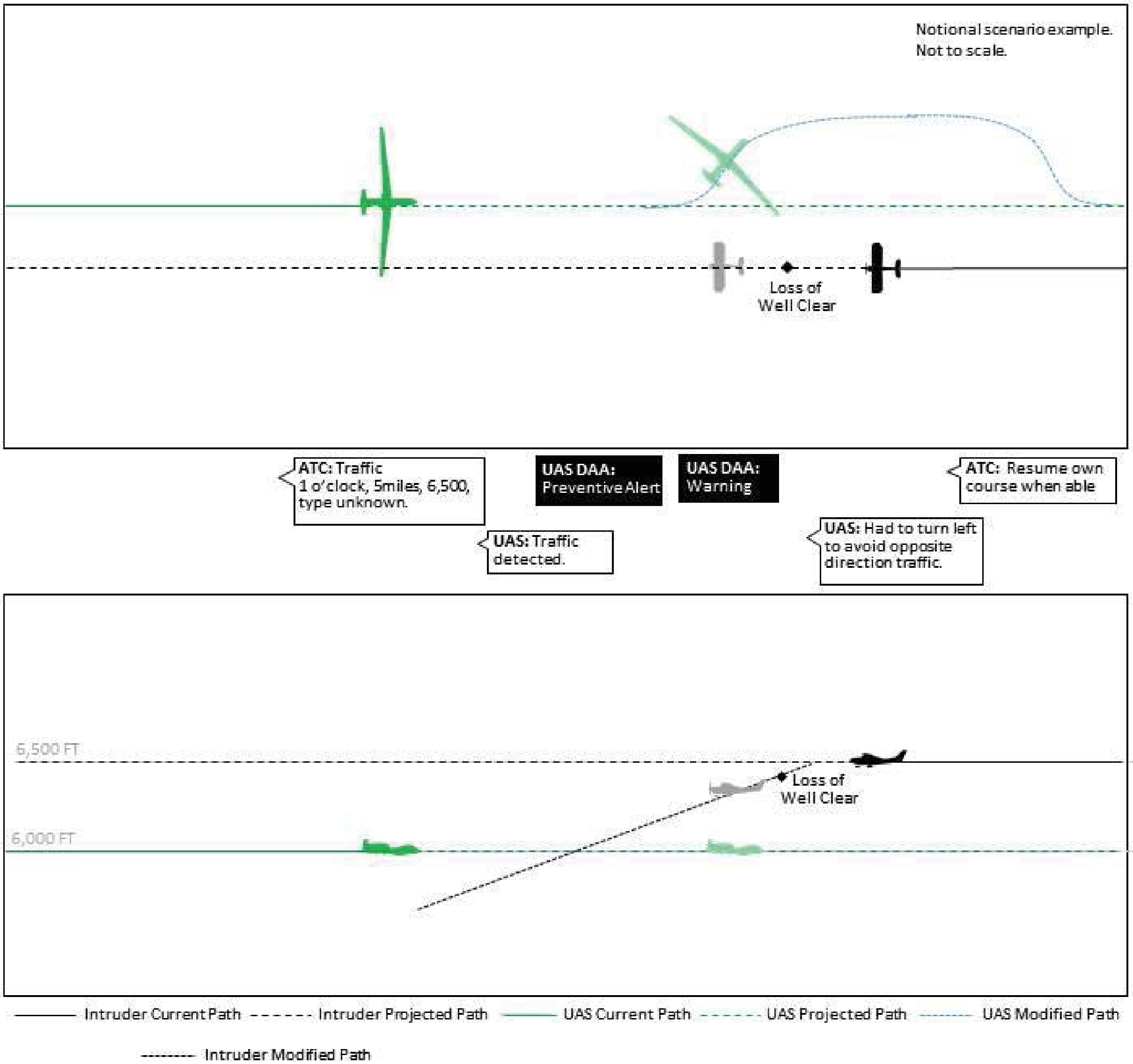


Figure A-55 **Scenario A.6.8 – UA Maneuvers to Regain DWC**

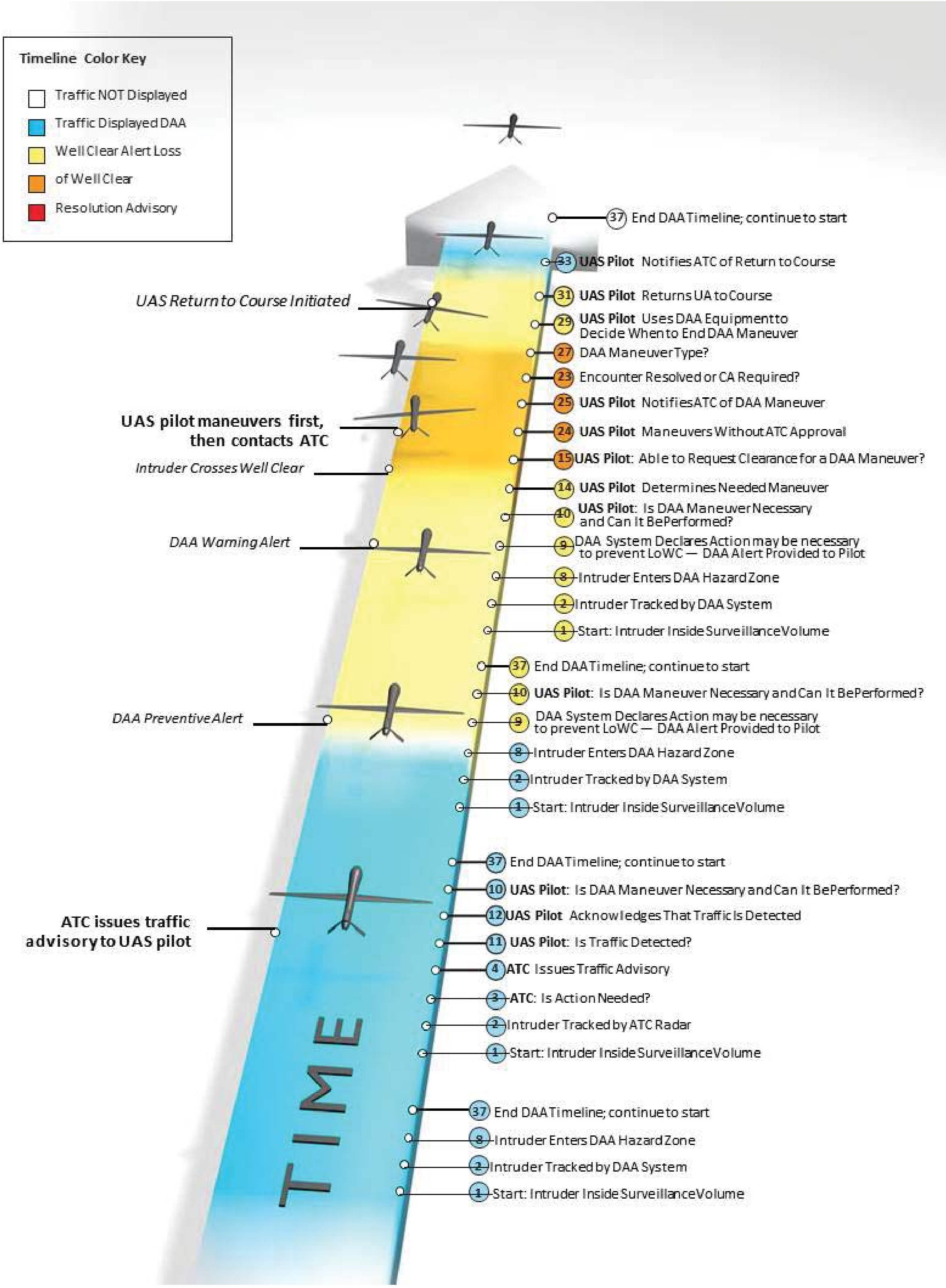


Figure A-56 Scenario A.6.8 – Timeline for UA Maneuvers to Regain DWC

A.7 Assumptions

This subsection includes a list of each operational requirement (labeled **ASSUMP-OSED.##**).

ASSUMP-OSED.1 DAA systems will be used during transit into, out of, or through Class D, E up to FL180, and G airspace, to or from Class A airspace or SUA.

ASSUMP-OSED.2 DAA systems will not be used for separation in surface operations, operations in the airport VFR traffic pattern, operations in Class A, B or C airspace, or operations outside of the performance capabilities of the DAA system.

ASSUMP-OSED.3 Operational limitations will be placed on UAs using DAA systems due to airspace regulations, vehicle performance, or the technical capabilities of the DAA system.

ASSUMP-OSED.4 99.9% of aircraft in ADS-B rule airspace (post-2020) below FL180 and 100% of aircraft above FL180 will have rule-compliant ADS-B Out.

ASSUMP-OSED.5 Outside of ADS-B rule airspace, 15% of aircraft will have no transponder or a Mode A transponder, 14% will have Mode C with 100’ altitude resolution and no ADS-B Out, and 71% will have ADS-B Out, of which 14% have 100’ altitude resolution and 57% have 25’ altitude resolution.

ASSUMP-OSED.6 Aircraft above 10,000’ MSL in Hawaii and Alaska without ADS-B Out or transponders will have velocities and accelerations similar to those unequipped aircraft below 10,000’ MSL.

ASSUMP-OSED.7 DAA equipment will operate in airspaces with maximum densities ranging from 0.3 aircraft/NM2 near metroplexes, to 0.06 aircraft/NM2 in high-altitude En Route airspace.

ASSUMP-OSED.8 DAA-equipped UAS will operate under IFR.

ASSUMP-OSED.9 Phase 1 DAA equipment will perform its intended function with intruder encounters in the following aircraft categories: airplane, rotorcraft, glider, lighter than air (airship and balloon), and powered lift. Those aircraft may be manned or unmanned.

ASSUMP-OSED.10 The DAA system will have appropriate airworthiness and operational approval.

ASSUMP-OSED.11 DAA sensors for detecting intruders will be onboard the UA in Phase 1

ASSUMP-OSED.12 The UAS PIC will have the ability to control the flight path of the UA to execute any DWC maneuvers for all operating conditions in which the CNPC data link is available and related systems are operating properly.

ASSUMP-OSED.13 ATC will provide the same separation service to UAS as they provide to manned IFR aircraft.

ASSUMP-OSED.14 The impact of UAS PIC-initiated traffic queries on ATC communications will be no more disruptive than manned aircraft pilots queries based on traffic visually observed or observed on traffic displays.

ASSUMP-OSED.15 For Phase 1, there will be no automatic DWC maneuvers during UAS lost CNPC link.

A.8 Operational Requirements

This subsection includes a list of each operational requirement (labeled **OR.##**), along with an explanation and indication of the applicable environment, airspace, and phase of flight.

The DAA operational requirements are set forth to denote the stipulations and provide a description, in terms of how the DAA system will be employed or operated by its user(s) and common stakeholder(s). This includes all appropriate internal and external interfaces, as well as interoperability with other systems. The composition of these operational requirements stem from the basic concept of use and operations as outlined in the SC-228 Terms of Reference (TOR). The DAA operational requirements, as derived, are expected to comply with aviation rules, guidance, policies, and procedures.

A.8.1 Operational Requirements Sources and Organization

The development of the DAA Operational Requirements involved the review, evaluation, and in some instances, the refinement of information from a plethora of sources, which include:

- RTCA SC-228 Terms of Reference (TORs)
- RTCA DO--344 Operational and Functional Requirements and Safety Objectives for Unmanned Aircraft Systems (UAS) Standards Volume II [54]
- FAA Advisory Circulars and Guidance, Policy, Regulations, Handbooks, Manuals, and Regulatory Guidance
- Department of Defense (DoD) UAS expertise
- Aviation Industry and Government expertise
- Title 14 of the Code of Federal Regulations
- Aeronautical Information Manual (AIM)
- JO 7110.65W, Air Traffic Control

A template has been created for each of the operational requirements, which includes a comprehensive list of applicable attributes; these include the Operational Environment (see Paragraph A.8.1.1), phase of flight (see Paragraph A.8.1.2), and airspace class (see Paragraph A.2.1). The forthcoming subparagraphs define each of these attributes as described in the requirements template. Please note that some of the attributes listed fall out of scope for the Phase 1 DAA MOPS, but they have been included to instill better comprehension and completeness of the OSED document. When applicable, an X is used to signify the appropriate attributes for each particular operational requirement.

[54] DO-344 Volume 1 & 2-Appendices F and G – Operational and Functional Requirements and Safety Objectives for Unmanned Aircraft System Standards – Volume 2-Appendices F and G, 19 June, 2013

A.8.1.1 Applicable Environments

Only environments that are in scope for Phase 1 DAA are associated with the operational requirements in the subsequent listings. The possible applicable environments are adapted from RTCA DO-344[55] and consist of:

- IFR Communicating with ATC
    - An environment where aircraft comply with IFR and communications are maintained between the pilot and ATC. IFR can be flown in IMC or VMC. (These aircraft are referred to as “ATC participating” aircraft.)
- VFR Communicating with ATC
    - An environment where the aircraft complies with VFR and communications are maintained between the pilot and ATC. (These aircraft are referred as “ATC participating” aircraft.)
- VFR Not Communicating with ATC
    - An environment where aircraft comply with VFR and do not have voice or data link communications between the pilot and ATC. (These aircraft are referred to as “non-ATC participating” aircraft.)
- Controlled Airport
    - An environment with an operating airport control tower, in which ATC provides the safe, orderly, and expeditious flow of ground and water-based traffic. Like manned aircraft, UAS PICs operating from a controlled airport must maintain two-way radio communications with ATC, acknowledging and complying with ATC instructions. Pilots must advise ATC if they cannot comply with the clearances or instructions and request amended clearances or instructions.
- Uncontrolled Airport
    - An environment where either there is no operating airport control tower or ATC is not providing traffic services for ground or water-based aircraft from the control tower (e.g., after normal hours of operation). In this environment, manned and unmanned pilots of aircraft broadcast intentions to taxi, takeoff or land, and listen for communications of other nearby aircraft, who may report their positions and observe movements of other aircraft in the vicinity. It is a recommended best practice for pilots to transmit their intentions on the specified CTAF, or equivalent, for the safety of other traffic in the area. The CTAF may be a Universal Integrated Community (UNICOM), MULTICOM, Flight Service Station (FSS), or tower frequency, as identified in appropriate aeronautical publications.
- Off-Airport Environment
    - An environment without common ground or water-based aircraft traffic control procedures. Typically, this environment includes cleared fields, unused roads, or bodies of water.

[55] RTCA DO-344, Operational and Functional Requirements and Safety Objectives for Unmanned Aircraft Systems Standards Volume 2, 19 June 2013

A.8.1.2 Phases of Flight

Only phases of flight that are in scope for Phase 1 DAA are associated with the operational requirements in the subsequent listings. The possible phases of flight, also adapted from RTCA DO-344, are:

- Flight Planning
    - This phase includes activities related to planning the flight route, addressing potential contingencies, determining adequate CNPC data link coverage, etc. Flight Planning includes filing and activating the flight plan.
- Start/Ground-movement/Taxi
    - This phase begins with the checkout of the aircraft and CS, engine start, preflight communications checks, surface movement (including hover taxi), ATC clearances/instructions (when applicable), etc.
- Takeoff/Departure
    - This phase starts with applying power with the intent of flight. It includes all communication exchanges, climb-out, and ends upon reaching the initial cruise (not intermediate) level-off.
- En Route/Cruise
    - This phase Includes all cruise flight, climbs and descents not part of the other phases of flight and ends upon entry into Aerial Work or Descent.
- Aerial Work
    - This phase includes any flight activity not part of transiting the aircraft. Examples include surveillance, search and rescue, flying a repeating pattern, etc.
- Descent
    - This phase begins upon descent from cruise altitude, arrival at the initial approach fix, or the beginning of any VFR procedure leading to landing
- Approach
    - This phase begins upon reaching an initial approach fix or the beginning of radar vectors leading to an instrument approach.
- Pattern and Landing
    - This phase includes flight in the airport traffic pattern and descent from the last altitude in an instrument approach to the landing surface.
- Post-Landing
    - The post-landing phase includes all activities after weight-on-wheels, hover, or termination of flight. It includes ground movement, taxiing (including hover taxi), securing the UA, performing engine/power plant shutdown, transferring data from the aircraft to the CS, shutting down the UAS, etc.

A.8.2 Operational Requirement List

A.8.2.1 Operational Requirement 1

ID	UAS Operational Requirement				
OR.1	The UAS PIC shall have access to information and controls related to the environment and operation of the UAS necessary to ensure that the UA remains within DAA-imposed operational limitations. (see A.2.1)				
Applicable Environment		**Applicable Airspace**		**Applicable Phase of Flight**	
IFR	x	Class A, Oceanic		Flight Planning	x
VFR Communicating with ATC		Class B		Start and Taxi	
VFR Not Communicating with ATC		Class C		Takeoff	
Controlled Airport		Class D	x	Departure	x
Uncontrolled Airport		Class E	x	En Route	x
Off-Airport		Class G	x	Aerial Work	x
				Descent	x
				Approach	x
				Pattern and Landing	
				Post-Landing	
General References					
AIM §7-1-14, §7-1-23, §7-1-25, §7-3					
Explanation					

This operational requirement addresses the separation of the PIC from the UA in UAS designs, and the need for UAS PICs to comply with weather, terrain, and atmospheric limitations.

UAS PICs cannot look out the aircraft window to directly observe weather or terrain and do not have access to the sensory feedback that pilots of manned aircraft receive. This limited sensory feedback results in a diminished state of situational awareness for UAS PICs that must be compensated for to ensure safe flight in the NAS.

"x" indicates the applicability of the attribute

A.8.2.2 Operational Requirement 2

ID	UAS Operational Requirement
OR.2	The UAS PIC shall maintain two-way communication with ATC where applicable, in order to query, respond to, and be informed of traffic advisories and traffic-related safety alerts, and develop avoidance strategies in a timely and expedient manner, commensurate with the urgency and phase of flight. (see A.2.1)

Applicable Environment		Applicable Airspace		Applicable Phase of Flight	
IFR	x	Class A, Oceanic	x	Flight Planning	
VFR Communicating with ATC		Class B	x	Start and Taxi	
VFR Not Communicating with ATC		Class C	x	Takeoff	
Controlled Airport	x	Class D	x	Departure	x
Uncontrolled Airport		Class E	x	En Route	x
Off-Airport		Class G	x	Aerial Work	x
				Descent	x
				Approach	x
				Pattern and Landing	
				Post-Landing	

General References

14 CFR §91.111 14 CFR §91.113 14 CFR §91.123 14 CFR §91.126 14 CFR §91.127 14 CFR §91.129 14 CFR §91.221 14 CFR §91.223	FAA AIM §3-2-5.b.3

Explanation

Two-way communications with Air Traffic Control (ATC) must be established and maintained while in Class D airspace for all aircraft (FAA AIM 3-2-5.b.3). In Class E and G airspace, communications with ATC are not required when operating VFR. DAA-equipped UAs operating IFR will be in two-way communications with ATC, as will other IFR aircraft. Party-line radio communications provide partial traffic situational awareness to UAS PICs.

The two-way communications between the UAS PIC and ATC should occur in a timely manner and remain reliable and available (without interruption) during operational use.

"x" indicates the applicability of the attribute

A.8.2.3 Operational Requirement 3

ID	UAS Operational Requirement
OR.3	The UAS PIC shall be able to follow ATC instruction for IFR flight for the intended flight environment, including published routes and procedures for which the UA is equipped. (see A.2.4)

Applicable Environment		Applicable Airspace		Applicable Phase of Flight	
IFR	x	Class A, Oceanic	x	Flight Planning	
VFR Communicating with ATC		Class B	x	Start and Taxi	
VFR Not Communicating with ATC		Class C	x	Takeoff	
Controlled Airport	x	Class D	x	Departure	x
Uncontrolled Airport		Class E	x	En Route	x
Off-Airport		Class G	x	Aerial Work	x
				Descent	x
				Approach	x
				Pattern and Landing	
				Post-Landing	

General References

14 CFR Part 91, §93, §95, §97, §99 (or as required by type of approved operation)

Aeronautical Information Manual (AIM), Chapter 1,Air Navigation

Flight Standards Information Management System 8900.1, Volume 4, Chapter 1

Explanation

Safe integration of UAS into the NAS requires operational interoperability with existing navigation routes and procedures when flying under IFR. The intent of this requirement is to allow ATC and UAS PICs to manage flight in the NAS using published routes and procedures. The UAS equipment must provide information to the UAS PIC so as allow use of Victor airways, Jet/high-level routes, Standard Instrument Departures (SID), Standard Terminal Arrivals (STARs), Instrument departures, standard practices for Class I and Class II navigation operations, Standard Instrument Procedures, unique routes and procedures published for UA, etc., as appropriate. UA may use applicable procedures published for manned aviation. Unique procedures may have to be developed for UA with lower performance envelopes. Determining the required navigation equipment will be part of the type certification process for each UAS.

"x" indicates the applicability of the attribute

A.8.2.4 Operational Requirement 4

ID	UAS Operational Requirement				
OR.4	The UAS PIC must comply with the CFR, operational rules and regulations and, when applicable, should follow other guidance and procedures used for manned aircraft. (see A.2.4)				
Applicable Environment		**Applicable Airspace**		**Applicable Phase of Flight**	
IFR	x	Class A, Oceanic	x	Flight Planning	x
VFR Communicating with ATC		Class B	x	Start and Taxi	x
VFR Not Communicating with ATC		Class C	x	Takeoff	x
Controlled Airport	x	Class D	x	Departure	x
Uncontrolled Airport	x	Class E	x	En Route	x
Off-Airport		Class G	x	Aerial Work	x
				Descent	x
				Approach	x
				Pattern and Landing	x
				Post-Landing	x

General References

14 CFR §23 14 CFR §25 14 CFR §27 14 CFR §29 14 CFR §91 14 CFR §121 14 CFR §135	RTCA DO-304[56] RTCA DO-320[57]

Explanation

To ensure safety for all NAS users, both manned and unmanned aircraft flying in the NAS must be compliant with current NAS operations, rules, regulations, guidance, procedures, and systems. For example, the DAA equipment would meet all TSOs invoked by the applicable CFRs.

UA have unique operational, performance, and design characteristics not found in manned aircraft; however, their operation in the NAS should be done to a vast extent within the framework of existing NAS rules, regulations, guidance, and procedures. This includes following 14 CFR §91.113 right-of-way regulations when performing DWC maneuvers.

"x" indicates the applicability of the attribute

[56] RTCA DO-304, Guidance Material and Considerations for Unmanned Aircraft Systems, 22 March 2007
[57] RTCA DO-320, Operational Services and Environmental Definition (OSED) for Unmanned Aircraft Systems, 10 June 2010

A.8.2.5 Operational Requirement 5

ID	UAS Operational Requirement
OR.5	The UAS PIC shall use the UAS DAA equipment to properly maneuver the UA in accordance with ATC clearances and instructions, as well as Right-of-Way (ROW) rules under §91.113, to remain well clear of and avoid creating a collision hazard with other aircraft under 14 CFR §91.111.

Applicable Environment		Applicable Airspace		Applicable Phase of Flight	
IFR	x	Class A, Oceanic		Flight Planning	
VFR Communicating with ATC		Class B		Start and Taxi	
VFR Not Communicating with ATC		Class C		Takeoff	
Controlled Airport		Class D	x	Departure	x
Uncontrolled Airport		Class E	x	En Route	x
Off-Airport		Class G	x	Aerial Work	x
				Descent	x
				Approach	x
				Pattern and Landing	
				Post-Landing	

General References	
14 CFR §91.111, 14 CFR §91.113 14 CFR §91.123, 14 CFR §91.126 14 CFR §91.127, 14 CFR §91.129	RTCA DO-317B[58]

Explanation

The UA PIC will be authorized to use the DAA equipment, including the traffic display, to detect surrounding traffic, analogous to manned aircraft having the traffic in sight. The DAA traffic display will provide the ability for early detection or the prediction of traffic conflicts as they arise and aid the UA PIC in developing avoidance strategies. By providing this source of traffic awareness, the DAA traffic display is expected to improve NAS safety and efficiency, but by no means does it give authorization to disregard ATC instructions and clearances.

The UAS system, in conjunction with the DAA display, will provide visual and aural alerts to the UA PIC when appropriate; these prompts act as alerting mechanisms to the UA PIC, and provide guidance, advisories, or other information to aid in proper decision making and safe maneuvers.

The DAA traffic display will be similar to the ADS-B CDTI defined in RTCA DO-317B, but will include additional information or guidance necessary for DAA capability.

"x" indicates the applicability of the attribute

[58] DO-317B, Minimum Operational Performance Standards (MOPS) for Aircraft Surveillance Applications (ASA) System, 17 June 2014

A.8.2.6 Operational Requirement 6

ID	UAS Operational Requirement
OR.6	The UAS PIC shall refuse visual separation, delegated separation, visual approach, and contact approach responsibilities if the DAA equipment is not certified to support the operation. (see A.3)

Applicable Environment		Applicable Airspace		Applicable Phase of Flight	
IFR	x	Class A	x	Flight Planning	
VFR Communicating with ATC		Class B	x	Start and Taxi	
VFR Not Communicating with ATC		Class C	x	Takeoff	
Controlled Airport		Class D	x	Departure	x
Uncontrolled Airport		Class E	x	En Route	x
Off-Airport		Class G	x	Aerial Work	x
				Descent	x
				Approach	x
				Pattern and Landing	
				Post-Landing	

General References	
FAA AIM §4-1-14, §5-4-23, §5-5-3 FAA JO 7110.65W §7-2-1, §7-4-1, §7-5-6, §7-4-6	

Explanation
SC-228 has not assessed the safety of the Phase 1 MOPS DAA system for these intended functions. Until the safety of these applications has been determined, the PIC is unable to accept these responsibilities. "x" indicates the applicability of the attribute

A.8.2.7 Operational Requirement 7

ID	UAS Operational Requirement
OR.7	UAS operations involving the transfer of UA PIC responsibilities from one pilot to another (whether in the same CS or a different CS) shall ensure the availability of DAA traffic information to the next PIC to provide continuity in UA flight control and command authority over the UAS and the DAA system. (see A.3)

Applicable Environment		Applicable Airspace		Applicable Phase of Flight	
IFR	x	Class A	x	Flight Planning	
VFR Communicating with ATC		Class B	x	Start and Taxi	
VFR Not Communicating with ATC		Class C	x	Takeoff	
Controlled Airport		Class D	x	Departure	x
Uncontrolled Airport		Class E	x	En Route	x
Off-Airport		Class G	x	Aerial Work	x
				Descent	x
				Approach	x
				Pattern and Landing	
				Post-Landing	

General References	
14 CFR §91.5 RTCA DO-304, §1.6.6 RTCA DO-320	

Explanation
Long-endurance and other UAS-unique operations may require PIC responsibilities to be transferred during flight from one pilot to another, who may or may not be physically co-located. In all cases, this transfer of responsibility will be performed in accordance with the certification rule for the UAS, in a manner that will maintain the seamless transfer of operational control and the continuity of traffic situational awareness data being shown on the DAA traffic display. "x" indicates the applicability of the attribute

A.8.2.8 Operational Requirement 8

ID	UAS Operational Requirement
OR.8	Threshold values for CNPC data link performance (e.g., availability, continuity, integrity) shall define the nominal operating conditions of the DAA equipment.

Applicable Environment		Applicable Airspace		Applicable Phase of Flight	
IFR	x	Class A, Oceanic	x	Flight Planning	
VFR Communicating with ATC		Class B	x	Start and Taxi	
VFR Not Communicating with ATC		Class C	x	Takeoff	
Controlled Airport	x	Class D	x	Departure	x
Uncontrolled Airport		Class E	x	En Route	x
Off-Airport		Class G	x	Aerial Work	x
				Descent	x
				Approach	x
				Pattern and Landing	
				Post-Landing	

General References	

Explanation

The DAA equipment is dependent on the operation of the CNPC data link. Therefore the data link performance must be adequate to support DAA operations. The data link performance consists of numerous parameters, including availability, continuity, and integrity. A portion of DAA system performance budget, e.g., latency in displayed track updates, will be set aside to accommodate the performance of the data link.

"x" indicates the applicability of the attribute

A.8.2.9 Operational Requirement 9

ID	UAS Operational Requirement
OR.9	The UA shall perform approved, preplanned, and predictable lost CNPC data link maneuvers in the event of an operational failure of the CNPC data link.

Applicable Environment		Applicable Airspace		Applicable Phase of Flight	
IFR	X	Class A, Oceanic	x	Flight Planning	
VFR Communicating with ATC		Class B	x	Start and Taxi	
VFR Not Communicating with ATC		Class C	x	Takeoff	
Controlled Airport	x	Class D	x	Departure	x
Uncontrolled Airport		Class E	x	En Route	x
Off-Airport		Class G	x	Aerial Work	x
				Descent	x
				Approach	x
				Pattern and Landing	
				Post-Landing	

General References	
RTCA DO-320 §A-5 14 CFR §91.123 14 CFR §91.187	

Explanation

The introduction of UAS into the NAS should have no greater effect than the integration of any other aircraft; however, a CNPC data link loss introduces a level of operational uncertainty that affects safety in the NAS.

To minimize the level of uncertainty and maintain a safe environment for all NAS users, an operational requirement exists for UAS to only perform standardized, and preplanned actions upon loss of the CNPC data link between the CS and the UA. This minimizes the uncertainty that would result if each UAS performed its own unique actions and maneuvers during a CNPC data link loss.

To meet this requirement, an approved set of standardized actions and maneuvers must be provided for use during UAS operations in the event of a CNPC data link loss. These are to be preprogrammed into the aircraft and known to the UAS PIC and other crewmembers as appropriate (e.g., chase aircraft crew). It is expected that air traffic controllers will be familiar with these predictable lost CNPC link maneuvers, so contingencies involving the loss of a UAS data link can be safely managed.

Examples of possible actions and maneuvers include automatically transmitting an appropriate transponder code; automatically flashing the UA position lights, maintaining a constant speed, altitude, heading for a predetermined period of time; following the filed flight plan, or performing a standard rate spiral climb in an attempt to re-acquire CNPC data link communications. These preprogrammed maneuvers would allow automatic RA capability for UA equipped with Class 2 DAA system.

"x" indicates the applicability of the attribute

A.8.2.10 Operational Requirement 10

ID	UAS Operational Requirement
OR.10	The UAS PIC controlling the UA during its flight operation shall explicitly acknowledge any DAA failures or contingency modes in a manner consistent with the DAA system's certification basis. (see A.3.1.3)

Applicable Environment		Applicable Airspace		Applicable Phase of Flight	
IFR	x	Class A, Oceanic	x	Flight Planning	
VFR Communicating with ATC		Class B	x	Start and Taxi	
VFR Not Communicating with ATC		Class C	x	Takeoff	
Controlled Airport	x	Class D	x	Departure	x
Uncontrolled Airport		Class E	x	En Route	x
Off-Airport		Class G	x	Aerial Work	x
				Descent	x
				Approach	x
				Pattern and Landing	
				Post-Landing	

General References	
14 CFR §21.5 14 CFR §91.9 14 CFR §91.103 14 CFR §91.185 14 CFR §91.187 14 CFR §91.503 14 CFR §91.505 AIM §5-1 AIM §5-3-3	RTCA DO-304, §1.1.2 RTCA DO-304, §5.8.2 RTCA DO-304, §5.10.1 RTCA DO-304, §5.12.1 RTCA DO-304, §5.11.1 RTCA DO-304, §5.13.1 RTCA DO-304, §5.14.1 RTCA DO-320 Etc.

Explanation

The physical separation of a UAS control system from the aircraft requires a PIC/operator to consider contingencies (defined as abnormal conditions or emergencies) not normally present in manned aircraft.

The requirement for PIC acknowledgement of a DAA system failure ensures that an alert (e.g., auditory alarm) will not time out without the pilot's awareness of the failure. Specific contingencies to be planned for will be defined by the certification rule applicable to the UA being flown, but as a best practice for safety pilots should preplan for the following contingencies in order to limit risks to people and property to acceptable levels.

- Loss or degradation in the availability or integrity of the UAS Control Station(s) CNPC data link.
- Loss or degradation of the primary or alternate PIC-controller communications path.
- Loss or degradation of the ability to perform DAA operations.

"x" indicates the applicability of the attribute

A.8.2.11 Operational Requirement 11

ID	UAS Operational Requirement
OR.11	The UAS PIC and other required crewmembers and ground support personnel shall be trained on the proper use, maintenance, phraseology, and theory of the DAA system and TCAS II system (when installed).

Applicable Environment		Applicable Airspace		Applicable Phase of Flight	
IFR	x	Class A, Oceanic	x	Flight Planning	
VFR Communicating with ATC		Class B	x	Start and Taxi	
VFR Not Communicating with ATC		Class C	x	Takeoff	
Controlled Airport	x	Class D	x	Departure	x
Uncontrolled Airport		Class E	x	En Route	x
Off-Airport		Class G	x	Aerial Work	x
				Descent	x
				Approach	x
				Pattern and Landing	
				Post-Landing	

General References

14 CFR §91.401
14 CFR §91.403
14 CFR §91.405
14 CFR §91.407
14 CFR §91.409
14 CFR §91.1039

Explanation

The UAS PIC and crewmembers will undergo specialized training to understand DAA procedures, capabilities, and limitations unique to the UA being flown. This also includes any transition training to operate a known DAA system on a different UA.

Routine maintenance checks and repairs will be done to the UAS DAA system as scheduled and will be performed only by qualified and authorized UAS personnel.

Some UAS DAA equipment (i.e., the DAA traffic display) may require modifications to current phraseology, symbology, syntax, or other nuances; the UAS PIC and flight crew members are expected to be thoroughly trained in these areas of change.

"x" indicates the applicability of the attribute

A.8.2.12 Operational Requirement 12

ID	UAS Operational Requirement
OR.12	The UAS PIC shall notify ATC as soon as practical when there is a loss of DAA functionality.

Applicable Environment		Applicable Airspace		Applicable Phase of Flight	
IFR	x	Class A, Oceanic	x	Flight Planning	
VFR Communicating with ATC		Class B	x	Start and Taxi	
VFR Not Communicating with ATC		Class C	x	Takeoff	
Controlled Airport	x	Class D	x	Departure	x
Uncontrolled Airport		Class E	x	En Route	x
Off-Airport		Class G	x	Aerial Work	x
				Descent	x
				Approach	x
				Pattern and Landing	
				Post-Landing	

General References	
14 CFR §91.187	

Explanation

The UAS PIC must notify ATC as soon as practical after a loss of DAA functionality. This allows the controller to understand new limitations on UAS functionality and issues instructions accordingly. This could include prioritizing issuing instructions to the intruder over issuing instructions to the UAS PIC or vectoring the UA around all traffic regardless of possible visual or DAA acquisition. If the loss of DAA is associated with a CNPC lost-link event, the UAS PIC may not be able to immediately notify ATC.

"x" indicates the applicability of the attribute

A.8.2.13 Operational Requirement 13

ID	UAS Operational Requirement
OR.13	Controllers shall be trained on DAA phraseology and functionality.

Applicable Environment		Applicable Airspace		Applicable Phase of Flight	
IFR	x	Class A, Oceanic	x	Flight Planning	
VFR Communicating with ATC		Class B	x	Start and Taxi	
VFR Not Communicating with ATC		Class C	x	Takeoff	
Controlled Airport	x	Class D	x	Departure	x
Uncontrolled Airport		Class E	x	En Route	x
Off-Airport		Class G	x	Aerial Work	x
				Descent	x
				Approach	x
				Pattern and Landing	
				Post-Landing	

General References	
FAA JO 7110.65W FAA JO 3120.4	

Explanation

Controllers will be trained in any new DAA phraseology so that they can use the phraseology in their voice communications. Controllers will also be trained in DAA functionality, like other new avionics systems, so that they are aware of the systems' capabilities and limitations.

"x" indicates the applicability of the attribute

This Page Intentionally Left Blank

B APPENDIX B ACRONYMS AND DEFINITIONS

B.1 Acronyms and Abbreviations

.com	Commercial URL identifier
.docx	Microsoft Word 2010 document filename extension
.edu	Educational Institution URL identifier
.gov	Government URL identifier
.pdf	Portable Document Format filename extension
§	Section
1090ES	1090 MegaHertz Extended Squitter
2D	Two-Dimensional
A	Active Surveillance Article designator OR RLP Availability
a.k.a.	Also known as
A/C	Mode A/C transponder type
a/c	Aircraft
A/G	Air/Ground aircraft status
AA	ATC code for American Airlines
AAT	Average Alert Time (before HAZ violation)
abs	Absolute Value
AC	Advisory Circular OR Aircraft OR Alternating Current
ACAS	Airborne Collision Avoidance System
ACAS X	Airborne Collision Avoidance System Model X
ACAS Xa	Airborne Collision Avoidance System with updated architecture
ACAS Xo	Airborne Collision Avoidance System with operation-specific alerts
ACAS Xp	Airborne Collision Avoidance System - Passive
ACAS Xu	Airborne Collision Avoidance System Model X for unmanned aircraft
accel	Acceleration
ACE	Active Coordination Emulation
ACES	Airspace Concept Evaluation System
acq	Acquisition
Act.	Active
ADSB	Automatic Dependent Surveillance-Broadcast
ADS-B	Automatic Dependent Surveillance-Broadcast
ADS-R	Automatic Dependent Surveillance-Rebroadcast
AG	Air-Ground
AGL	Above Ground Level
AIAA	American Institute of Aeronautics and Astronautics
AIM	Aeronautical Information Manual
AIRB	Basic Airborne Situational Awareness Application
ALG	Algorithm
ALT	Altitude
ANA	Average Number of Alerts
APA	Absolute Position Accuracy
API	Application Programming Interface
APSD	Acceleration Power Spectral Density

AR	Alerting Ratio
ARA	Active Resolution Advisory
ARC	Aviation Rulemaking Committee
ARINC	Aeronautical Radio Incorporated
ARNS	Aeronautical Radio Navigation Service
ARP	Aerospace Recommended Practice (SAE)
ARSS	Actual Received Signal Strength
ARTCC	Air Route Traffic Control Center
ASA	Airborne Surveillance Application
ASD	Acceleration Spectral Density
ASDP	Airborne Surveillance Data Processor
ASSUMP	Assumption
AST	Active Surveillance Transponder
ATAR	Air-to-Air Radar
ATC	Air Traffic Control
ATCRBS	Air Traffic Control Radar Beacon System
ATM	Air Traffic Management
AVAL	ACAS on VLJs and LJs –Assessment of safety Level
AVF	Altitude Validity Flag
avg	Average
B/R	Broadcast/Rebroadcast
BDS	Comm-B Data Selector
BIT	Built-In Test
BRG	Bearing
BVF	Bearing Validity Flag
BVLOS	Beyond Visual-Line-of-Sight
C	Celsius OR Mode C transponder code
C2	Command and Control
CA	Conflict Alert OR Collision Avoidance
CAS	Collision Avoidance System
CASSAT	Collision Avoidance System Safety Assessment Tool
CAT	Category OR Collision Avoidance Threshold
CAVS	CDTI-Assisted Visual Separation
CC	Crosslink Capability
CCB	Coordination Capability Bit (TCAS)
CCCB	Conflict Alert Coordination Capability Bits
CDTI	Cockpit Display of Traffic Information
CFR	Code of Federal Regulations
CFT	Craft
CHC	Cancel Horizontal Resolution Complement
CNA	Correct Non-Alert
CNPC	Control and Non Payload Communication
COM	Communications
COMMS	Communications
COMS	Communications
Cond	Condition

CONOPS	Concept of Operations
Conv	Converging
CORR	Corrective Alert
cos	Cosine
CPA	Closest Point of Approach
CPR	Compact Precision Report
CRA	Correct Required Alert
crit	Criterion
CS	Control Station
CSE	Computed Signal Estimate
CSPO	Closely Spaced Parallel Runway Operations
CST	Coast Mode indicator
CTAF	Common Traffic Advisory Frequency
CVC	Cancel Vertical Resolution Complement
D	Horizontal distance OR Prefix for Designer test vectors
D	Minimum Horizontal Separation
D/C	Descend/Climb
DAA	Detect and Avoid
DAL	Design Assurance Level
dB	Decibel
dBm	Decibels Referenced to One Milliwatt
DC	District of Columbia
DDT	DAA Declaration Threshold
desc.	Description
DET	DAA Execution Threshold
det	Detector
Dev	Deviation
DF	Downlink Format
DME	Distance Measuring Equipment
DMOD	Distance Modification of Modified Tau
DNC	Do Not Climb
DND	Do Not Descend
DO	Document
dps	Degrees per second
DTED	Digital Terrain Elevation Data
DTHR	Distance Threshold
DTIF	Display Traffic Information File
DWC	DAA Well Clear
E	East OR Exponent
e.g.	Exempli Gratia, For example
EAA	Elevation Angle Accuracy
ECEF	Earth-Centered, Earth-Fixed
ED	Eurocontrol Document
EFC	Expected Further Clearance Time
EFR	Extended Flight Rules
EKF	Extended Kalman Filter

EMERG	Emergency
enc.	Conditional probability of an encounter set (given the DAA system)
Encs	Encounters
EPA	Early Permissible Alert
EPL	Excess Path Loss
EPU	Estimated Position Uncertainty
EQ	Intruder TCAS Equipage
ERA	Early Required Alert
ERP	Effective Radiated Power
et al.	Et alia, And others
etc.	Et Cetera, And so forth
EUROCAE	European Organization for Civil Aviation Equipment
EWV	East/West (E/W) Velocity
Exp.	Expiration
Expon.	Exponential
F	Fahrenheit
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FCC	Federal Communications Commission
FCS	Flight Control System
FH	Flight Hour
FL	Flight Level
FMS	Flight Management System
fpm	Feet Per Minute
fps	Feet per Second
Fr	From
FRUIT	False Replies Unsynchronized In Time
FSPL	Free Space Loss
FSS	Flight Service Station
ft	Feet/foot
FT	Flight Test
G	Give Way Conflict Partition Zone
g	Acceleration of Gravity
GA	General Aviation
GCS	Ground Control Station/Segment
GDTI	GCS Display of Traffic Information
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPWS	Ground Proximity Warning System
GS	Absolute Ground Speed OR Guidance System OR Ground Station
H	Height OR Vertical Distance OR Test vector prefix for Head-on encounters
H	Minimum Vertical Separation
HAE	Height Above the Ellipsoid (GNSS Height)
HALE	High Altitude Long Endurance Aircraft
HAZ	Hazard Zone
HAZNot	Non-Hazard Zone

HAZOP	Hazard and Operability process
HDG	Heading
HDGA	Heading/Track Accuracy
HFOM	95% Accuracy Figure of Merit for Horizontal Position
HFOMR	95% Accuracy Figure of Merit for Horizontal Velocity
hh	Two-digit hours
HIL	Horizontal Integrity Limit
HMD	Horizontal Miss Distance
HMDPen	HMD Penetration
HMI	Human-Machine Interface OR Hazardous and Misleading Information
Horiz	Horizontal
HPA	Horizontal Position Accuracy
HRC	Horizontal Resolution Advisory Complement
HSB	Horizontal Sense Bits
HTAWS	Helicopter Terrain Awareness and Warning System
http	Hypertext Transfer Protocol
https	Secure Hypertext Transfer Protocol
HVA	Horizontal Velocity Accuracy
I	Integrity
i.e.	Id Est, That is
I/O	Input/Output
IA	Incorrect Alert
IAC	Instantaneous Aircraft Count
IAF	Initial Approach Fix
ICAO	International Civil Aviation Organization
ICD	Interface Control Document
ID	Identifier
IF	Intermediate Frequency
IFR	Instrument Flight Rules
IL	Interference Limiting (TCAS)
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
Inc.	Incorporated
INS	Inertial Navigation System
Int	Intruder
IRS	Inertial Reference System
ISRA	Inter-Special Committee Requirements Agreement
ITP	In-Trail Procedures
ITU	International Telecommunication Union
JFK	John F Kennedy International Airport, NY, NY
JO	Joint Order
kft	One thousand feet
kg	Kilogram, One thousand grams
km	Kilometer, One thousand meters
kPa	Kilopascal = 1000 Newtons per Square Meter
kt	Knots

KTAS	Knots True Air Speed
kts	Knots
LA	Late Alert OR Los Angeles
Lat	Latitude
LEPR	Low End Performance Representative (UAS)
Lft	Left
LLCEM	Lincoln Laboratory Correlated Encounter Model
Lon	Longitude
Long	Longitude
LOS	Line of Sight
LoWC	Loss of DAA Well Clear
LR	LoWC Ratio
M	Test vector prefix for encounters with a maneuvering target
M&S	Modeling and Simulation
m/s	Meters per Second
MA	Missed Alert
MAC	Mid-Air Collision
MALE	Medium-Altitude Long-Endurance
MASPS	Minimum Aviation System Performance Standards
Max	Maximum
Max.	Maximum
MAZ	May Alert Zone
ME	Message Extended
MFD	Multifunctional Display
MHz	MegaHertz, One million cycles per second
MIL	Military
MIT	Massachusetts Institute of Technology
MIT LL	Massachusetts Institute of Technology/Lincoln Laboratory
mm	Millimeters, One thousandth of a meter
MOA	Memorandum of Agreement
Mode C	Altitude-Reporting Mode of Secondary Surveillance Radar
Mode S	Mode Select
MOPS	Minimum Operational Performance Standards
mph	Miles per Hour
MPL	Measured Path Loss
ms	Millisecond(s), One thousandth of a second
msec	Millisecond(s), One thousandth of a second
MSL	Mean Sea Level
MTB	Multiple Threat Bit
MTE	Multiple Threat Encounter
MTL	Minimum Triggering Level
N	North OR No OR Nose-on Conflict Partition Zone OR Non-alerted Encounter
NAC	Navigation Accuracy Category
NACp	Navigation Accuracy Category for Position
NACv	Navigation Accuracy Category for Velocity
NAS	National Airspace System
NASA	National Aeronautics and Space Administration

NAV	Navigation
NAVAID	Navigational Aid
ND	Navigation Display
nec.	Necessary
NED	North, East, Down
NFM	NASA Formal Methods
NGA	National Geospatial−Intelligence Agency
NHZ	Non-Hazard Zone
NIC	Navigation Integrity Category
NJ	New Jersey
NM	Nautical Mile(s), (1.15 Statute Miles = 1.852 km)
nm	Nautical Mile(s), (1.15 Statute Miles = 1.852 km)
NMAC	Near-Mid-Air Collision
nmi	Nautical Mile(s), (1.15 Statute Miles = 1.852 km)
No.	Number
NORDO	No Radio
NSV	North/South (N/S) Velocity
NTA	Number of TCAS-equipped Aircraft in the area
NUC	Navigation Uncertainty Category
NW	Northwest
O	Overtake Conflict Partition Zone OR Test vector prefix for Overtake encounters
OCM	Operational Coordination Message
Oct.	Octave
OEM	Original Equipment Manufacturer
OR	Operational Requirement
OSED	Operational Services and Environment Definition
p	Page
P	Probability OR Priority Conflict Partition Zone
P/A	Passive/Active Flag
PA	Preventive Alert
PAA	Pressure Altitude Accuracy
PC	Personal Computer
Pen	Penetration
PermA	Permissible Alert
PFD	Primary Flight Display
PI	Penetration Integral
PIC	Pilot In Command
PITL	Pilot In The Loop
PMC	Program Management Committee
PNA	Permissible Non-Alert
POTL	Pilot On The Loop
pp	Pages
PQM	Prediction Quality Metric
PRSS	Predicted Received Signal Strength
PVS	Prototype Verification System
QROW	Quantified Right of Way

QUANT	Altitude Quantization
RA	Resolution Advisory
RAA	Relative Altitude Accuracy
RAC	Resolution Advisory Complement
rad	Radian(s)
RAT	Resolution Advisory Termination
RBA	Relative Bearing Accuracy
RCO	Remote Communications Outlet
RCP	Required Communication Performance
rcv'd	Received
RDR	Radar Declaration Range
REA	Relative Elevation Angle
RF	Radio Frequency
RI	Reply Information code (TCAS)
RLOS	Radio Line of Sight
RLP	Required Link Performance
RNAV	Area Navigation
RNG	Range
ROW	Right of Way
RPA	Remotely Piloted Aircraft
RR	Risk Ratio OR Range Rate
RRA	Range Rate Accuracy
RRS	Required Response Spectrum
Rt	Right
RVF	Range Validity Flag
RVSM	Reduced Vertical Separation Minimum
RWC	Remain Well Clear
RWY	Runway
S	South OR Second(s) OR Test vector prefix for convergence with a fast jet
s	Second(s)
SA	Short Alert
SA01	Safety issue SA01 described in RTCA DO-298
SAA	Sense and Avoid
SAE	Society of Automotive Engineers
SaRP	Science and Research Panel
SBS	Surveillance Broadcast Services
SC	Special Committee OR Source
SDA	System Design Assurance
SEM	Spherical-Earth-Model
SESAR	Single European Sky ATM Research
SET	Self-Separation Execution Threshold
SHF	Super High Frequency
SID	Standard Instrument Departure
SIL	Surveillance Integrity Level
sin	Sine
SL	Sensitivity Level

SLoWC	Severity of Loss of Well Clear
SME	Subject Matter Expert
SRA	Slant Range Accuracy
SRC	Source Data Type
SRM	Safety Risk Management
ss	Two-digit seconds
SS	Self-Separation
SSR	Secondary Surveillance Radar
SST	Self-Separation Threshold
STAR	Standard Terminal Arrival Route
STC	Supplemental Type Certificate
STD	Standard
SUA	Special Use Airspace
sUAS	Small Unmanned Aircraft
SUM	Sensor Uncertainty Mitigation
Surv.	Surveillance
SV	State Vector
SVFR	Special Visual Flight Rules
T	Temperature OR Time OR Time of Detection
T	Look-ahead Time
TA	Traffic Advisory
TABS	Traffic Awareness Beacon System
TACAN	Tactical Air Navigation
tan	Tangent
TAWS	Terrain Awareness and Warning System
TBD	To Be Determined
TBIM	TCAS Broadcast Interrogation Message
TC	Type Certificate
TCA	Time to Closest Approach
TCAS	Traffic Alert and Collision Avoidance System
TCAS II	Traffic Alert and Collision Avoidance System Model 2
TCOA	Time to Co-Altitude (Vertical Time Threshold)
TDC	Traffic Display Criteria
Temp.	Temperature
TET	Transaction Expiration Time (DAA)
thr	Threshold
TID	Threat Identity Data
TIREM	Terrain Integrated Rough Earth Model
TIS-B	Traffic Information Services-Broadcast
TOA	Time of Applicability
TOR	Terms of Reference
ToR	Time of Report
TPM	Technical Performance Metric(S)
TPS	Track Processing Subsystem
TRAMS	TCAS Resolution Advisory Monitoring System
trk	Track

TSAA	Traffic Situation Awareness with Alerts
TSO	Technical Standard Order
TTHR	Time of Detection Threshold
TTI	Threat Type Indicator
U	Unmitigated
UA	Unmanned Aircraft
UAS	Unmanned Aircraft Systems
UAT	Universal Access Transceiver
UAV	Unmanned Aircraft Vehicle
UF	Uplink Format
UHF	Ultra High Frequency
UNICOM	Universal Integrated Community
US	United States
USA	United States of America
UTC	Universal Time Coordinated
V/S	Vertical Sense
VEH	Vehicle
Vert	Vertical
VFOM	Vertical Figure of Merit
VFOMR	95% Accuracy Figure of Merit for Vertical Velocity
VFR	Visual Flight Rules
VHF	Very High Frequency
vis	Visual
VMC	Visual Meteorological Conditions
VMOD	Vertical Modification
VO	Visual Observer
Vol.	Volume
VOR	VHF Omnidirectional Range Radar
VR	Vertical Rate
VRC	Vertical Resolution Advisory Complement
vs.	Versus
VSB	Vertical Sense Bits
VV	Verification & Validation OR Vertical Velocity
w/	With
w/o	Without
WA	Warning Alert
WARN	Warning Alert
WC	Well Clear
WCD	Well Clear Detection Logic
WCV	Well Clear Violation
WG	Working Group
WGS-84	World Geodetic System - 1984
WiFi	Wireless Fidelity
WILCO	Will Comply
WSR	Weighted Slant Range
ZTHR	Vertical Distance Threshold

B.2 Definitions

Acronym	Terminology	Definition
	Active Surveillance	Systems that interrogate transponders, receive replies, and use those replies to determine the range, bearing, and reported altitude of other aircraft in the vicinity.
	Automated	The automatic performance of scripted actions.
	Automatic	The execution of a predefined process that is pilot monitored, and may be overridden.
BVLOS	Beyond Visual Line-of-Sight	Operations where the pilot is not capable of using his or her vision to determine the location or orientation of the UA, hazards in the airspace, or potential of the UA to endanger life or property of another.
CA	Collision Avoidance (upper case)	A last-resort method of preventing mid-air collisions between aircraft, as directed by a Collision Avoidance System.
	collision avoidance (lower case)/avoid collisions	A general term referring to the act of maneuvering to prevent mid-air collisions, not tied to any specific Collision Avoidance System.
	Collision Avoidance Function	See “collision avoidance (lower case)/avoid collisions.”
	Collision Avoidance Maneuver	A maneuver following the directive guidance from a Collision Avoidance System to avoid mid-air collisions with other aircraft.
CAS	Collision Avoidance System	A system that produces directive guidance in the form of Resolution Advisories to avoid mid-air collisions with other aircraft, specifically the Traffic Alert and Collision Avoidance System (TCAS), TCAS II, and the anticipated variants of the Airborne Collision Avoidance System (ACAS), ACAS X, ACAS Xu, ACAS Xa, ACAS Xp and ACAS Xo.
CNPC	Control and Non-Payload Communications	Data and information sent to/from the pilot station and the UA for control of the UA and other safety-critical functions. It does not include any messages sent to achieve mission (payload) objectives.

Acronym	Terminology	Definition
CNPC Link	Control and Non-Payload Communications Link	The link between the CNPC Link System airborne radio and the CNPC Link System ground radio that propagates the CNPC data and information.
CS	Control Station	The equipment used to command, communicate with, or otherwise pilot an unmanned aircraft. Note: Synonymous with "Pilot Station" in the C2 MOPS.
	Cooperative Aircraft	Those equipped with a functioning means of electronic identification (e.g., a transponder) aboard and operating.
	DAA Corrective Alert	A caution-level aural and visual annunciation intended to draw immediate pilot attention to traffic and make the pilot aware that action may be needed.
	Data Age	Elapsed time since a report from any sensor source has been correlated with the track.
	Data Link	See "CNPC Link."
DAA	Detect and Avoid	The capability of an unmanned aircraft to remain a safe distance from other airborne aircraft to avoid collisions.
	DAA Alert Time	The time thresholds specified for providing DAA Preventive, Corrective, and Warning annunciations. See Subparagraph 2.2.4.3.4.
	DAA Equipment	Includes hardware, software, firmware, processors, displays, and controls to perform the DAA intended functions. See Subsection 1.4 of these MOPS.
	DAA Lost Link	Any time the specified DAA transaction expiration time is exceeded due to a degradation or failure of the CNPC Link.
	DAA Mode	The operation status of the DAA equipment. See Paragraph 2.2.6 of these MOPS.

Acronym	Terminology	Definition
	DAA System	Consists of the DAA Equipment, the Pilot In Command, CNPC datalink, and other UAS components necessary to maneuver from traffic intruders.
DWC	DAA Well Clear	A temporal and/or spatial boundary around the aircraft intended to be an electronic means of avoiding conflicting traffic. See equation in Appendix C.
	Directive Display	A DAA visual presentation that provides a specific recommended resolution to avoid a hazard with manual or automated execution. An algorithm informs the pilot when and how to perform a single recommended maneuver. See also “Suggestive Display” and “Informative Display.”
	Guidance Traffic	A nearby aircraft that does not meet the criteria of an alert but could generate an alert upon a change in relative trajectory.
	In-the-Loop	A term used to describe a UA pilot who directly controls the flight path of the UA.
	Informative Display	A DAA visual presentation that provides essential information of a hazard that the remote pilot may use along with other information to develop and execute an avoidance maneuver. No maneuver guidance is provided to the pilot. See also “Directive Display” and “Suggestive Display.”
	Intruder	An aircraft within the surveillance volume.
	CNPC Link Interruption	An occurrence when either the unmanned aircraft or the aircraft control station detects the loss of the CNPC link. Link Interruption becomes failure of the CNPC Link if the loss of link lasts longer than a calculated interval. See Appendix K.
LoWC	Loss of Well Clear	Any time another aircraft penetrates the DAA Well Clear boundary of the ownship UAS.
	Lost CNPC Link	An interruption to the CNPC Link that is longer than deemed safe depending on the circumstances of the UA.

Acronym	Terminology	Definition
NMAC	Near Mid-Air Collision	Two aircraft simultaneously coming within 100' vertically and 500' horizontally.
	Non-Cooperative Aircraft	Aircraft that do not have an electronic means of identification (i.e., a transponder) or not operating such equipment due to malfunction or deliberate action.
	On-the-Loop	A term used to describe a UAS with the capability to perform many flight functions, but with a human providing activation/ deactivation instructions.
	Payload	All elements of a remotely piloted aircraft which are not necessary for flight but are carried for the purpose of fulfilling specific mission objectives.
	Pilot	See "Pilot In Command."
PIC	Pilot In Command	The person who has final authority and responsibility for the operation and safety of flight. This person has been designated as PIC before or during the flight, and holds the appropriate category, class, and type rating, if applicable, for the conduct of the flight. The responsibility and authority of the PIC as described by §91.3 apply to the UA PIC. The PIC position may rotate duties as necessary with equally qualified pilots. The individual designated as PIC may change during flight. NOTE: The PIC can only be the PIC for one aircraft at a time.
	DAA Preventive Alert	A caution-level aural and visual annunciation intended to draw immediate pilot attention to traffic.
RWC	Remain Well Clear	The ability to detect, analyze and maneuver to avoid potential conflicting traffic by applying adjustments to the current flight path in order to prevent the conflict from developing into a collision hazard. For these MOPS, Remain Well Clear consists of two components: maintain DWC and regain DWC.
RCP	Required Communication Performance	A statement of the required Pilot/ATC voice and data communication performance necessary for aircraft operation within a defined airspace.

Acronym	Terminology	Definition
	See and Avoid	When weather conditions permit, pilots operating under instrument flight rules or visual flight rules are required to observe and maneuver to avoid another aircraft. Right-of-way rules are contained in 14 CFR Part 91.
	Self-Separation	A system function where the UA maneuvers within a sufficient timeframe to remain well clear (Note: legacy term).
SAA	Sense and Avoid	The capability of a UAS to remain well clear from and avoid collisions with other airborne traffic. Sense and Avoid provides the functions of self-separation and collision avoidance to establish an analogous capability to "see and avoid" required by manned aircraft regulations. (Note: This is the legacy definition of SAA from the 2013 FAA UAS Roadmap, provided for reference purposes).
	Suggestive Display	A DAA visual presentation that provides a range of potential resolution maneuvers to avoid a hazard with manual execution. An algorithm provides the pilot with maneuver decision aiding regarding advantageous or disadvantageous maneuvers. See also "Directive Display" and "Informative Display."
	Surveillance Equipment	Provides intruder position and other related information to the DAA System.
	Transaction Expiration Time	The maximum time for completion of a transaction after which peer parties should revert to an alternate procedure. See Appendix K for a quantitative definition of Required Link Performance Transaction Expiration Time.
UAS	Unmanned Aircraft System	An unmanned aircraft and associated elements (including communication links and the components that control the UA) that are required for the remote PIC to operate safely and efficiently in the NAS.
UA	Unmanned Aircraft	An aircraft operated without the possibility of direct human intervention from within or on the aircraft.

Acronym	Terminology	Definition
	DAA Warning Alert	A warning-level aural and visual annunciation intended to notify the pilot that immediate awareness and immediate action is required to Remain Well Clear.
	Well Clear	See “DAA Well Clear” or “DWC.” Note: “Well Clear” as used in these MOPS refers to a temporal and/or spatial boundary around the aircraft intended to be an electronic means of avoiding conflicting traffic.
WCV	Well Clear Violation	See “Loss of Well Clear” (Note: legacy term).

C APPENDIX C DEVELOPMENT OF DAA WELL CLEAR (DWC)

C.1 Background

The RTCA Detect-and-Avoid (DAA) white paper provides background on the Special Committee 228 (SC-228) Working Group 1 (WG 1) task as follows. [Reference 1]

The requirement to "see and avoid" other aircraft is part of the regulations governing the general operation of aircraft in the National Airspace System (NAS) under Title 14 of the Code of Federal Regulations (14 CFR), Part 91, §91.111, §91.113(b), and §91.181(b). Although the requirements stated in the regulations are described as right-of-way rules, the intent of these regulations when taken together is to avoid collisions, **remain well clear** from other aircraft, and comply with right-of-way rules. [Emphasis added]

The same white paper states that:

The Sense-and-Avoid (SAA) Science and Research Panel (SaRP) will provide input to the DAA WG with regards to the definition of Well Clear, with additional input from SC-228 members.

and,

Defining Well Clear is an urgent priority for development of the Phase 1 Minimum Operational Performance Standards (MOPS)for DAA Systems. To that end, the SaRP conducted a Well Clear workshop from 27-29 August, 2013. The workshop produced consensus agreement on five principles to describe Well Clear with accompanying rationale and minority dissent documented as necessary. These principles were used in conjunction with insight into ongoing research to propose three Well Clear straw man concepts that can be tuned to a common collision risk and then evaluated against common operational acceptability criteria. Interim updates from ongoing SaRP Well Clear efforts will be shared with SC-228 at each DAA work group meeting with a goal to recommend a preliminary Well Clear standard to the DAA WG for consideration by the end of [fiscal year] 2014.

C.2 SaRP Well Clear Efforts

The SaRP was originally established in 2011 by the Office of the Undersecretary of Defense for Acquisition, Technology, and Logistics for Unmanned Warfare. The SaRP consists of experts from public organizations performing SAA research (e.g., government laboratories, federally funded research and development centers, etc.) to identify SAA research gaps, ensure that sound technical approaches are being evaluated to overcome these challenges, and minimize duplication of effort. In 2013 the SaRP was aligned under the Unmanned Aircraft Systems (UAS) UAS Executive Committee Senior Steering Group, a four-agency organization of Federal UAS stakeholders created under United States Public Law 110 417 to identify solutions to technical, procedural, and policy issues related to integration of UAS into the NAS. The need for a quantitative definition of DAA Well Clear (DWC) was considered in 2013 to be the SaRP's most urgent research gap. In June of 2013, the SaRP was charged with making a recommendation for a quantitative definition for DWC.

In August 2013, the SaRP held a workshop with over thirty experts from eleven organizations within the SaRP to determine a technical approach to quantitatively define DWC. At the outset, the SaRP sought to define a set of consensus DWC principles to accurately frame the research questions. The Second Caucus Federal Aviation

Administration (FAA) SAA Workshop was used as a starting point to propose five Well Clear principles for UAS [Reference 2]. In order to move forward in an efficient manner it was agreed that if the group was unable to achieve unanimous consensus then minority dissents would be documented. The five consensus DWC principles from the workshop are as follows:

1. Well Clear is a separation standard between airborne traffic. (There was one dissenting view that Well Clear should be a performance standard with operational considerations.)
2. A UAS DAA system (i.e., any technical system providing the function of remaining well clear to Unmanned Aircraft (UA)) needs quantitative definitions of the separation minima for this standard, informed by operational acceptability considerations as well as by analytical derivations. This guidance does not apply to the separation performance of manned aircraft.
3. The quantitative definition of Well Clear separation minima should be based on acceptable collision risks in consideration of its operating environment (e.g., airspace class and associated Air Traffic Control separation standards) and compatibility with aircraft collision avoidance systems.
4. A time-based parameter with minimum separation thresholds should be used as the basic separation measure for defining horizontal Well Clear separation minima for a UAS DAA system (No dissent). The workshop agreed to note that a combination of Closest Point of Approach (CPA) and time-to-CPA was considered to be the most promising metric to define Well Clear in the horizontal dimension.
5. Distance, adjusted as needed by closure rate and horizontal separation, should be used as the basic separation measure for defining vertical Well Clear separation minima for a UAS DAA system. (There were two dissenting views that a time-based criterion should be included as a parameter in the vertical dimension. One rationale for this dissent was that workshop participants universally agreed that a time-based criterion is required in the horizontal dimension. The other was that the Traffic Alert and Collision Avoidance System (TCAS) II system uses time to co-altitude in determining whether to issue a Resolution Advisory (RA).)

Also at this workshop, the organizations performing SAA research were surveyed to determine what research was planned and identify additional research required to obtain a recommended definition for DWC within a year, in accordance with the SC-228 need date. Massachusetts Institute of Technology Lincoln Laboratory (MIT LL) made available their Monte Carlo-based Collision Avoidance and System Safety Assessment Tool (CASSAT) for collision risk tuning and analysis. The National Aeronautics and Space Administration (NASA) had planned human-in-the-loop analysis through their Controller Acceptability Study for Well Clear research. Additionally, they were planning to conduct fast-time simulation using the Airspace Concept Evaluation System (ACES) tool. The United States (US) Air Force Research Laboratory provided their six-degree-of-freedom simulation to conduct stressing case analyses.

Each one of the organizations conducting the research agreed to formulate a quantitative definition for DWC, tune the model parameters to a common collision risk value, and then evaluate that DWC model against eight agreed-upon safety and operational metrics (e.g., TCAS II RA rate). The SaRP then evaluated the three candidates against the metrics to produce a recommended DWC definition. The preferred formulation consisted of a horizontal dimension of a modified tau value of 35 seconds with a distance threshold (both a minimum distance modification and horizontal miss distance filter) of 4000’. In the vertical dimension, the DWC definition was specified by a fixed distance from the ownship of 700’. In this formulation, loss of DWC occurs when both the horizontal and vertical thresholds are breached by an intruder aircraft. This DWC definition is notionally depicted in Figure C-1. Detailed descriptions of the SaRP DWC development are provided in Reference 3.

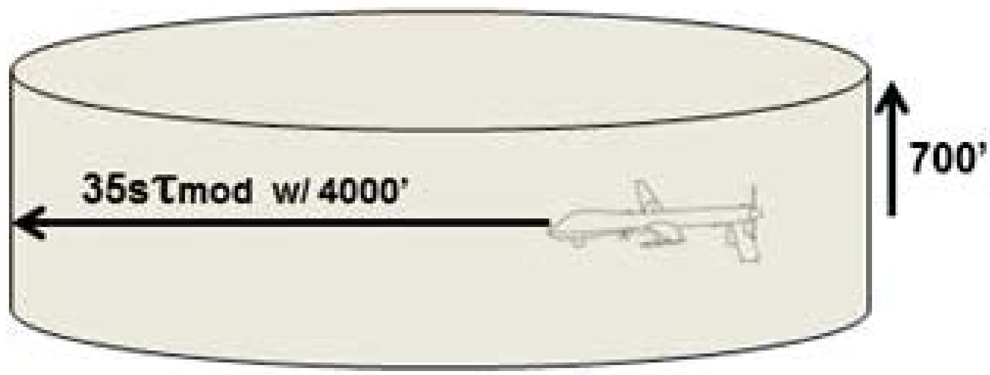


Figure C-1 **DAA Well Clear Recommendation from SaRP to SC-228**

In August 2014 the SaRP provided this recommended DWC definition to SC-228 Working Group 1 in accordance to the schedule specified by the DAA white paper. The Working Group accepted the SaRP recommendation as the starting point for MOPS requirements. A key area of concern regarding the recommended DWC was the 700’ vertical threshold which provided robustness against TCAS II RAs in level-level encounters with another aircraft, but also exceeded the accepted 500’ separation criteria between Instrument Flight Rules (IFR) and Visual Flight Rules (VFR) traffic (using reported barometric altitudes). FAA representatives decided to solicit additional feedback from internal FAA stakeholders to determine how to address this concern over operational impacts.

C.3 FAA White Paper on DAA Well Clear

In September 2014 the FAA issued a white paper stating the FAA position on the DWC recommendation [Reference 5]. In response to the concern about operational impacts of the 700’ vertical component of the DWC definition, the FAA proposed “…to modify the existing vertical definition of Well Clear to 450’ with no change to the horizontal modified tau.” Additionally, the FAA white paper proposed a DAA “Traffic Advisory Alert Threshold” at the 700’ vertical boundary that would provide alerting to the Pilot-in-Command (PIC) in order to maintain “…the validity of the selection process performed by the SaRP while ensuring that 500’ vertical separation is deemed Well Clear.” This proposal was accepted by SC-228 WG 1 and is notionally depicted in Figure C-2.

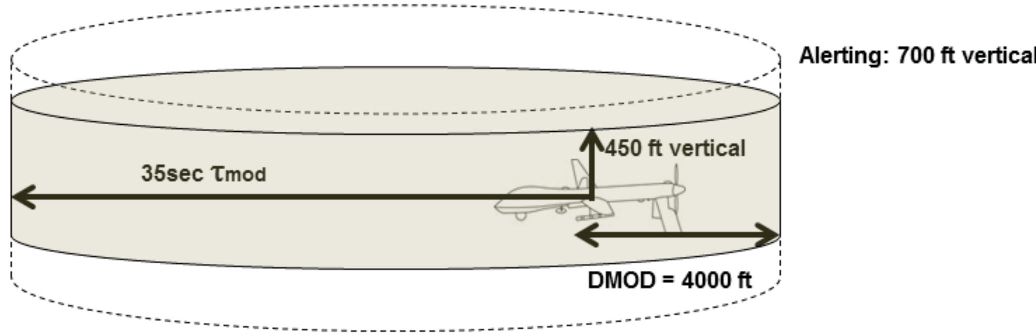


Figure C-2 **DAA Well Clear Proposal from the FAA White Paper**

C.4 Implications of DAA Well Clear

It was recognized that for some aircraft encounter geometries (e.g., head-on encounters) that the resulting DWC surveillance requirement may exceed the performance of the average human eye, and thus a human pilot's ability to remain well clear under 91.113. This outcome stems from three factors. First, the decision to base the DWC on "acceptable collision risks" resulted in a time-based horizontal component of DWC (see Reference 6 for background). Second, the choice to derive a single definition of DWC "in consideration of its operating environment" required that simulations were performed that were consistent with the Class E airspace environment that included both cooperative (e.g., TCAS II equipped) and non-cooperative traffic. Third, the choice to base DWC on "compatibility with aircraft collision avoidance systems" resulted in a tau value that is largely compatible with the higher sensitivity levels of TCAS II, which resulted in large surveillance detection ranges for certain encounter geometries. It is recognized that using a non-risk-based methodology for deriving DWC, or imposing different assumptions regarding operating environment may have resulted in a different definition of DWC. Additionally, it should be noted that removing the pilot from the aircraft has profound impacts on the threat detection and resolution capabilities of the human pilot and therefore a direct comparison with onboard pilot functional performance is no longer considered appropriate. Future work could be considered to tailor the DWC definition for particular intruder equipage classes (e.g., non-cooperative only) and/or specific operations (e.g., VFR traffic pattern).

C.5 Mathematical DAA Well Clear (DWC) Definition

The definition of DWC in this subparagraph is used to support DAA performance evaluation. The values in these equations represent the true, as opposed to measured or estimated, separation. However, for cooperative aircraft, reported barometric altitude information may be used since that is the altitude information used for vertical separation in the NAS.

There is a loss of DWC when:

$$[0 \le \tau_{mod} \le \tau^*_{mod}]\ .and.\ [HMD \le HMD^*]\ .and.\ [-h^* \le d_h \le h^*]$$

with $\tau^*_{mod} = 35\ sec$, $HMD^* = 4000'$, $DMOD = 4000'$, and $h^* = 450'$

where

τ_{mod} *is Modified Tau (based on horizontal ranges not slant ranges),*

τ^*_{mod} *is the Modified Tau Threshold,*

HMD *is Horizontal Miss Distance (HMD) at Closest Point of Approach (CPA),*

HMD^* *is the HMD Threshold,*

d_h *is the current Vertical Separation,*

h^* *is the Vertical Separation Threshold, and*

$DMOD$ *is the Distance Modification of Modified Tau.*

Modified Tau (τ_{mod}) is defined as:

$$\tau_{mod} = \frac{-(r^2 - DMOD^2)}{r\dot{r}} = \frac{DMOD^2 - r^2}{d_x \cdot v_{rx} + d_y \cdot v_{ry}} \qquad \textit{for closing geometries}$$

where

$$r > DMOD$$

$$\tau_{mod} = 0 \qquad \textit{for } r \leq DMOD$$

$$\tau_{mod} = inf \qquad \textit{for non-closing geometries where } r > DMOD$$

where:

$$r = \sqrt{{d_x}^2 + {d_y}^2} \textit{ (the horizontal range between the aircraft)}$$

$$\dot{r} = \frac{d_x \cdot v_{rx} + d_y \cdot v_{ry}}{r} \textit{ (the horizontal range rate between the aircraft)}$$

$$d_x = x_2 - x_1 \textit{ (the current horizontal separation in the x dimension)}$$

$$d_y = y_2 - y_1 \textit{ (the current horizontal separation in the y dimension)}$$

$$v_{rx} = \dot{x}_2 - \dot{x}_1 \textit{ (the relative horizontal velocity in the x dimension)}$$

$$v_{ry} = \dot{y}_2 - \dot{y}_1 \textit{ (the relative horizontal velocity in the y dimension)}$$

Note:

1. *$\dot{r}$ is negative for closing geometries*
2. *τ_{mod} is positive for closing geometries*
3. *All ranges and range rates are in the horizontal dimension and are not slant ranges.*
4. *These equations just define the values, but do not imply that the values must be calculated in this manner.*

The Modified Tau Threshold (τ^*_{mod}) is the value to which the calculated τ_{mod} is compared.

Horizontal Miss Distance (HMD) at the CPA is defined as:

$$HMD = \sqrt[2]{(d_x + v_{rx}t_{CPA})^2 + (d_y + v_{ry}t_{CPA})^2} \qquad for\, t_{CPA} \geq 0$$

$HMD = -inf\ for\ t_{CPA} < 0$ *(equivalently, HMD could be simply defined as 0 or r)*

where:

$$t_{CPA} = -\frac{d_x v_{rx} + d_y v_{ry}}{v_{rx}^2 + v_{ry}^2}$$

Note: *t_{CPA} is time to closest point of approach; positive for closing geometries*

The HMD Threshold (HMD^*) is the value to which the calculated HMD is compared.

Vertical Separation (d_h) is defined as:

$$d_h = h_2 - h_1$$

where h_1 and h_2 are the altitudes (heights) of the two aircraft. Vertical Separation is equivalent to relative altitude. Vertical separation can be calculated either using reported barometric altitudes or true geometric altitudes (Height Above Ellipsoid (HAE)), but not one of each.

The Vertical Separation Threshold (h^*) is the value against which the calculated vertical separation is compared.

C.6 Conclusion

The FAA Sense and Avoid Workshop concluded in 2013 that "For a technical system to perform the function of a PIC to remain well clear, it is necessary to have an unambiguous, implementable definition of the separation minima." [Reference 2] Determining a quantitative definition for DWC was an important step forward in requirements generation for DAA MOPS, and allowed clear success criteria for the DAA intended function of remaining well clear. It is recommended that data from simulation, flight test, and human factors analyses be continuously evaluated to ensure operational acceptability of the DWC from all stakeholders.

C.7 References

1 Detect and Avoid (DAA) White Paper, RTCA Paper No. 074-14/PMC-1200, 18 March 2014.

2 Sense and Avoid (SAA) for Unmanned Aircraft Systems (UAS) Second Caucus Workshop Report, FAA, 18 January 2013.

3 Cook, S., Brooks, D., Cole, R., Hackenberg, D., and Raska, V., "Defining Well Clear for Unmanned Aircraft Systems," AIAA-2015-0481, American Institute of Aeronautics and Astronautics (AIAA) SciTech, Orlando, FL, 2015.

4 Cook, S., and Brooks, D., "A Quantitative Metric to Enable Unmanned Aircraft Systems to Remain Well Clear," Air Traffic Control Quarterly, Volume 23, No. 2/3, 2015.

5 Walker, D., "FAA position on building consensus around the SaRP Well Clear definition," 16 September 2014.

6 Weibel, R., Edwards, M., and Fernandes, C., "Establishing a Risk-Based Separation Standard for Unmanned Aircraft Self Separation," 11th AIAA Aviation Technology, Integration, and Operations Conference, AIAA, 2011.

This Page Intentionally Left Blank

D APPENDIX D UAS MANEUVER PERFORMANCE REQUIREMENTS

D.1 Introduction

The mitigation required by an Unmanned Aircraft System (UAS) to maintain Detect and Avoid (DAA) Well Clear (DWC) or avoid collisions is dependent on the aircraft's maneuverability. This appendix analyzes various ranges between aircraft and times required to maneuver prior to a loss of DWC. More information on how the requirements were derived can be obtained from [References 1, 2, 3].

D.2 Impact on DAA Timeline

The presented maneuver performance requirements provide minimum range values required to maintain DWC from intruder aircraft as a function of UAS maneuverability. Using assumptions on maximum expected closure rate, insight into the time associated with the range requirements is also presented. The given time needed to avoid a Loss of DAA Well Clear (LoWC) is the time required to perform the commanded maneuver from the instant the actuators begin to deflect control surfaces. The times provided on the figures are the time to the closest point of approach (CPA) at which a maneuver must begin to maintain DWC. In order to determine a complete DAA system time requirement, designers must add the time and range requirements of their particular DAA system to the times presented herein.

D.3 Domain/Assumptions

The provided maneuver performance requirements were developed using an idealized model of aircraft dynamics. The presented requirements are valid for encounters involving co-altitude non-accelerating intruders. Encounters with bearing (χ) ranging from -110 to +110 degrees were evaluated. Scenarios with the Unmanned Aircraft (UA) overtaking an intruder were not evaluated beyond understanding that this type of encounter will not drive the minimum requirements for DAA systems' look-ahead time (τ) or range. The most stressing cases are head-on encounters (i.e., intruder positioned such that $\chi = 0$ degrees with velocity vector aligned at 180 degrees from the UA's) against aircraft near the speed limit for the airspace they are in. These cases drove the minimum requirements presented.

D.3.1 Altitude Ranges

Two altitude ranges are considered due to the change in statute aircraft speed limitations at 10,000' Mean Sea Level (MSL) [Reference 4]. For these Minimum Operational Performance Standards (MOPS), lower-altitude airspace is defined as being below 10000' MSL, and higher-altitude airspace is defined as being at or above 10000' MSL and below 18000' MSL. In lower-altitude airspace, intruder speeds up to 250 Knots Indicated Airspeed (KIAS) were considered. In higher-altitude airspace, intruder speeds up to 600 Knots True Airspeed (KTAS) were considered in order to avoid supersonic flight and to align with assumptions made for collision avoidance systems available when these MOPS were published, such as the Traffic Alert and Collision Avoidance System Version II (TCAS II).

D.3.2 Intruder Equipage

Requirements were developed for non-cooperative and cooperative intruders. The majority of non-cooperative intruders (95%) are expected to fly at or below 170 KTAS and are only applicable to lower-altitude airspace [Reference 5]. For lower-altitude airspace, range requirements are presented in Nautical Miles (NM or nmi) for non-cooperative aircraft flying at speeds up to 170 KTAS, and cooperative aircraft flying at speeds up to 250 KIAS (291 KTAS at 10000' MSL). For higher-altitude airspace, only cooperative aircraft flying at speeds up to 600 KTAS are considered.

D.3.3 Speed Limitations

DAA-equipped aircraft speed is limited based on maneuverability:

1. Aircraft only capable of turning at 1.5 degrees/second (deg/s) (half-standard rate) shall operate above 60 KTAS, and
2. Aircraft capable of turning at 3.0 degrees/second (standard rate) shall operate above 40 KTAS.

The upper bound of aircraft speed varies based on the altitude of the encounter. In lower-altitude airspace the upper aircraft speed limit regardless of maneuverability is 200 KTAS. In higher-altitude airspace the upper aircraft speed limit regardless of maneuverability is 600 KTAS. Table D-1 lists these bounds with respect to turn capability and altitude.

Table D-1 Aircraft Speed Bounds per Altitude and Turn Capability

Turn Capability (Degrees/Second)	Low Altitude		High Altitude	
	Minimum Airspeed (KTAS)	Maximum Airspeed (KTAS)	Minimum Airspeed (KTAS)	Maximum Airspeed (KTAS)
1.5	60	200	60	600
3.0	40	200	40	600

D.3.3.1 Maximum Closing Speed

In lower-altitude airspace the maximum relative closing speed between the ownship and a cooperative intruder is 491 KTAS (200+291). Similarly, the maximum relative closing speed between the ownship and a non-cooperative intruder is 370 KTAS (200+170). The maximum relative closing speed occurs when both aircraft are flying directly towards each other.

In higher-altitude airspace the maximum relative closing speed between two aircraft is 1200 KTAS (600 + 600), which occurs when both aircraft are flying directly towards each other.

D.3.4 DAA Turn Maneuvers

The provided maneuver performance requirements were developed using an idealized model of aircraft dynamics. The requirements assume that the aircraft is capable of sustaining the commanded turn rate while maintaining the aircraft's initial airspeed throughout the encounter. The aircraft does not turn beyond a change in heading of 90 degrees and is assumed to turn in the most favorable direction. The presented requirements were derived using encounters involving co-altitude non-maneuvering intruders flying at a constant airspeed. The UA was modelled assuming a roll rate of at least 5 degrees/second with instantaneous roll acceleration.

Maneuver performance requirements are separated based on combinations of three parameters: turn rate, altitude of encounter, and whether the intruder is cooperative or non-cooperative.

Two turn rate capability ranges are considered:

- 1.5 deg/s ≤ turn rate < 3.0 deg/s
- 3.0 deg/s ≤ turn rate.

The influence of turn rate on the range required to maneuver is non-linear. Thus, linear interpolation between the range requirements of the two presented turn rates is not valid. If a UA is capable of sustaining a turn rate between the two provided rates, the range requirements of the half-standard-rate turn shall be used to ensure DWC is maintained. If the UA is capable of sustaining a 3-degree/second turn rate or better, the range requirements from the 3-degree/second table shall be used. Aircraft capable of performing mitigation maneuvers at rates greater than those specified above, must comply with the requirements associated with the nearest lesser turn rate.

If a UA is unable to maintain its initial speed throughout the maneuver, the minimum speed that will be experienced through a 90-degree level turn shall be used for the τ requirements. This will ensure no LoWC occurs regardless of how quickly the aircraft loses speed.

D.3.5 DAA Vertical Maneuvers

Maneuver performance in the positive (climb) and negative (descent) vertical direction are comparable for aircraft that maintain initial airspeed throughout the maneuver with some minor differences. Vertical maneuver range requirements are presented for three commanded vertical rates: 500 feet per minute (fpm), 1000 fpm, and 1500 fpm. For a constant airspeed, the range required to maintain DWC is inversely proportional to the vertical climb rate commanded.

The required ranges assume that the UA sustain the commanded vertical rate throughout the maneuver. The DWC definition plus a small buffer indicate that the maneuver will require a 500’ altitude change at most. Thus the vertical rate must be sustainable for an altitude change of 500’for vertical DAA maneuvers.

For the climb maneuver, during aggressive commanded climbs the UA may lose airspeed while attempting to maintain the commanded vertical rate. The reduction in airspeed reduces the forward distance travelled in order to reach the required vertical displacement. Therefore, the initial airspeed, rather than the minimum or final airspeed, must be used as input for the appropriate figures.

For the descent maneuver, during aggressive commanded descents the UA may gain airspeed while attempting to maintain the commanded vertical rate. The additional airspeed increases the forward distance traveled in order to reach the required vertical displacement. Therefore, the maximum airspeed, rather than initial airspeed, must be used as input for the appropriate figures.

Additionally, slower airspeeds require greater flight path angles than faster airspeeds. With a relatively shallow flight path angle, the fastest flying aircraft will require more forward distance than a slower aircraft flying to reach the same change in altitude.

The presented vertical maneuver range requirements are calculated assuming a normal load factor increment of ±0.25 times the acceleration of gravity (g) and instantaneous pitch acceleration. This normal load factor corresponds to a rate of vertical change of velocity vector ($\dot{\gamma}$) of 6.8 deg/s at 40 KTAS, 4.5 deg/s at 60 KTAS, 1.3 deg/s at 200 KTAS, and 0.45 deg/s at 600 KTAS.

D.4 Application

The provided figures and tables detail the requirements on maneuver range based on ownship airspeed in KTAS. The figures show the boundary for the encounter where maneuvers initiated before the boundary (green) will result in maintaining DWC and those initiated after (red) will lose DWC.

To calculate the time requirement associated with the specified range requirement, assume the intruder is flying at the maximum airspeed for the airspace in which the encounter occurs. The associated time to maneuver is determined by dividing the range requirement obtained from the applicable figure by the closure rate.

D.4.1 Level-Turn Maneuver

Figure D-1 and Figure D-2 show the range requirement for encounters involving cooperative and non-cooperative intruders in lower-altitude airspace based on a commanded turn rate of 1.5 deg/s. Figure D-3 shows the time associated with the maneuver range requirements.

The presented range requirements are in terms of half-standard-rate turns (1.5 deg/s (Table D-2))and standard-rate turns (3 deg/s (Table D-3))To determine the required time and range to avoid a loss of DWC for a given encounter, interpolate between the given minimum UA airspeeds to determine the time and range based on intruder equipage.

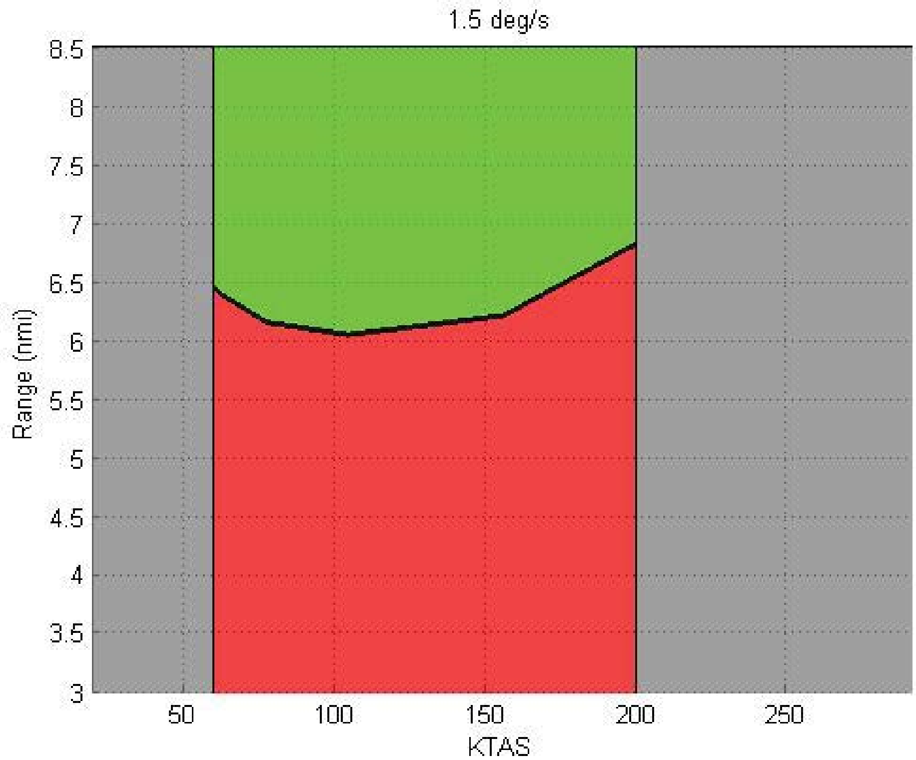


Figure D-1 **Cooperative Intruders, 1.5 deg/s, Altitude < 10000**

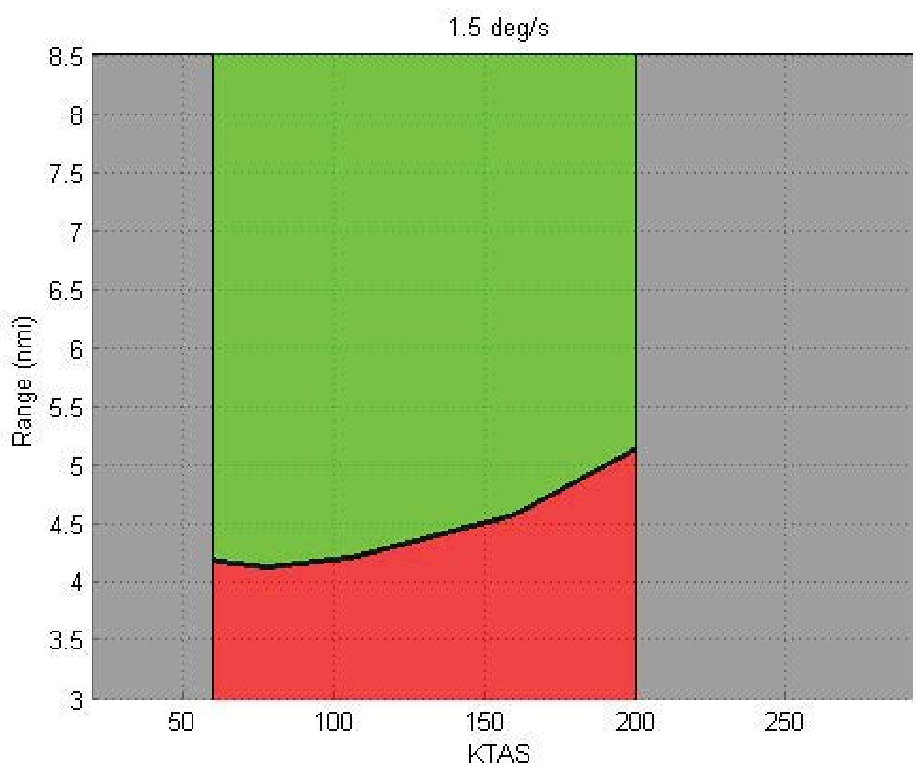


Figure D-2 **Non-Cooperative Intruders, 1.5 deg/s, Altitude < 10000'**

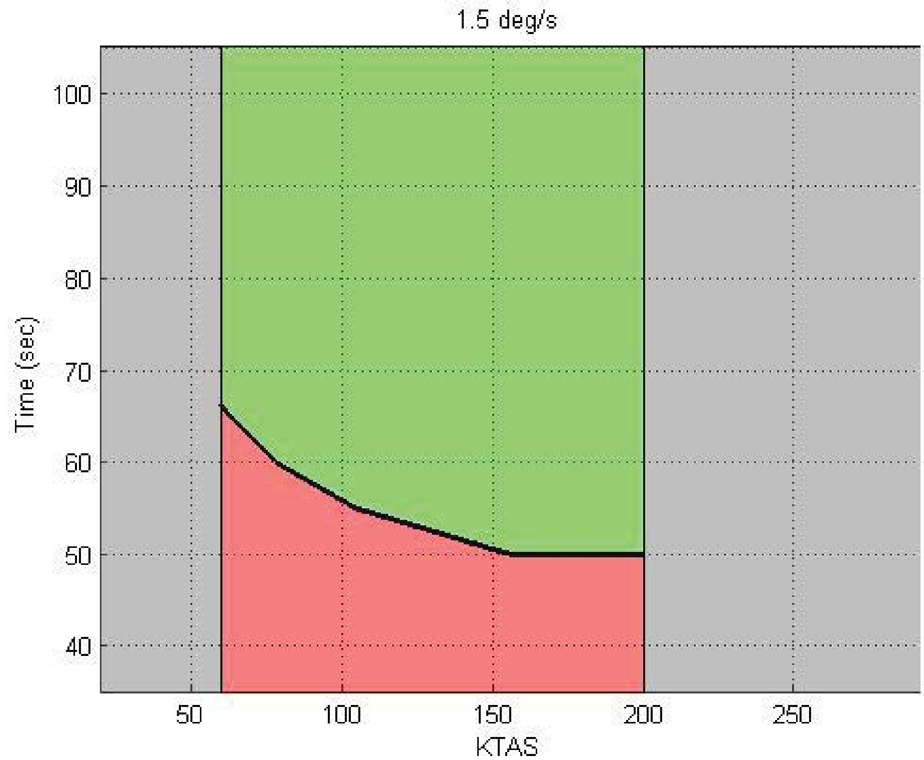
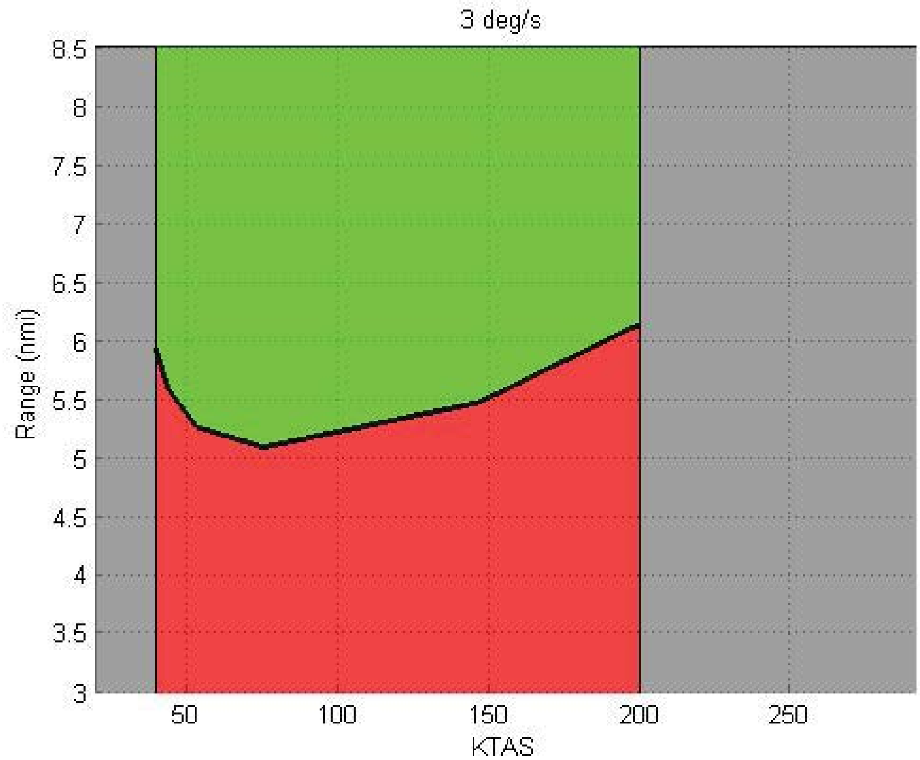


Figure D-3 **Maneuver Time associated w/Range Requirements, 1.5 deg/s, Altitude < 10000'**

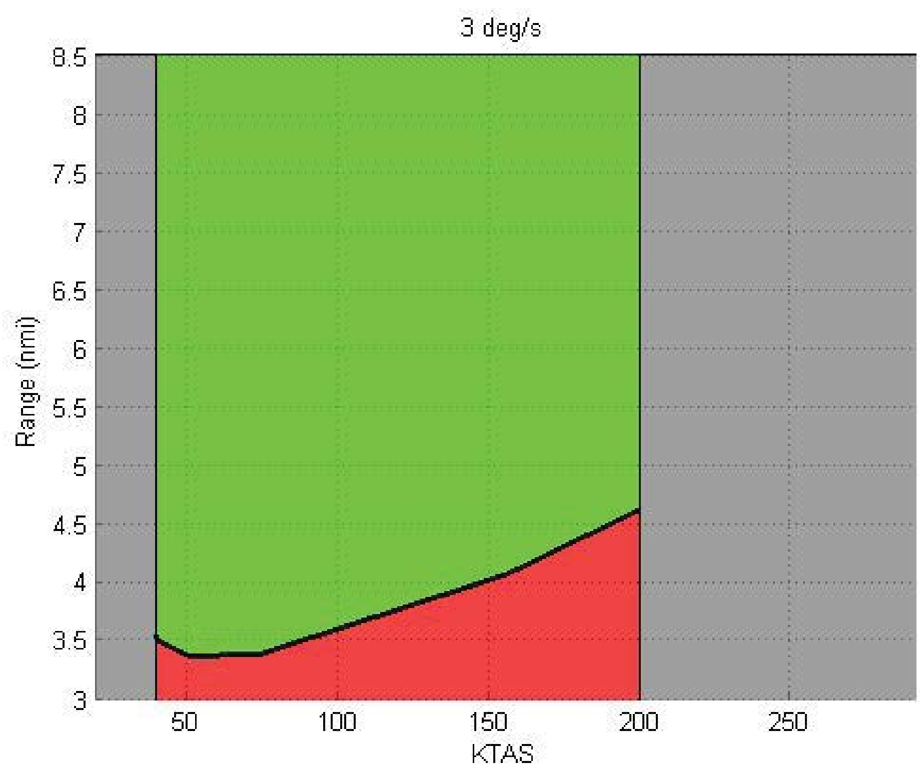
Table D-2 **Range & Time Requirements for a 1.5º/s Turn Rate, Altitude < 10000'**

Range for Cooperative Intruder (NM)		6.82	6.21	6.04	6.15	6.39	6.46	
Range for Non-Cooperative Intruder (NM)		5.14	4.57	4.21	4.13	4.18	4.20	
τ (seconds)	Not allowed	50	50	55	60	65	66	Not allowed
Minimum UA Airspeed to Avoid LoWC (KTAS)	> 200	200	159	106	78	62	60	< 60

Figure D-4 and Figure D-5 show the range requirement for encounters involving cooperative and non-cooperative intruders in lower-altitude airspace based on a commanded turn rate of 3 deg/s. Figure D-6 shows the time associated with the maneuver range requirements.



<u>Figure D-4</u> **Cooperative Intruders, 3 deg/s, Altitude < 10000'**



<u>Figure D-5</u> **Non-Cooperative Intruders, 3 deg/s, Altitude < 10000'**

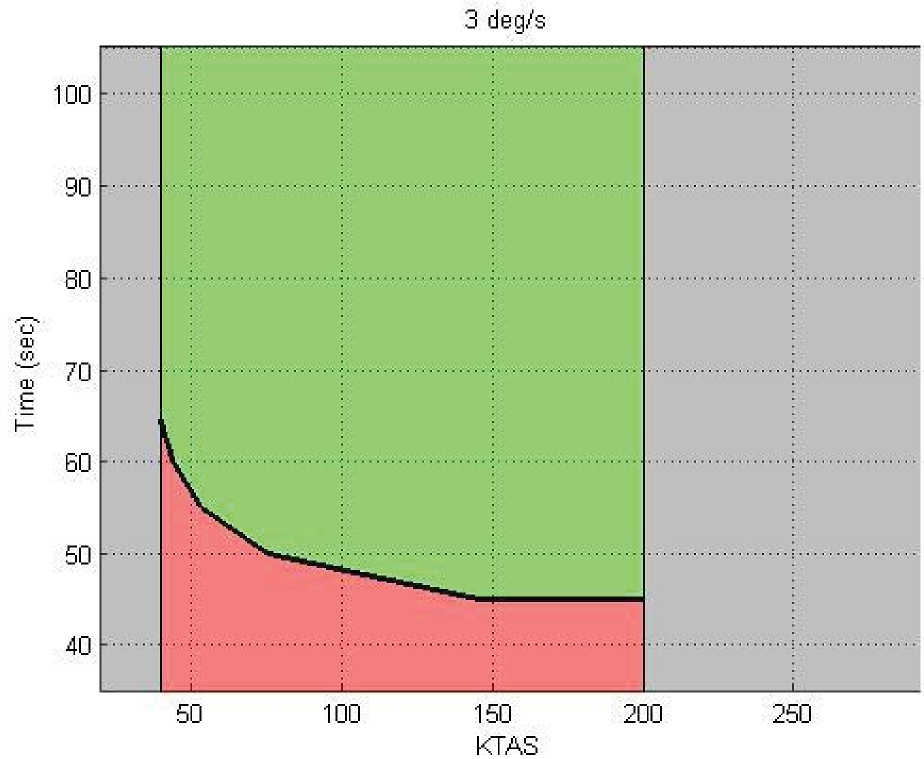


Figure D-6 **Maneuver Time associated w/Range Requirements, 3 deg/s, Altitude < 10000'**

Table D-3 **Range & Time Requirements for a 3º/s Turn Rate, Altitude < 10000'**

Range for Cooperative Intruder (NM)		6.14	5.47	5.09	5.26	5.59	5.93	
Range for Non-Cooperative Intruder (NM)		4.63	4.07	3.39	3.38	3.51	3.56	
τ (seconds)	Not allowed	45	45	50	55	60	64	Not allowed
Minimum UA Airspeed to avoid LoWC (KTAS)	> 200	200	147	76	54	44	40	< 40

Figure D-7 and Figure D-8 show the range requirement for cooperative intruders in higher-altitude airspace based on commanded turn rates of 1.5 and 3 deg/s, respectively.

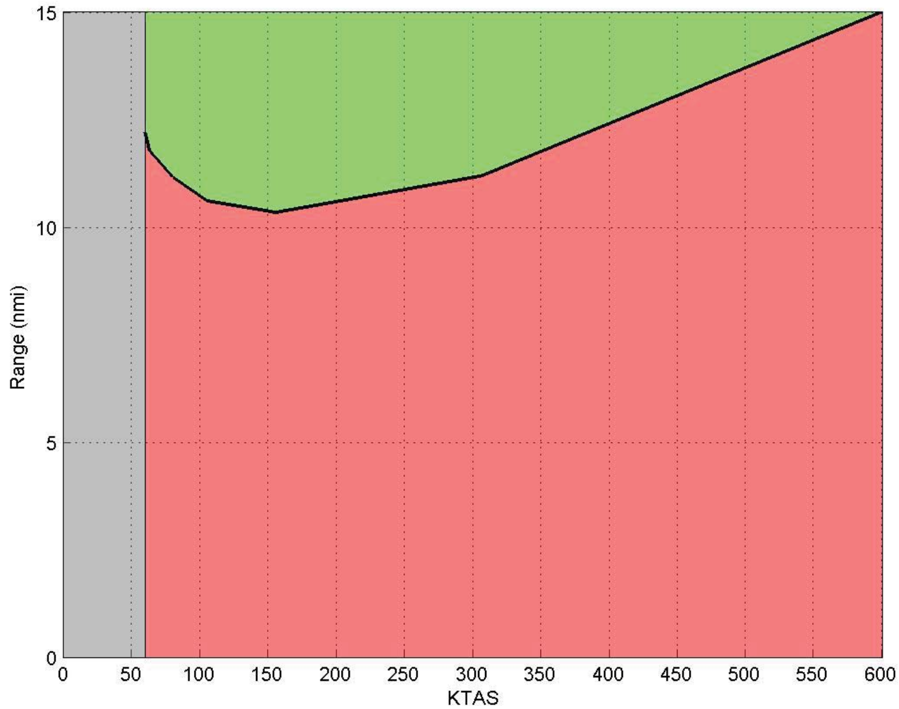


Figure D-7 1.5 deg/s Turn Rate, 10000' ≤ Altitude < 18000' MSL

Table D-4 Range & Time Requirements for a 1.5º/s Turn Rate, 10000'≤ Altitude < 10000'

Range for Cooperative Intruder (NM)	Not allowed	15	11.2	10.34	10.6	11.15	11.8	12.2	Not allowed
τ (seconds)		45	45	50	55	60	65	67	
Minimum UA Airspeed to avoid LoWC (KTAS)	> 600	600	306	156	106	80	64	60	< 60

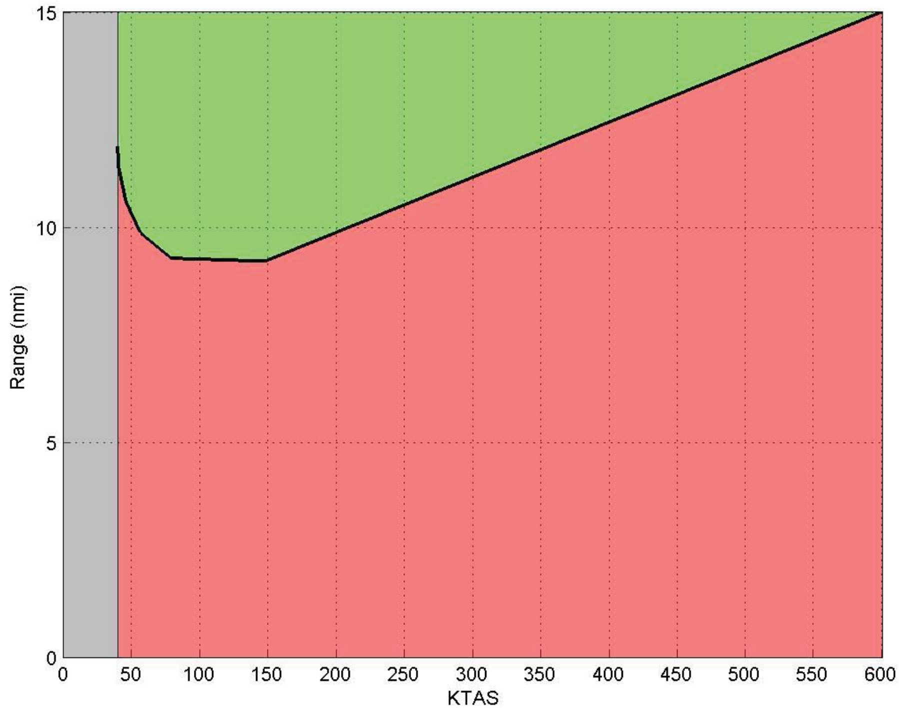


Figure D-8 **3 deg/s Turn Rate, 10000' ≤ Altitude < 18000' MSL**

Table D-5 **Range & Time Requirements for a 3°/s Turn Rate, 10000' ≤ Altitude < 18000'**

Range for Cooperative Intruder (NM)	Not allowed	15	9.21	9.28	9.9	10.6	11.37	11.86	Not allowed
τ (seconds)		45	45	50	55	60	65	67	
Minimum UA Airspeed to Avoid LoWC (KTAS)	> 600	600	148	79	57	46	41	40	< 40

D.4.2 Vertical Maneuver

Figure D-9 through Figure D-14 show the range requirement for encounters involving cooperative and non-cooperative intruders in lower-altitude airspace based on commanded climb rates of 500, 1000, and 1500 fpm.

The vertical dashed line shown in the following figures represents the lower speed limit of UA limited to half-standard rate (1.5 degree/second) level turns.

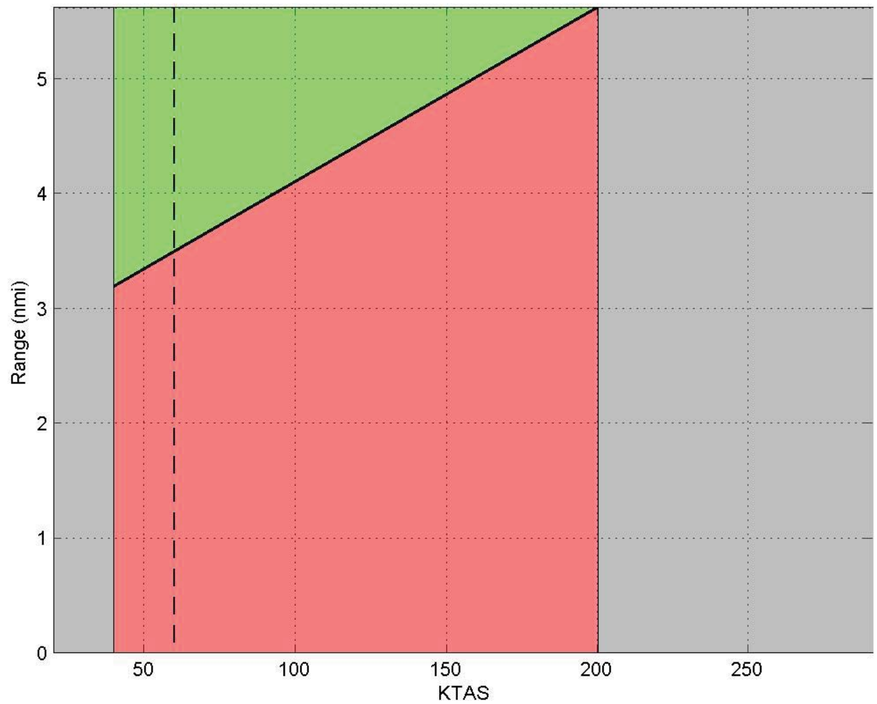


Figure D-9 Cooperative Intruders, 500 fpm Climb Rate, Altitude < 10000'

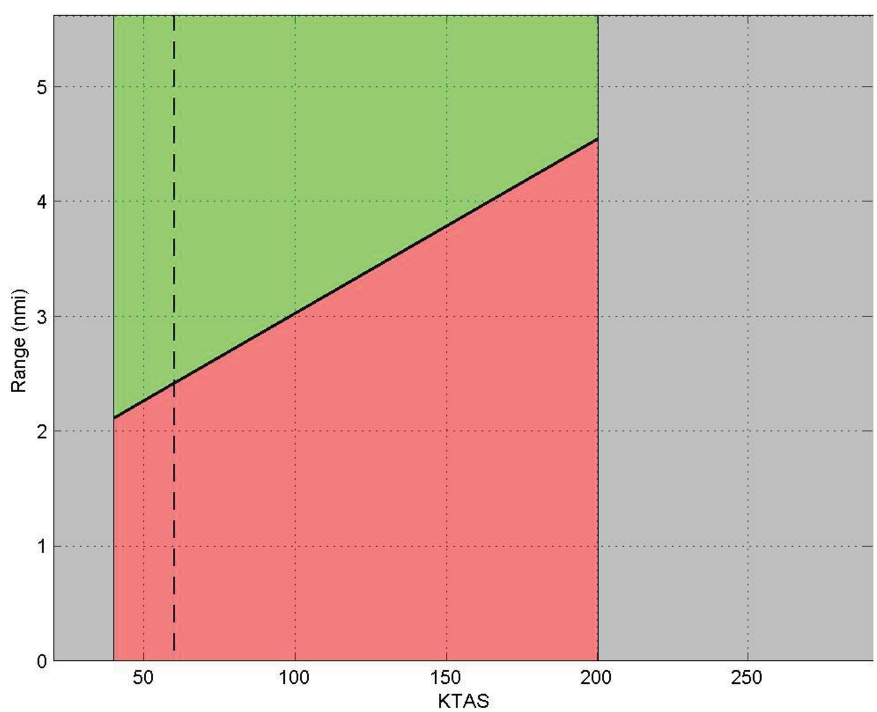
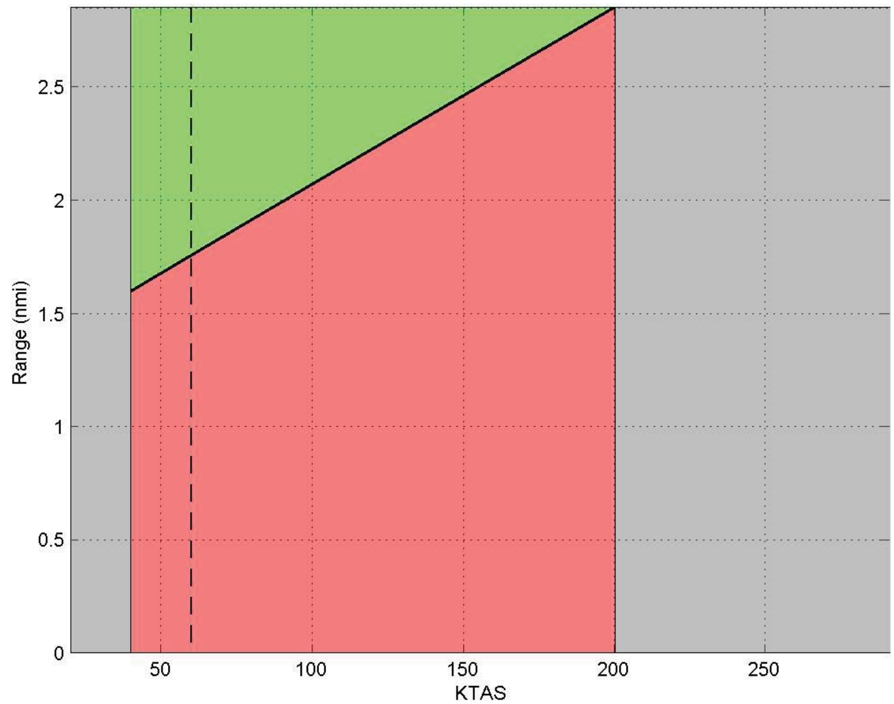
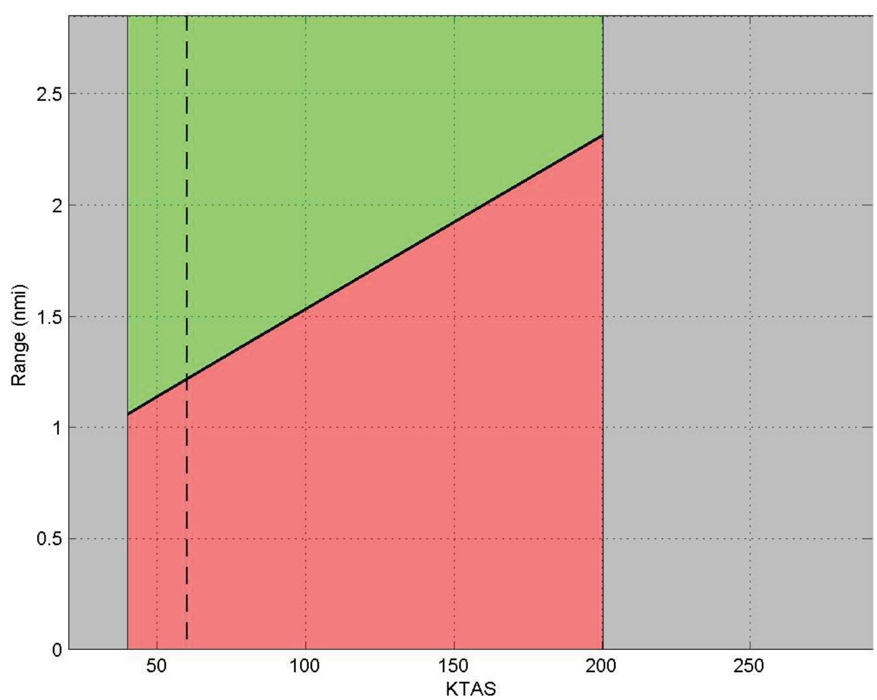


Figure D-10 Non-cooperative Intruders, 500 fpm Climb Rate, Altitude < 10000'



<u>Figure D-11</u> **Cooperative Intruders, 1000 fpm Climb Rate, Altitude < 10000'**



<u>Figure D-12</u> **Non-cooperative Intruders, 1000 fpm Climb Rate, Altitude < 10000'**

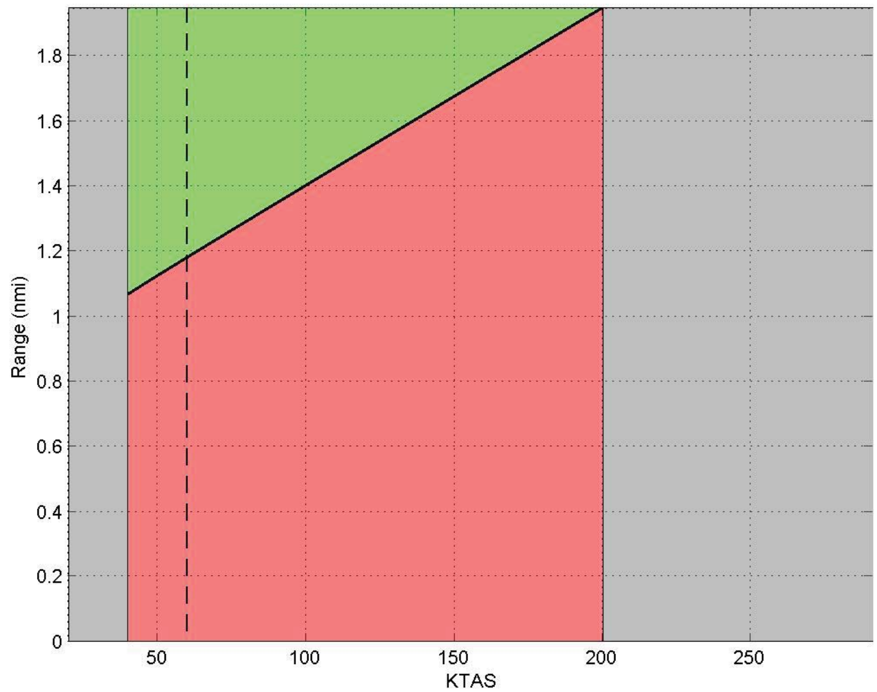


Figure D-13 **Cooperative Intruders, 1500 fpm Climb Rate, Altitude < 10000'**

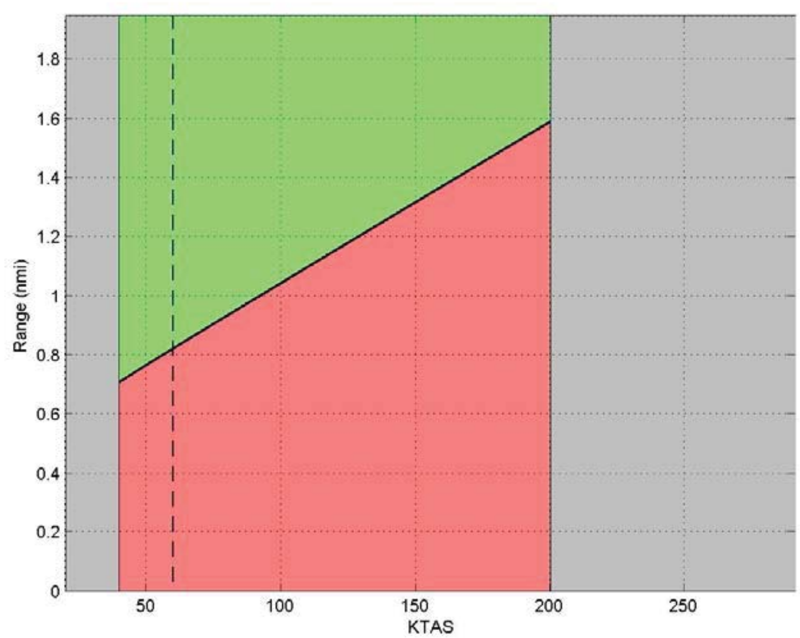
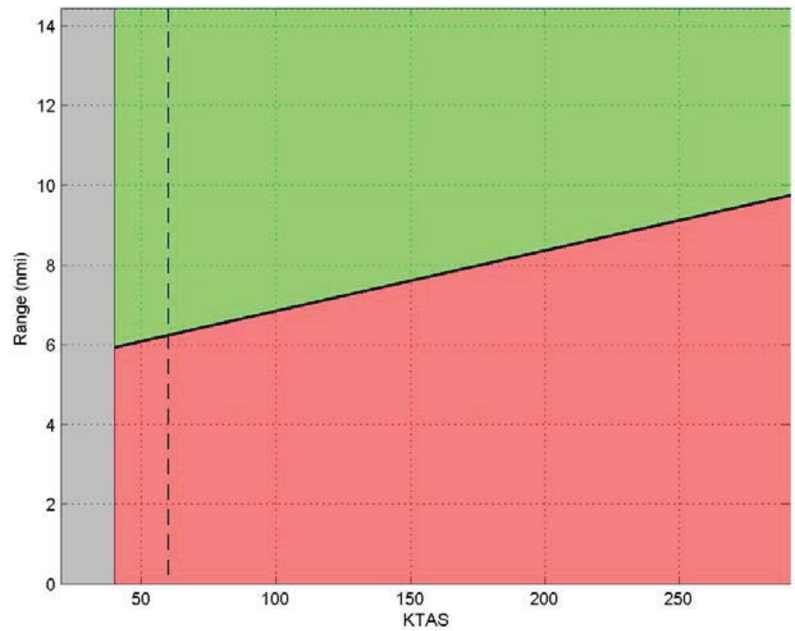
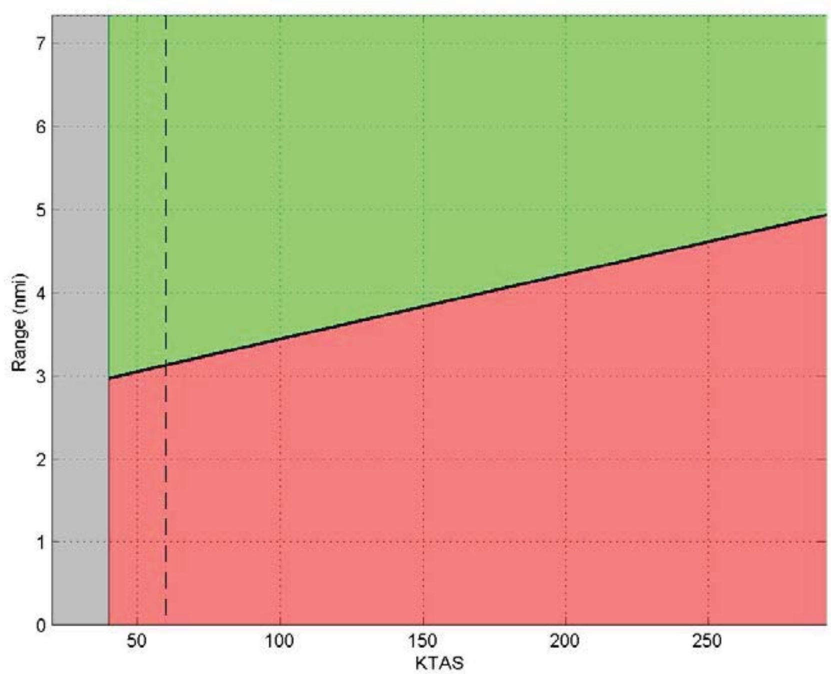


Figure D-14 **Non-cooperative Intruders, 1500 fpm Climb Rate, Altitude < 10000'**

Figure D-15 through Figure D-17 show the range requirement for encounters in higher-altitude airspace based on commanded climb rates of 500, 1000, and 1500 fpm.



<u>Figure D-15</u> **Cooperative Intruders, 500 fpm Climb Rate, 10000' MSL ≤ Altitude < 18000'**



<u>Figure D-16</u> **Cooperative Intruders, 1000 fpm Climb Rate, 10000' MSL ≤ Altitude < 18000'**

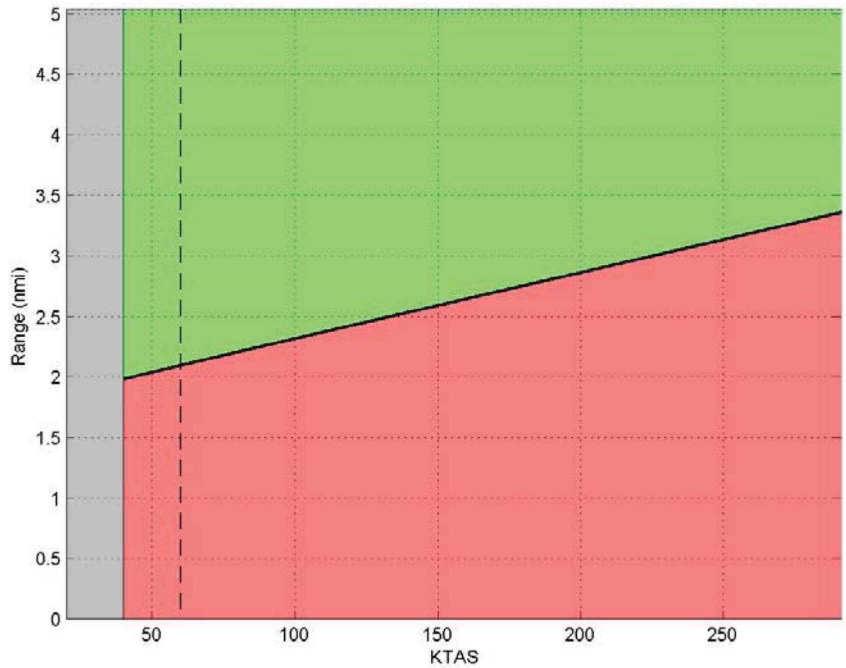


Figure D-17 **Cooperative Intruders, 1500 fpm Climb Rate, 10000' MSL ≤ Altitude < 18000'**

D.4.3 Combining Vertical and Horizontal Maneuver Requirements

Figure D-18 through Figure D-20 show the range requirements for the vertical and horizontal maneuvers as a function of UA Airspeed in KTAS when the encounter begins. The range when the UA begins to maneuver must be above the respective lines for the maneuver type and performance available. Note that the horizontal maneuvers drive range requirements as long as a minimum of 500 fpm vertical rate is sustainable.

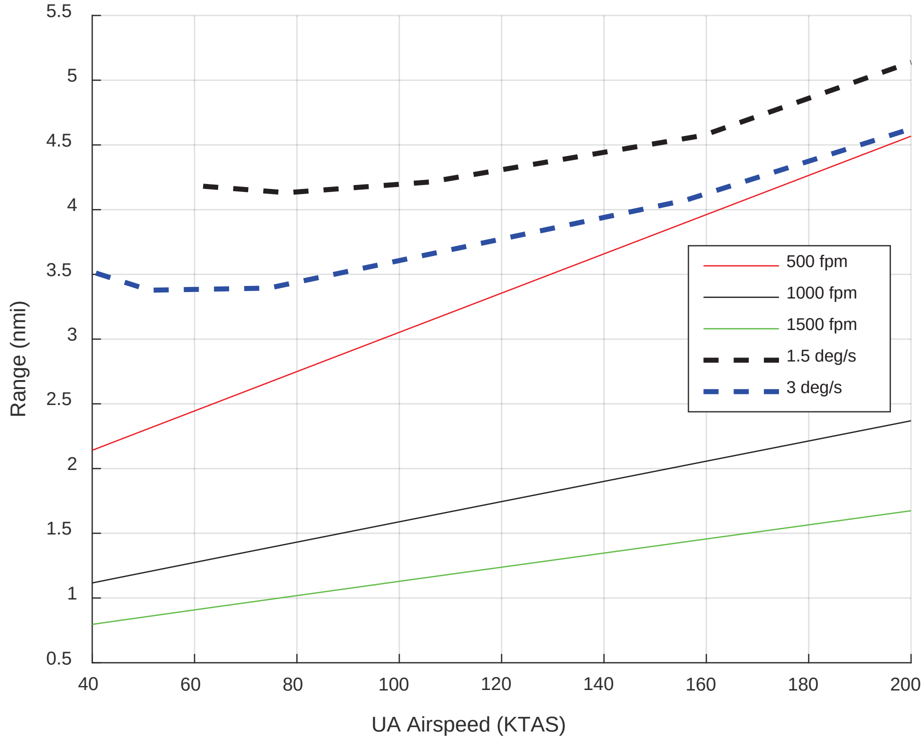
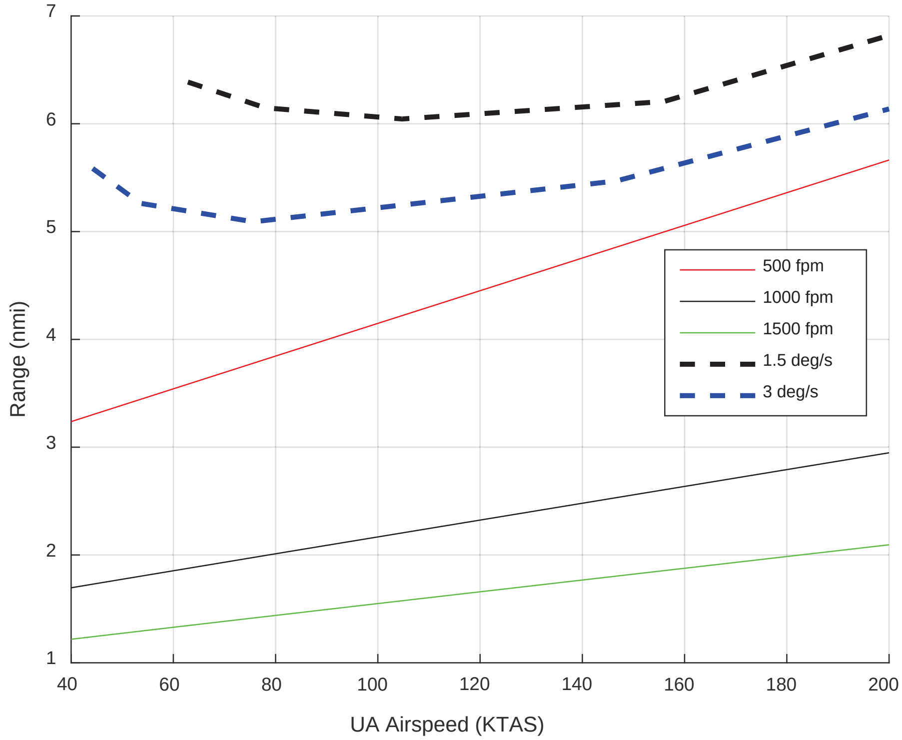


Figure D-18 **Non-Cooperative Intruders, Horizontal & Vertical Maneuver, Altitude < 10000'**



<u>Figure D-19</u> **Cooperative Intruders, Horizontal & Vertical Maneuver, Altitude < 10000'**

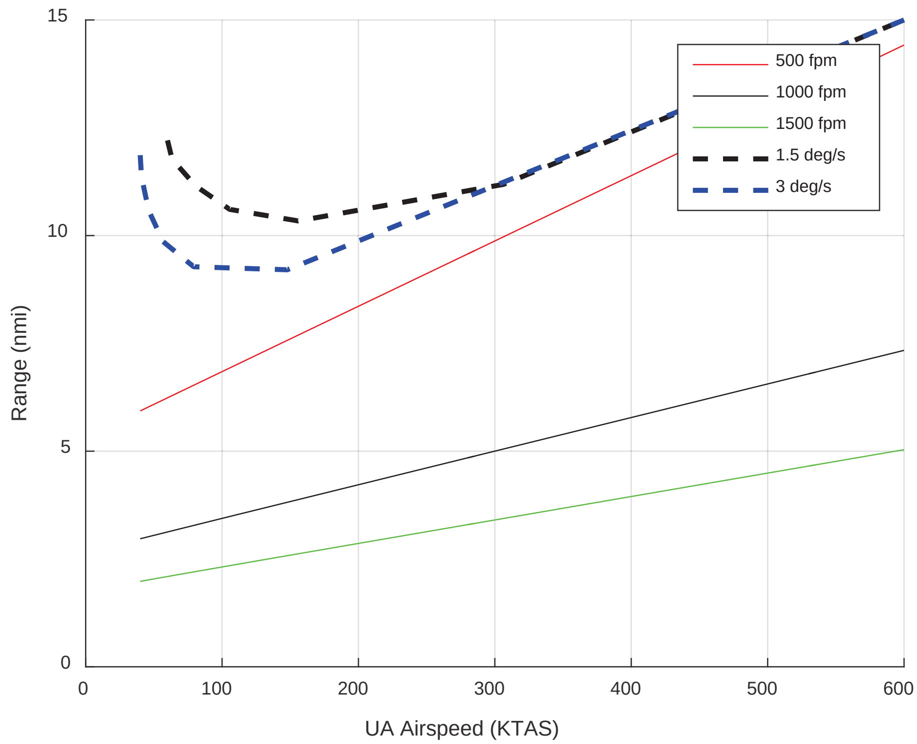


Figure D-20 **Horizontal & Vertical Maneuver, 10000' MSL ≤ Altitude < 18000'**

D.5 References

1. Jack, D. P., Hoffler, K. D., and Johnson, S. C., "An Assessment of Unmanned Aircraft System Level-Turn Maneuver Performance Requirements in Relation to a Quantified Well Clear Definition," 14th American Institute of Aeronautics and Astronautics (AIAA) Atmospheric Flight Mechanics Conference, June 2015.
2. Jack, D. P., Hoffler, K. D., and Johnson, S. C., "Evaluation of the Trade Space Between UAS Maneuver Performance and SAA System Performance Requirements," National Aeronautics and Space Administration (NASA) CR-2014-218264, May 2014.
3. Jack, D. P., Hoffler, K. D., and Johnson, S. C., "Exploration of the Trade Space between Unmanned Aircraft Systems Descent Maneuver Performance and Sense-and Avoid System Performance Requirements," 14th AIAA Aviation Technology, Integration, and Operations Conference, June 2014.
4. Code of Federal Regulations Title 14, §91.113, Part 91 General Operating and Flight Rules, Subpart B, Flight Rules.
5. Kochenderfer, M., et al., "Uncorrelated encounter model of the National Airspace System Version 1.0," Massachusetts Institute of Technology Lincoln Laboratory, Project Report ATC-345, 2008.

E APPENDIX E LATENCY ANALYSIS

The Detect and Avoid (DAA) system described in these Minimum Operational Performance Standards (MOPS) consists of a series of independent systems that together provide the DAA function. As such, existing literature (e.g., RTCA Document 260B (DO-260B), DO-185B, etc.) defines latency requirements for individual subsystems of the DAA system. This appendix analyzes how latency at the subsystem level affects DAA system performance and maps it to how latency requirements are derived for DAA.

E.1 Definitions and Terminology

Various definitions of latency exist in literature; thus, to ensure clarity in this appendix, the following definitions will be used within this appendix (refer to Figure E-1).

- **Total Latency:** The time between the measurement of state data and its arrival at an interface or its use. Commonly this is not known in real-time but can be determined by analysis or bench measurements of flight hardware.
- **Compensated Latency:** Amount of total latency (in seconds (sec)) that is compensated by extrapolation of the measured data. In order to compensate for latency, avionics extrapolate state data to a new Time of Applicability. Since total latency may not be known in real time, this Time of Applicability is not always correct, introducing Latency Compensation Error.
- **Latency Compensation Error:** Since total latency is not commonly known in real time, the compensation of latency cannot be done precisely. The difference between the attempted compensation and the compensation that should have happened is the "Latency Compensation Error." This error is in seconds and can be negative (over-compensation) or positive (under-compensation). Latency compensation error is measured with respect to a specific time of applicability and is a measure of how precisely data was extrapolated. Adding latency compensation errors is done using root mean squares.
- **State Uncertainty due to Latency Compensation:** Over- or under-compensation of latency results in the introduction of state uncertainty. Additionally, latency compensation is commonly not aware of real-time operational dynamics, generating additional errors when the compensation uses dynamics that are not representative of actual dynamics (e.g., straight line extrapolation when the aircraft is turning). Lastly, latency compensation uses reported states that are inherently uncertain as well (e.g., velocity derived from the Global Positioning System (GPS). Thus, additional state uncertainty is introduced to states compensated for latency.

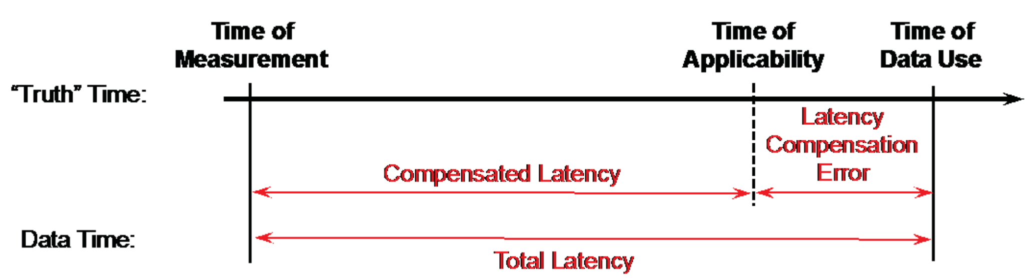


Figure E-1 **Notional Representation of Latency Terminology**

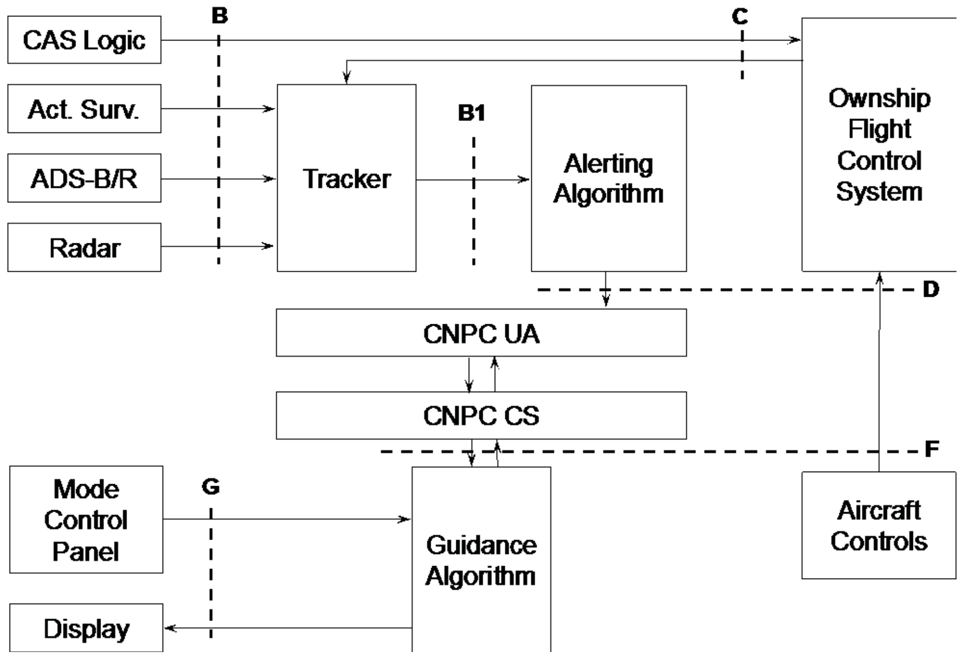
The latency numbers provided in this appendix are to be considered as Not-To-Exceed values; i.e., upper or lower bounds. Table E-1 summarizes the required latency allocation for each subsystem; it is recommended that manufacturers follow these allocations to ensure interoperability and interchangeability among subsystems from different vendors. For the same reason it is recommended that manufacturers publish latency specifications for their equipment. As used in this appendix, the numbers listed in Table E-1 represent the latency as observed at the input interface of the next, downstream subsystem. For example, total ADS-B latency is 2.5 seconds at the input interface of the DAA Tracker.

Table E-1 Allowable Latency Contributions for DAA Subsystems

Subsystem	Total Latency (Seconds)	Latency Compensation Error (Milliseconds) (ms)	Source of Requirement
ADS-B (1090ES/UAT)	2.5	-200/+400	DO-260/282
ADS-B (ADS-R)	3.5	-300/+500	DO-260/282
Radar	0.5	30	DO-TBD (MOPS for Air-to-Air Radar for Traffic Surveillance (RTCA Paper No. 170-16/ SC228 034))
Active Surveillance (Mode C/S)	1.0	500	DO-185
DAA Tracker	1.0	100	2.2.3.2.3
DAA Alerting Algorithm	0.1	0	2.2.4.3.4.1
CNPC Data Link	Maximum: 2.0 Nominal: 0.2	0	Appendix K
DAA Guidance Processing	0.2	0	2.2.4.4
DAA Display	0.5	0	2.2.5.4.1
Command-To-Execute	Maximum: 2.0 Nominal: 0.2	0	Appendix K

E.2 Data Flow Diagram

Figure E-2 shows a simplified data flow diagram. It is not intended to be a system architecture diagram, but rather show the paths that data takes through a notional DAA system, and thus where latency can be introduced. The interfaces in Figure E-2 map to the interfaces in Figure 2-1 in the main body of these MOPS. Note that while it is assumed to be the case here, the control station does not necessarily need to be on the ground.



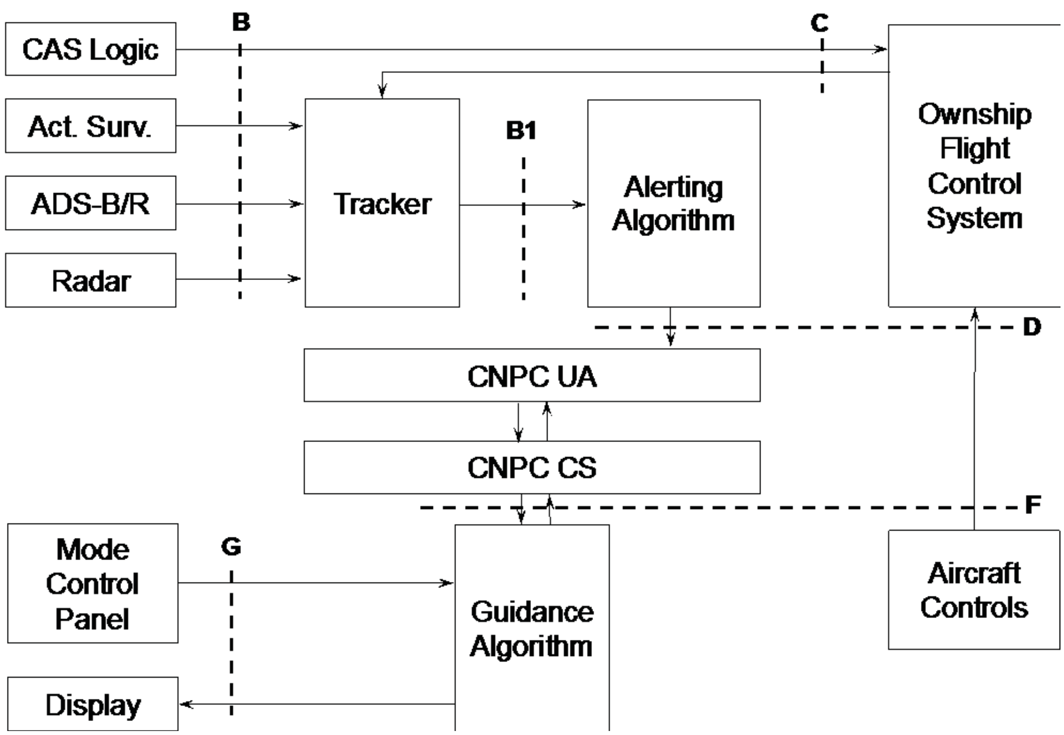


Figure E-2 **Simplified Data Flow Diagram for DAA Systems**

E.2.1 Interface B

The sensors delivering surveillance data to the DAA tracker onboard the ownship are all designed to meet latency requirements defined in separate MOPS documents. Table E-2 summarizes the latency values for the various subsystems. Note that in some of these requirements are derivative in the sense that the maximum latency is assumed to be the worst-case combination of measurement and update rate. For example, while an update may occur at 1 Hertz (Hz), if the measurement occurs immediately after an update, the data will have aged by 1 second by the time it is output.

.

Table E-2 Latency Requirements from MOPS of Sensors Used in DAA (Interface B)

Sensor/Track	Total Latency	Latency Compensation Error	Notes
1090ES ADS-B	2.5 sec	-200/+400 ms	RTCA DO-260B
UAT ADS-B	2.5 sec	-200/+400 ms	RTCA DO-282B
ADS-R	3.5 sec	-300/+500	RTCA DO-260B/282B and Surveillance Broadcast Services (SBS) Service Definition Document
Mode C Active Surv.	1.0 sec	500 ms	Assuming 1 Hz Updates
Mode S Active Surv.	1.0 sec	500 ms	Assuming 1 Hz Updates
Radar	0.5 sec	30 ms	MOPS for Air-to-Air Radar for Traffic Surveillance, RTCA DO-TBD (RTCA Paper No. 170-16/ SC228-034)

ADS-B/ADS-R Traffic

The maximum allowable total latency in ADS-B messages at the point of transmission from the intruder is 2.0 seconds, with a latency compensation error of -200 ms to +400 ms. Upon reception by the ownship, the maximum allowable processing time for the ADS-B message before it is delivered to the DAA processor is 0.5 seconds all of which is allowed to be uncompensated, thus resulting in a maximum total latency value of 2.5 seconds.

In the case of an ADS-R intruder, the ADS-R ground system is allowed to add a maximum of 1.0 seconds of latency with a compensation error of 0.1 seconds. Total latency for an ADS-R intruder is thus 3.5 seconds.

Active Surveillance and Collision Avoidance System (CAS) Logic

The TCAS II MOPS (DO-185B) does not explicitly define requirements for data latency. However, these DAA MOPS require a 1 Hz update, resulting in a maximum of 1 second of latency.

__Note:__ *Intruders with only a transponder onboard and a TCAS tau of greater than 60 will be interrogated every 5 seconds, potentially introducing an additional 4 seconds data age which may also need to be compensated.*

Refer to Subsection E.3 for latency considerations specific to the CAS logic in TCAS II systems (Class 2).

Radar Traffic

The maximum allowable total latency for radar data as defined in the MOPS for Air-to-Air Radar for Traffic Surveillance, RTCA DO-TBD (RTCA Paper No. 170-16/SC228-034) is 0.5 seconds. There is a recommendation that compensation error be limited to 30 ms.

E.2.2 Interface B1

The DAA tracker is required to generate track estimates at least once per second. Thus, maximum additional total latency introduced by the tracker is 1 second. These MOPS also limit the latency compensation error to 1.0 second at Interface B1 and Interface G. Using the root sum square method to combine compensation errors, the compensation error allowed for the tracker is 900 ms. Table E-3 summarizes latency values at Interface B1.

Table E-3 Latency Values at Interface B1

Sensor/Track	Total Latency	Latency Compensation Error
1090ES ADS-B	3.5 sec	1.0 sec
UAT ADS-B	3.5 sec	1.0 sec
ADS-R	4.5 sec	1.0 sec
Mode C Active Surv.	2.0 sec	1.0 sec
Mode S Active Surv.	2.0 sec	1.0 sec
Radar	2.0 sec	1.0 sec

E.2.3 Interface C

Global Navigation Satellite System (GNSS) industry standards as well as DO-317B limit total latency of ownship state data to 200 ms at the output of the GNSS equipment.

These MOPS allow for the use of ownship data as well as radar data up to 2.6 seconds in age. While the total latency associated with the data at Interface C does not change from this requirement, the tracker uses data that is allowed to be up to 2.6 seconds older.

E.2.4 Interface D

The Alerting Algorithm is triggered at least once per second and within 100 ms of reception of a new track update from the DAA tracker as required by these MOPS.

Note that alerting is not required to occur onboard the ownship. Rather, the requirement is for the track data to be prioritized according to threat level for the tracked targets. This can be achieved by running the alerting algorithm onboard the ownship, or, alternatively, the tracker can perform the prioritization, and the alerting decision can occur in the Control Station. In either architecture, the sum of total latency added by the tracker and alerting algorithm is limited to a total of 1.1 seconds.

Table E-4 Latency Values at Interface D

Sensor/Track	Total Latency	Latency Compensation Error
1090ES ADS-B	3.6 sec	1.0 sec
UAT ADS-B	3.6 sec	1.0 sec
ADS-R	4.6 sec	1.0 sec
Mode C Active Surv.	3.1 sec	1.0 sec
Mode S Active Surv.	3.1 sec	1.0 sec
Radar	3.1 sec	1.0 sec

E.2.5 Interface F

The C2 MOPS developed by RTCA Special Committee 228 (SC-228) recommends that a CNPC link limit fade durations to less than 2 seconds, which implies that in a worst-case situation a downlink message may be delayed by up to 2 seconds. Thus, the CNPC link has the potential to add a maximum of 2 seconds of total latency. Under nominal conditions, as discussed in Appendix D, the latency added is 200 ms. Both cases are tracked here for completeness.

Table E-5 Latency Values at Interface F

Sensor/Track	Maximum Total Latency	Nominal Total Latency	Latency Compensation Error
1090ES ADS-B	5.6 sec	3.8 sec	1.0 sec
UAT ADS-B	5.6 sec	3.8 sec	1.0 sec
ADS-R	6.6 sec	4.8 sec	1.0 sec
Mode C Active Surv.	5.1 sec	3.3 sec	1.0 sec
Mode S Active Surv.	5.1 sec	3.3 sec	1.0 sec
Radar	5.1 sec	3.3 sec	1.0 sec

E.2.6 Interface G

The DAA Guidance Processing is required to generate guidance within 100 ms or receiving new track data. Additionally, an additional 0.5 seconds of latency is allowed between the reception of surveillance data by the display and its appearance on the screen such that it is visible to the pilot. Together this adds another 0.6 seconds of total latency, as outlined in Table E-6.

Table E-6 Latency Values at Interface G

Sensor/Track	Maximum Total Latency	Nominal Total Latency	Latency Compensation Error
1090ES ADS-B	6.2 sec	4.4 sec	1.0 sec
UAT ADS-B	6.2 sec	4.4 sec	1.0 sec
ADS-R	7.2 sec	5.4 sec	1.0 sec
Mode C Active Surv.	5.7 sec	3.9 sec	1.0 sec
Mode S Active Surv.	5.7 sec	3.9 sec	1.0 sec
Radar	5.7 sec	3.9 sec	1.0 sec

E.2.7 Additional Total Latency Between Tracker and Display

Since the DAA tracker is onboard the ownship, the last extrapolation of data before its display to the pilot may occur onboard the aircraft. As a result, the data displayed to the pilot will age by the time it takes for the track data arrive at the display by at least 0.9 seconds. This additional data age differs from latency compensation error; the latency compensation error quantifies the uncertainty of the *extrapolated* data around its time of applicability, while this data age is effectively additional total latency after the data has been extrapolated.

If additional steps are taken to compensate for this additional total latency, manufacturers must ensure that the alerting and guidance processing algorithms act on the same data; i.e., no additional latency compensation should occur between alerting and guidance processing.

E.2.8 End-To-End Latency

In response to an alert or guidance, the pilot will contact ATC to determine a suitable maneuver, or a pilot may elect to immediately maneuver. Once the pilot does command a maneuver, the MOPS assumes a command-to-execute latency of ≤ 2 seconds. Combining the total latencies with this command-to-execute delay results in the values as shown in Table E-7 (nominal numbers assume a one-way 200 ms command-to-execute). The values in Table E-7 represent the maximum amount of time between a sensor measurement of intruder data until the first movement of the control surfaces on the UA.

Table E-7 End-To-End Latency

Sensor/Track	Nominal Time Difference	Maximum Time Difference
1090ES ADS-B	6.4 sec	10.0 sec
UAT ADS-B	6.4 sec	10.0 sec
ADS-R	7.4 sec	11.0 sec
Mode C Active Surv.	4.9 sec	8.5 sec
Mode S Active Surv.	4.9 sec	8.5 sec
Radar	4.9 sec	8.5 sec

E.3 Interoperability Considerations of Class 2 Systems

The TCAS II MOPS (DO-185B) does not explicitly define requirements for data latency. It does, however, limit system delay:

> *TCAS II equipment shall display the correct Resolution Advisory (RA) within 1.5 seconds after receipt of the first reply that causes the target's track indicate the need for an RA. (DO-185B, Subparagraph 2.2.4.2)*

Additionally, TCAS assumes that a pilot responds within 5 seconds of being alerted. Even if automated, a UA pilot will likely still require some time to respond to a Resolution Advisory. Lastly, a pilot responding to an RA while onboard the aircraft will experience less delay between moving the flight controls than the 2-second delay assumed as part of these MOPS.

This Page Intentionally Left Blank

F APPENDIX F EXAMPLE FUNCTIONAL DESCRIPTION FOR AIRBORNE SURVEILLANCE DATA PROCESSOR (ASDP) SUBSYSTEM

F.1 Introduction

In order to satisfy the Detect and Avoid (DAA) functional requirements detailed in Appendix Q and Subparagraph 2.2.3.2 of these Minimum Operational Performance Standards (MOPS), a sample tracker algorithm must be implemented. This appendix presents the description of an example implementation for an airborne Track Processing Subsystem (TPS) algorithm, which is a part of the Unmanned Aircraft (UA) DAA processor. The main function of the TPS algorithm is to receive surveillance data from various sensors, form a single track for each detected target and present the track information together with ownship information to the DAA algorithm so it can perform the alerting and guidance functions contained in these MOPS.

The tracking algorithms in this appendix were developed by the Air Traffic Systems Division of ARCON Corporation under contract # DTFACT-15-D-00004 initiated by the Federal Aviation Administration (FAA) William J. Hughes Technical Center (WJHTC) Surveillance Branch, ANG-C33. The associated software was developed as a reference implementation to show the availability of the kind of technology which could provide such a tracking capability. Further efforts would be required to develop a fully functional and operational set of tracker software for use in a commercial DAA system. While satisfying the key requirements in Subparagraph 2.2.3.2, this tracker is not necessarily designed to perform all the functionalities described in the MOPS. This sample tracker does not prioritize the tracks or perform the report validity checks provided in Subparagraph 2.2.3.2.1.3.1 through Subparagraph 2.2.3.2.1.3.4.2.

F.2 Assumptions

The Active Surveillance Transponder (AST) sensor detects aircraft equipped with Secondary Surveillance Radar (SSR) transponders, either Air Traffic Control Radar Beacon System (ATCRBS) or Mode S, and provides range, azimuth, altitude, aircraft International Civil Aviation Organization (ICAO) address and time of applicability for Mode S equipped aircraft.

Automatic Dependent Surveillance-Broadcast (ADS-B) and optionally ADS-Rebroadcast (ADS-R) information are received by a compliant 1090ES receiver installed on the UAS.

ADS-B and ADS-R reports have been passed by all validity checks and quality monitoring.

A radar sensor compliant with the Air-to-Air Radar MOPS,[59] provides surveillance of intruders to enable detection of non-cooperative intruders.

Ownship state parameters (position, velocity, attitude and time of applicability) and their accuracies are available to the TPS.

[59] Minimum Operational Performance Standards (MOPS) for Air-to-Air Radar for Traffic Surveillance, RTCA Paper No. 170-16/SC228-034

F.3 Airborne Track Processing Subsystem

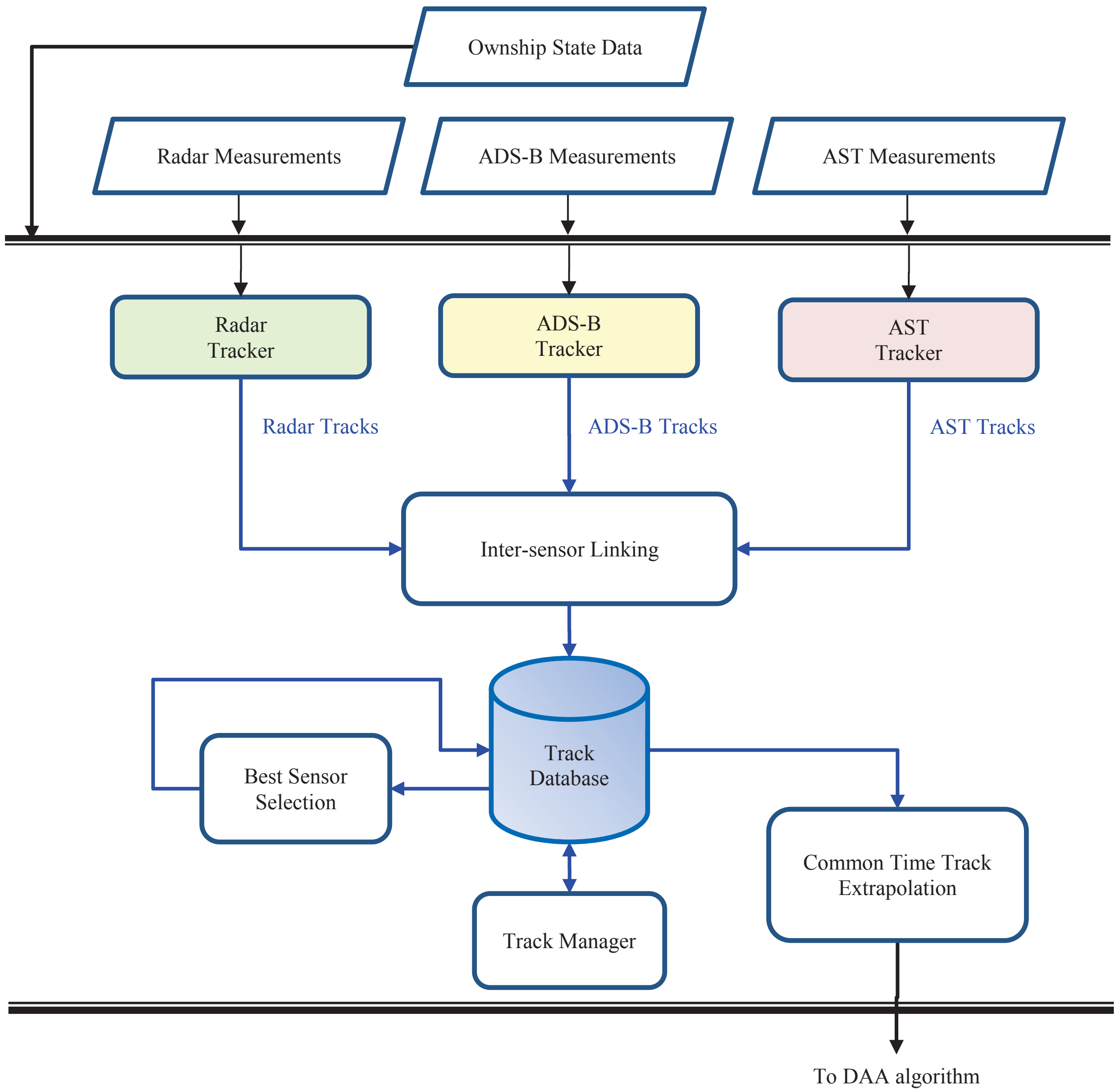


Figure F-1 **Surveillance Processing Module**

The TPS is responsible for:

1. Receiving sensor data from various sensors
2. Establishing tracks for each detected target for each sensor
3. Identifying and linking tracks of the same target coming from different sensors
4. Finding the best sensor track among the linked tracks for horizontal state reporting and the best sensor track for vertical state reporting
5. Extrapolating the estimated position and velocity to a common time epoch
6. Sending the information to the DAA algorithm processing.

The TPS module consists of the following sub functions as shown in Figure F-1

1. Radar Tracker
2. AST Tracker
3. ADS-B Tracker
4. Inter Sensor Linking
5. Track Database
6. Best Sensor Selection
7. Track Manager
8. Common Time Track Extrapolation

F.4 Radar Tracker

Figure F-2 illustrates the radar tracker architecture. The radar tracker receives measurements from the radar sensor. The measurements, at minimum, will contain the following parameters:

1. Track Number
2. Range (ρ)
3. Range Rate ($\dot{\rho}$)
4. Bearing (β)
5. Elevation (ϵ)
6. Time of measurement (t)
7. Range Error Standard Deviation (σ_ρ)
8. Range Rate Error Standard Deviation ($\sigma_{\dot{\rho}}$)
9. Bearing Error Standard Deviation (σ_β)
10. Elevation Error Standard Deviation (σ_ϵ)

The range, range rate, bearing and elevation are measured with respect to the ownship frame. At the receipt of a measurement, the Track/Measurement Association function searches the track records in the radar track database to find the track record that has the same track number as that in the measurement. If the measurement can be associated with the a track the Track/Measurement pair is sent to the Track Establishment module or Extended Kalman Filter module depending on whether the track has been established or not. If a track is not found, the measurement is sent to the Track Initiation function to start a track record.

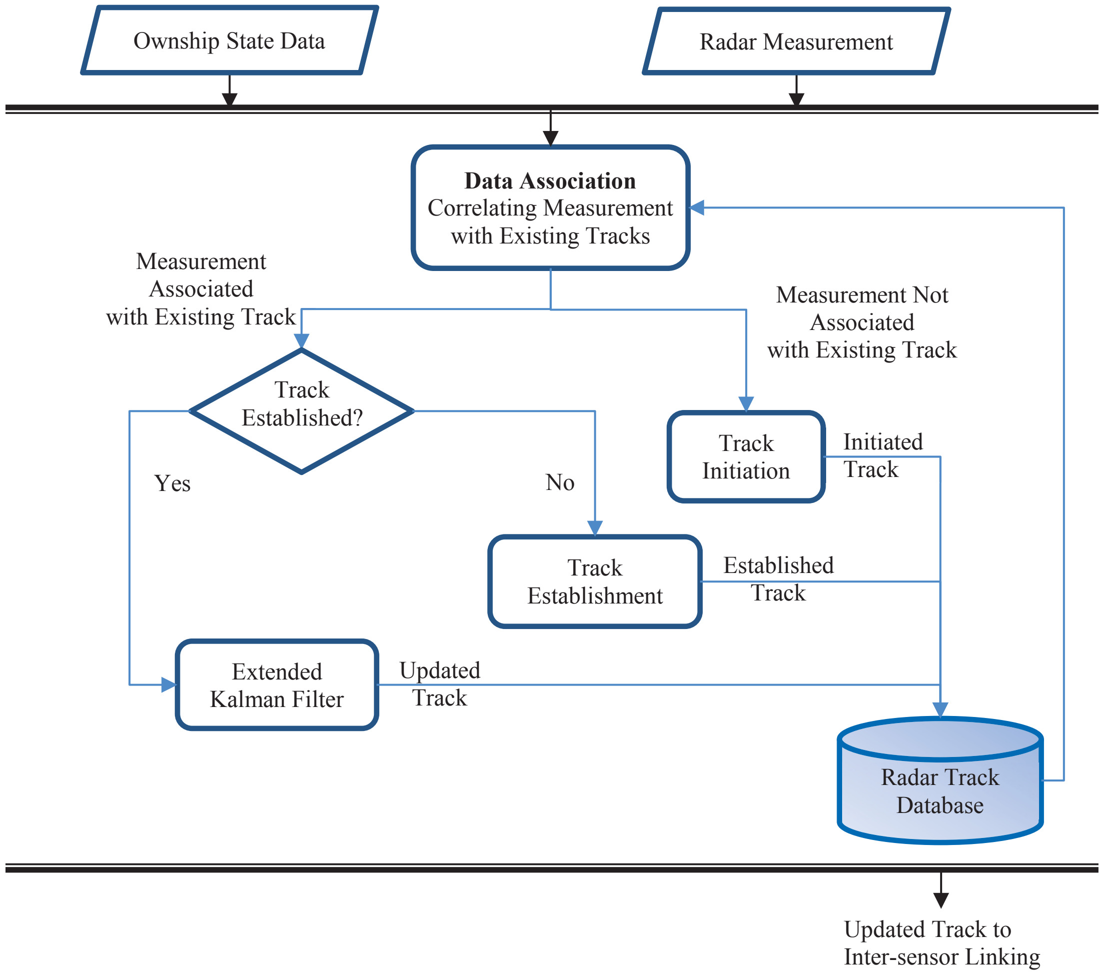


Figure F-2 **Radar Tracker**

F.4.1 Track Initiation

Radar tracks are maintained in ENU (East, North, Up) coordinate system local to the ownship. Thus, Track Initiation function starts a track record containing the following parameters:

1. Position in ownship ENU (East, North, Up)
2. Velocity in target local ENU (East velocity, North velocity, Up velocity)
3. Position in World Geodetic System – 1984 (WGS-84) coordinates (latitude, longitude, altitude)
4. State vector error covariance matrix (P)
5. Track Time
6. Track Number

F.4.1.1 Position in Ownship ENU

The measured position in ownship ENU is found as follows:

$$\begin{bmatrix} e \\ n \\ u \end{bmatrix} = \mathbf{M}(\alpha, \gamma, \eta) \begin{bmatrix} \rho \cos \epsilon \sin \beta \\ \rho \cos \epsilon \cos \beta \\ \rho \sin \epsilon \end{bmatrix} \tag{F5.1}$$

where:

$\rho =$ range measurement in meters (m)

$\beta =$ bearing measurement in radians (rad)

$\epsilon =$ elevation measurement (rad)

The rotation matrix, $\mathbf{M}(\alpha, \gamma, \eta)$, which rotates the measurement from ownship frame coordinates to ownship ENU coordinates is given by:

$$\begin{gathered} \mathbf{M}(\alpha, \gamma, \eta) = \begin{bmatrix} m_{00} & m_{01} & m_{02} \\ m_{10} & m_{11} & m_{12} \\ m_{20} & m_{21} & m_{22} \end{bmatrix} \\ m_{00} = \cos \eta \cos \gamma \\ m_{01} = \sin \eta \cos \alpha + \cos \eta \sin \gamma \sin \alpha \\ m_{02} = -\sin \eta \sin \alpha + \cos \eta \sin \gamma \cos \alpha \\ m_{10} = -\sin \eta \cos \gamma \\ m_{11} = \cos \eta \cos \alpha - \sin \eta \sin \gamma \sin \alpha \\ m_{12} = -\cos \eta \sin \alpha - \sin \eta \sin \gamma \cos \alpha \\ m_{20} = -\sin \gamma \\ m_{21} = \cos \gamma \sin \alpha \\ m_{22} = \cos \gamma \cos \alpha \end{gathered} \tag{F5.2}$$

where

$\alpha =$ ownship pitch angle (rad)

$\gamma =$ ownship roll angle (rad)

$\eta =$ ownship yaw angle (rad)

The position vector of target in ownship ENU is set as $[e \quad n \quad u]'$ from (F5.1).

F.4.1.2 Velocity in Target Local ENU

The velocity vector in target local ENU is set as $[0 \quad 0 \quad 0]'$.

F.4.1.3 Position in Geodetic Coordinates

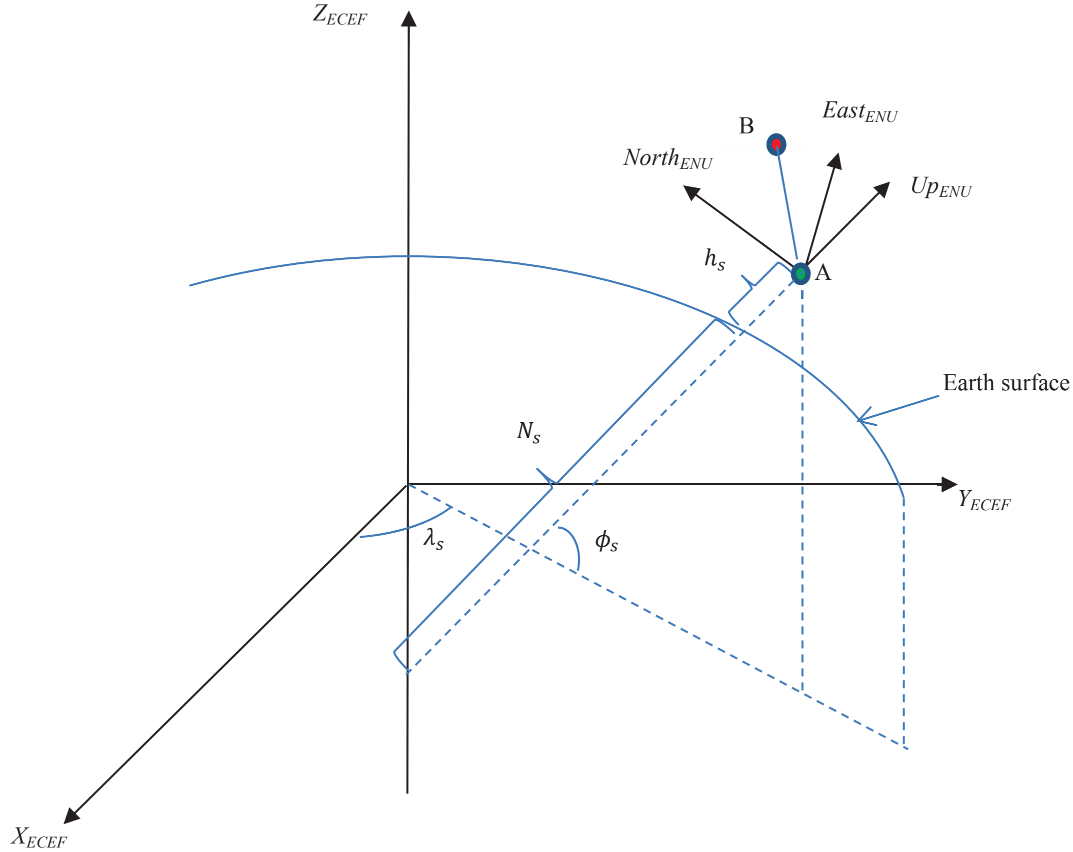


Figure F-3 **Geometry of Ownship/Target in an ECEF Coordinate System**

Figure F-3 shows the target (B) position in ownship (A) ENU coordinate system, where ϕ_s, λ_s and h_s are latitude, longitude and altitude of the ownship, respectively. Hence the ownship's Earth-Centered, Earth-Fixed (ECEF) position is calculated by:

$$\begin{bmatrix} X_s \\ Y_s \\ Z_s \end{bmatrix} = \begin{bmatrix} (N_s + h_s)\cos\phi_s \cos\lambda_s \\ (N_s + h_s)\cos\phi_s \sin\lambda_s \\ (N_s(1-\varepsilon^2) + h_s)\sin\phi_s \end{bmatrix} \tag{F5.3}$$

where:

$\phi_s =$ ownship geodetic latitude (rad)

$\lambda_s =$ ownship geodetic longitude (rad)

$h_s =$ ownship geodetic altitude (m)

$N_s = a/\sqrt{1-\varepsilon^2 \sin^2\phi_s}$

$a =$ semi major axis of the Earth = 6.378137×10^6 m

$\varepsilon =$ first eccentricity of the Earth = 0.081819190842622

If the altitude of the ownship is measured as height above Mean Sea Level (MSL) from a barometric sensor, it should be converted to WGS-84 Height Above Ellipsoid (HAE) using the following steps:

$$\begin{aligned}
\xi(\phi_s) &= g\,\frac{1 + k\sin^2\phi_s}{\sqrt{1-\varepsilon^2\sin^2\phi_s}} \\
R(\phi_s) &= \frac{a}{1 + f + m_r - 2f\sin^2\phi_s} \\
h_s &= \frac{R(\phi_s)h}{\frac{R(\phi_s)\xi(\phi_s)}{\xi(\frac{\pi}{4})} - h}
\end{aligned} \tag{F5.4}$$

where

$\phi_s =$ ownship latitude (rad)

$\varepsilon =$ first eccentricity of the Earth = 0.081819190842622

$g =$ equatorial gravity = 9.7803253359 meters per second squared (m/s^2)

$\xi(\phi_s) =$ normal gravity on the surface of an ellipsoid at ϕ_s (m/s^2)

$a =$ semi major axis of the Earth = 6.378137×10^6 m

$b =$ semi minor axis of the Earth = 6.3567523142×10^6 m

f =flattening of earth = $(a-b)/a$

$m_r =$ gravity ratio = 0.003449787

$R(\phi_s) =$ radius of earth at ϕ_s (m)

$h =$ measured ownship height above MSL

$h_s =$ ownship geodetic height above ellipsoid

The target position with respect to the ownship in ECEF coordinate system is calculated as

$$\begin{bmatrix} X_{t-s} \\ Y_{t-s} \\ Z_{t-s} \end{bmatrix} = \mathbf{T}(\phi_s, \lambda_s) \begin{bmatrix} e \\ n \\ u \end{bmatrix} \tag{F5.5}$$

The transformation matrix $\boldsymbol{T}(\phi_s, \lambda_s)$ is given by

$$\mathbf{T}(\phi_s, \lambda_s) = \begin{bmatrix} -\sin\lambda_s & -\sin\phi_s\cos\lambda_s & \cos\phi_s\cos\lambda_s \\ \cos\lambda_s & -\sin\phi_s\sin\lambda_s & \cos\phi_s\sin\lambda_s \\ 0 & \cos\phi_s & \sin\phi_s \end{bmatrix} \tag{F5.6}$$

where

$\phi_s =$ ownship latitude (rad)

$\lambda_s =$ ownship longitude (rad)

The target position in ECEF coordinates is calculated as

$$\begin{bmatrix} X_t \\ Y_t \\ Z_t \end{bmatrix} = \begin{bmatrix} X_{t-s} \\ Y_{t-s} \\ Z_{t-s} \end{bmatrix} + \begin{bmatrix} X_s \\ Y_s \\ Z_s \end{bmatrix} \tag{F5.7}$$

The target position in WGS-84 geodetic coordinates is obtained following the 15-step process presented below (extracted from RTCA DO-317A):

$$\begin{aligned}
r_{ecef} &= \sqrt{{X_t}^2 + {Y_t}^2} \\
E^2 &= a^2 - b^2 \\
F &= 54b^2{Z_t}^2 \\
G &= r_{ecef}^2 + (1-\varepsilon^2){Z_t}^2 - \varepsilon^2 E^2 \\
C &= \frac{\varepsilon^4 F r_{ecef}^2}{G^3} \\
S &= \sqrt[3]{1 + C + \sqrt{C^2 + 2C}} \\
P &= \frac{F}{3\left(S + \frac{1}{S} + 1\right)^2 G^2} \\
Q &= \sqrt{1 + 2\varepsilon^4 P} \\
r_o &= \frac{-P\varepsilon^2 r_{ecef}}{1+Q} + \sqrt{\frac{a^2}{2}\left(1 + \frac{1}{Q}\right) - \frac{P(1-\varepsilon^2){Z_t}^2}{Q(1+Q)} - \frac{P r_{ecef}^2}{2}} \\
U &= \sqrt{\left(r_{ecef} - \varepsilon^2 r_o\right)^2 + {Z_t}^2} \\
V &= \sqrt{\left(r_{ecef} - \varepsilon^2 r_o\right)^2 + (1-\varepsilon^2){Z_t}^2} \\
Z_o &= \frac{b^2 Z_t}{aV} \\
\phi_t &= \tan^{-1}\left(\frac{Z_t + \varepsilon'^2 Z_o}{r_{ecef}}\right)
\end{aligned} \tag{F5.8}$$

$$\lambda_t = \tan^{-1}\left(\frac{Y_t}{X_t}\right)$$

$$h_t = U\left(1 - \frac{b^2}{aV}\right)$$

where

$a =$ semi major axis of the Earth = 6.378137×10^6 m

$b =$ semi minor axis of the Earth = 6.3567523142×10^6 m

$\varepsilon =$ first eccentricity of the Earth = 0.081819190842622

$\varepsilon' =$ second eccentricity of the Earth = 0.082094437935831

$\phi_t =$ target latitude (rad)

$\lambda_t =$ target longitude (rad)

$h_t =$ target geodetic altitude (m)

F.4.1.4 State Vector Error Covariance

The measurement error covariance in ownship frame coordinates is calculated as follows:

$$\mathbf{R}_{frm} = \mathbf{N}(\rho, \beta, \epsilon) \begin{bmatrix} \sigma_\rho^2 & 0 & 0 \\ 0 & \sigma_\beta^2 & 0 \\ 0 & 0 & \sigma_\epsilon^2 \end{bmatrix} \mathbf{N}'(\rho, \beta, \epsilon) \tag{F5.9}$$

where

$\sigma_\rho =$ range measurement error standard deviation (m)

$\sigma_\beta =$ bearing measurement error standard deviation (rad)

$\sigma_\epsilon =$ elevation measurement error standard deviation (rad)

The matrix $\mathbf{N}(\rho, \beta, \epsilon)$ is given by

$$\mathbf{N}(\rho,\beta,\epsilon) = \begin{bmatrix} n_{00} & n_{01} & n_{02} \\ n_{10} & n_{11} & n_{12} \\ n_{20} & n_{21} & n_{22} \end{bmatrix}$$
$$n_{00} = \cos\epsilon\sin\beta$$
$$n_{01} = \rho\cos\epsilon\cos\beta$$
$$n_{02} = -\rho\sin\epsilon\sin\beta$$
$$n_{10} = \cos\epsilon\cos\beta \tag{F5.10}$$
$$n_{11} = -\rho\cos\epsilon\sin\beta$$
$$n_{12} = -\rho\sin\epsilon\cos\beta$$
$$n_{20} = \sin\epsilon$$
$$n_{21} = 0$$
$$n_{22} = \rho\cos\epsilon$$

where

$\rho =$ range measurement (m)

$\beta =$ bearing measurement (rad)

$\epsilon =$ elevation measurement (rad)

The measurement error covariance in ownship ENU coordinates is calculated as follows:

$$\mathbf{R}_{enu} = \mathbf{M}(\alpha,\gamma,\eta)\mathbf{R}_{frm}\mathbf{M}'(\alpha,\gamma,\eta) \tag{F5.11}$$

where $\mathbf{M}(\alpha,\gamma,\eta)$ is found from (F5.2).

The measurement error covariance in target ENU coordinates is found from

$$\mathbf{R} = \mathbf{L}(\phi_t,\lambda_t,\phi_s,\lambda_s)\mathbf{R}_{enu}\mathbf{L}'(\phi_t,\lambda_t,\phi_s,\lambda_s) \tag{F5.12}$$

The matrix $\boldsymbol{L}$ is given by

$$\mathbf{L}(\phi_t,\lambda_t,\phi_s,\lambda_s) = \begin{bmatrix} l_{00} & l_{01} & l_{02} \\ l_{10} & l_{11} & l_{12} \\ l_{20} & l_{21} & l_{22} \end{bmatrix}$$
$$l_{00} = \cos(\lambda_t - \lambda_s) \tag{F5.13}$$
$$l_{01} = \sin\phi_s\sin(\lambda_t - \lambda_s)$$
$$l_{02} = -\cos\phi_s\sin(\lambda_t - \lambda_s)$$
$$l_{10} = -\sin\phi_t\sin(\lambda_t - \lambda_s)$$

$$l_{11} = \sin\phi_t \sin\phi_s \cos(\lambda_t - \lambda_s) + \cos\phi_t \cos\phi_s$$

$$l_{12} = -\sin\phi_t \cos\phi_s \cos(\lambda_t - \lambda_s) + \cos\phi_t \sin\phi_s$$

$$l_{20} = \cos\phi_t \sin(\lambda_t - \lambda_s)$$

$$l_{21} = -\cos\phi_t \sin\phi_s \cos(\lambda_t - \lambda_s) + \sin\phi_t \cos\phi_s$$

$$l_{22} = \cos\phi_t \cos\phi_s \cos(\lambda_t - \lambda_s) + \sin\phi_t \sin\phi_s$$

where

$\phi_t =$ target latitude calculated from (F5.8) (rad)

$\lambda_t =$ target longitude calculated from (F5.8) (rad)

$\phi_s =$ ownship latitude (rad)

$\lambda_s =$ ownship longitude (rad)

The state error covariance (**P**) of the initiated track is set as

$$\mathbf{P} = \begin{bmatrix} \mathbf{R} & \mathbf{0}_{3\times3} \\ \mathbf{0}_{3\times3} & \mathbf{0}_{3\times3} \end{bmatrix} \quad \text{(F5.14)}$$

where

$\mathbf{R} =$ measurement error covariance matrix from (F5.12)

$\mathbf{0}_{3\times3} =$ 3×3 matrix of zeros

F.4.1.5 Time of Update

Time of update in the track record is set to the time of measurement.

F.4.1.6 Track Number

Track number of the track record is set to the track number in the measurement.

F.4.2 Track Establishment

If a measurement is associated with a track then the Track/Measurement pair is sent to the Track Establishment module if the track has not been established yet.

The track establishment module performs the following functions:

1. Update track's estimated position in ownship ENU
2. Initialize track's velocity in target local ENU
3. Update track's geodetic coordinates
4. Update track's state vector error covariance
5. Track time update

F.4.2.1 Position in Ownship ENU

The position vector $[e \quad n \quad u]'$ in ownship ENU is updated using the new measurement following the steps in (F5.1) and (F5.2).

F.4.2.2 Velocity in Target Local ENU

From the last geodetic coordinates of the track, the last position of the track in current ownship ENU coordinates is calculated following the steps below:

1. Ownship's current ECEF coordinates $[X_s \quad Y_s \quad Z_s]'$ is found using (F5.3).
2. Starting with track's last geodetic coordinates, track's last position ECEF coordinates $[\mathrm{X_t} \quad \mathrm{Y_t} \quad \mathrm{Z_t}]'$ is also found using (F5.3).
3. The relative position of track's last position with respect to the ownship's current position in ECEF coordinates is given by:

$$\begin{bmatrix} X_{t-s} \\ Y_{t-s} \\ Z_{t-s} \end{bmatrix} = \begin{bmatrix} X_t \\ Y_t \\ Z_t \end{bmatrix} - \begin{bmatrix} X_s \\ Y_s \\ Z_s \end{bmatrix} \tag{F5.15}$$

4. Track's last position $[\mathrm{e_o} \quad \mathrm{n_o} \quad \mathrm{u_o}]'$ in current ownship local ENU coordinates is calculated from:

$$\begin{bmatrix} e_o \\ n_o \\ u_o \end{bmatrix} = \mathbf{T}'(\phi_s, \lambda_s) \begin{bmatrix} X_{t-s} \\ Y_{t-s} \\ Z_{t-s} \end{bmatrix} \tag{F5.16}$$

The transformation matrix $\mathbf{T}(\phi_s, \lambda_s)$ is given by (F5.6)

The time difference between the current measurement and the last update of the track is found by,

$\Delta t =$ measurement time – track update time

The velocity of the track in ownship local ENU coordinate system is found by,

$$\begin{bmatrix} \dot{e}_1 \\ \dot{n}_1 \\ \dot{u}_1 \end{bmatrix} = \begin{bmatrix} \dfrac{e - e_o}{\Delta t} \\ \dfrac{n - n_o}{\Delta t} \\ \dfrac{u - u_o}{\Delta t} \end{bmatrix} \tag{F5.17}$$

Starting with track's position in ownship ENU $[e \quad n \quad u]'$, new geodetic coordinates $(\phi_t, \quad \lambda_t, \quad h_t)$ of track is found following the steps in (F5.5) – (F5.8).

Next, the track's velocity in target local ENU coordinates is calculated from

$$\begin{bmatrix} \dot{e}_t \\ \dot{n}_t \\ \dot{u}_t \end{bmatrix} = \mathbf{L}(\phi_t, \lambda_t, \phi_s, \lambda_s) \begin{bmatrix} \dot{e}_1 \\ \dot{n}_1 \\ \dot{u}_1 \end{bmatrix} \qquad \text{(F5.18)}$$

where

$\boldsymbol{L}(\phi_t, \lambda_t, \phi_s, \lambda_s)$ is found from (F5.13) and

$\dot{e}_t =$ East velocity of the target (m/s)

$\dot{n}_t =$ North velocity of the target (m/s)

$\dot{u}_t =$ Up velocity of the target (m/s)

F.4.2.3 Position in Geodetic Coordinates

The geodetic coordinate position in the track record is updated with $(\phi_t, \quad \lambda_t, \quad h_t)$ found in the above step.

F.4.2.4 State Vector Error Covariance

The measurement error covariance in target local ENU coordinates is found using the steps in (F5.9) – (F5.13). The state vector error covariance is updated as follows:

$$\mathbf{P} = \begin{bmatrix} \mathbf{R} & \frac{1}{\Delta t}\mathbf{R} \\ \frac{1}{\Delta t}\mathbf{R} & \frac{2}{\Delta t^2}\mathbf{R} \end{bmatrix} \qquad \text{(F5.19)}$$

F.4.2.5 Time of Update

Time of update in the track record is set to the time of measurement.

F.4.3 Extended Kalman Filter

When an associated Track/Measurement pair is sent to the Extended Kalman Filter (EKF) module in Figure F-2, perform the following steps:

1. State prediction
2. State error covariance prediction
3. Predicted measurement calculation
4. Filter gain calculation
5. State update
6. Geodetic coordinates calculation
7. Velocity calculation

8. State error covariance update
9. Track time update

F.4.3.1 State Prediction

From the last geodetic coordinates of the track, the last position of the track in current ownship ENU coordinates is calculated following the steps below:

1. Ownship's current ECEF coordinates $[X_s \quad Y_s \quad Z_s]'$ is found using (F5.3).
2. Starting with track's last geodetic coordinates, track's last position ECEF coordinates $[\mathrm{X_t} \quad \mathrm{Y_t} \quad \mathrm{Z_t}]'$ is also found using (F5.3).
3. The relative position of track's last position with respect to the ownship's current position in ECEF coordinates is given by (F5.15)
4. Track's last position $[\mathrm{e_o} \quad \mathrm{n_o} \quad \mathrm{u_o}]'$ in current ownship local ENU coordinates is calculated from (F5.16).

The last estimated velocity of the track in the current ownship ENU coordinates is found using,

$$\begin{bmatrix} \dot{e}_o \\ \dot{n}_o \\ \dot{u}_o \end{bmatrix} = \mathbf{L}'(\phi_{to}, \lambda_{to}, \phi_s, \lambda_s) \begin{bmatrix} \dot{e}_t \\ \dot{n}_t \\ \dot{u}_t \end{bmatrix} \tag{F5.20}$$

where

$\boldsymbol{L}(\phi_{to}, \lambda_{to}, \phi_s, \lambda_s)$ is found from (F5.13) and

$\phi_{to} =$ track's last estimated latitude (rad)

$\lambda_{to} =$ track's last estimated longitude (rad)

$\phi_s =$ ownship's current latitude (rad)

$\lambda_s =$ ownship's current longitude (rad)

$\dot{e}_t =$ track's last estimated East velocity in track's last local ENU (m/s)

$\dot{n}_t =$ track's last estimated North velocity in track's last local ENU (m/s)

$\dot{u}_t =$ track's last estimated Up velocity in track's last local ENU (m/s)

$\dot{e}_o =$ track's last estimated East velocity in current ownship local ENU (m/s)

$\dot{n}_o =$ track's last estimated North velocity in current ownship local ENU (m/s)

$\dot{u}_o =$ track's last estimated Up velocity in current ownship local ENU (m/s)

The time difference between the current measurement and the last update of the track is found by,

$\Delta t =$ measurement time – track's last update time

The predicted state vector of the track is found from:

$$\begin{aligned}
\hat{e} &= e_o + \Delta t\, \dot{e}_o \\
\hat{n} &= n_o + \Delta t\, \dot{n}_o \\
\hat{u} &= u_o + \Delta t\, \dot{u}_o \\
\hat{\dot{e}} &= \dot{e}_o \\
\hat{\dot{n}} &= \dot{n}_o \\
\hat{\dot{u}} &= \dot{u}_o
\end{aligned} \tag{F5.21}$$

where

$(e_o, \quad n_o, \quad u_o) =$ last track position in ownship local ENU (m)

$(\hat{e}, \quad \hat{n}, \quad \hat{u}) =$ predicted position of track in ownship local ENU (m)

$(\dot{e}_o, \quad \dot{n}_o, \quad \dot{u}_o) =$ last track velocity in ownship local ENU (m/s)

$(\hat{\dot{e}}, \quad \hat{\dot{n}}, \quad \hat{\dot{u}}) =$ predicted velocity of track in ownship local ENU (m)

F.4.3.2 State Error Covariance Predication

The state error covariance in local ENU coordinates of target's last position is converted to state error covariance in ownship local ENU coordinates as follows:

$$\mathbf{P}_o = \mathbf{UPU}' \tag{F5.22}$$

where

$\mathbf{P} =$ track's last estimated state error covariance in target's local ENU

$\mathbf{P}_o =$ track's last estimated state error covariance in ownship local ENU

and,

$$\mathbf{U} = \begin{bmatrix} \mathbf{L}'(\phi_{to}, \lambda_{to}, \phi_s, \lambda_s) & \mathbf{0}_{3\times3} \\ \mathbf{0}_{3\times3} & \mathbf{L}'(\phi_{to}, \lambda_{to}, \phi_s, \lambda_s) \end{bmatrix} \tag{F5.23}$$

where

$\phi_{to} =$ track's last estimated latitude (rad)

$\lambda_{to} =$ track's last estimated longitude (rad)

$\phi_s =$ ownship's current latitude (rad)

$\lambda_s =$ ownship's current longitude (rad)

$\mathbf{0}_{3\times3} =$ 3 × 3 matrix of zeros

and $\mathbf{L}(\phi_{to}, \lambda_{to}, \phi_s, \lambda_s)$ is found from (F5.13)

The predicted state error covariance is calculated as follows:

$$\widehat{\mathbf{P}} = \mathbf{F}\mathbf{P}_{\mathrm{o}}\mathbf{F}' + \boldsymbol{Q} \tag{F5.24}$$

where

$\widehat{\mathbf{P}} =$ predicted state error covariance

$\mathbf{P}_o =$ track's last estimated state error covariance

F is given by

$$\mathbf{F} = \begin{bmatrix} 1 & 0 & 0 & \Delta t & 0 & 0 \\ 0 & 1 & 0 & 0 & \Delta t & 0 \\ 0 & 0 & 1 & 0 & 0 & \Delta t \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \tag{F5.25}$$

Q is given by

$$\mathbf{Q} = \mathbf{G}\boldsymbol{\Gamma}\mathbf{G}' \tag{F5.26}$$

where

$$\mathbf{G} = \begin{bmatrix} 0.5\Delta t^2 & 0 & 0 \\ 0 & 0.5\Delta t^2 & 0 \\ 0 & 0 & 0.5\Delta t^2 \\ \Delta t & 0 & 0 \\ 0 & \Delta t & 0 \\ 0 & 0 & \Delta t \end{bmatrix} \tag{F5.27}$$

and

$$\boldsymbol{\Gamma} = \begin{bmatrix} \sigma_e^2 & 0 & 0 \\ 0 & \sigma_n^2 & 0 \\ 0 & 0 & \sigma_u^2 \end{bmatrix} \tag{F5.28}$$

where

$\sigma_e =$ process noise standard deviation in East direction (m/s^2)

$\sigma_n =$ process noise standard deviation in North direction (m/s^2)

$\sigma_u =$ process noise standard deviation in Up direction (m/s^2)

F.4.3.3 Predicted Measurement Calculation

The predicted measurement is calculated from the predicted position of the track. First step in this process is to calculate the predicted position in ownship frame coordinates using:

$$\begin{bmatrix} \hat{l} \\ \hat{a} \\ \hat{v} \end{bmatrix} = \mathbf{M}'(\alpha, \gamma, \eta) \begin{bmatrix} \hat{e} \\ \hat{n} \\ \hat{u} \end{bmatrix} \tag{F5.29}$$

where

$\mathbf{M}(\alpha, \gamma, \eta)$ is found from (F5.2) and

$\hat{l} =$ coordinate of the predicted position in lateral direction of the aircraft frame (m)

$\hat{a} =$ coordinate of the predicted position in axial direction of the aircraft frame (m)

$\hat{v} =$ coordinate of the predicted position in vertical direction of the aircraft frame (m)

Next, the relative velocity in ownship ENU coordinates is calculated from

$$\begin{bmatrix} \Delta\hat{\dot{e}} \\ \Delta\hat{\dot{n}} \\ \Delta\hat{\dot{u}} \end{bmatrix} = \begin{bmatrix} \hat{\dot{e}} - \dot{e}_s \\ \hat{\dot{n}} - \dot{n}_s \\ \hat{\dot{u}} - \dot{u}_s \end{bmatrix} \tag{F5.30}$$

where

$(\hat{\dot{e}},\quad \hat{\dot{n}},\quad \hat{\dot{u}}) =$ predicted velocity of track in ownship local ENU (m/s)

$(\dot{e}_s,\quad \dot{n}_s,\quad \dot{u}_s) =$ velocity of ownship (m/s)

The predicted measurement is calculated using the following steps:

$$\begin{aligned} \hat{\rho} &= \sqrt{\hat{l}^2 + \hat{a}^2 + \hat{v}^2} \\ \hat{\beta} &= tan^{-1}\left(\frac{\hat{l}}{\hat{a}}\right) \\ \hat{\epsilon} &= sin^{-1}\left(\frac{\hat{v}}{\hat{\rho}}\right) \\ \hat{\dot{\rho}} &= \frac{\hat{e}\,\Delta\hat{\dot{e}} + \hat{n}\,\Delta\hat{\dot{n}} + \hat{u}\,\Delta\hat{\dot{u}}}{\hat{\rho}} \end{aligned} \tag{F5.31}$$

where

$\hat{\rho} =$ predicted range (m)

$\hat{\beta} =$ predicted bearing measurement (rad)

$\hat{\epsilon} =$ predicted elevation measurement (rad)

$\hat{\dot{\rho}} =$ predicted range rate measurement (m/s)

$(\hat{e},\quad \hat{n},\quad \hat{u}) =$ predicted position of track in ownship local ENU (m)

$(\Delta\hat{e},\quad \Delta\hat{n},\quad \Delta\hat{u}) =$ relative velocity of track in ownship local ENU (m/s)

$(\hat{l},\quad \hat{a},\quad \hat{v}) =$ predicted position of track in ownship frame coordinates (m)

F.4.3.4 Filter Gain Calculation

The following steps are performed in order to calculate the gain of the filter:

1. Calculate measurement matrix
2. Calculate innovation covariance matrix
3. Calculate gain matrix

F.4.3.4.1 Measurement Matrix

First, a 3×3 matrix, $\mathbf{U}$, is formed as follows:

$$\mathbf{U} = \boldsymbol{V}(\hat{\boldsymbol{\rho}}, \hat{\boldsymbol{\beta}}, \hat{\boldsymbol{\epsilon}})\mathbf{M}'(\boldsymbol{\alpha}, \boldsymbol{\gamma}, \boldsymbol{\eta}) \tag{F5.32}$$

where

$\mathbf{M}(\alpha, \gamma, \eta)$ is found from (F5.2). The matrix $\boldsymbol{V}(\hat{\rho}, \hat{\beta}, \hat{\epsilon})$ is given by:

$$\boldsymbol{V}(\hat{\boldsymbol{\rho}}, \hat{\boldsymbol{\beta}}, \hat{\boldsymbol{\epsilon}}) = \begin{bmatrix} \frac{\hat{\boldsymbol{l}}}{\hat{\boldsymbol{\rho}}} & \frac{\hat{\boldsymbol{a}}}{\hat{\boldsymbol{\rho}}} & \frac{\hat{\boldsymbol{v}}}{\hat{\boldsymbol{\rho}}} \\ \frac{\hat{\boldsymbol{a}}}{\hat{\boldsymbol{r}}} & \frac{-\hat{\boldsymbol{l}}}{\hat{\boldsymbol{r}}} & \mathbf{0} \\ \frac{-\hat{\boldsymbol{l}}\hat{\boldsymbol{v}}}{\hat{\boldsymbol{r}}\hat{\boldsymbol{\rho}}^2} & \frac{-\hat{\boldsymbol{a}}\hat{\boldsymbol{v}}}{\hat{\boldsymbol{r}}\hat{\boldsymbol{\rho}}^2} & \frac{\hat{\boldsymbol{r}}}{\hat{\boldsymbol{\rho}}^2} \end{bmatrix} \tag{F5.33}$$

where

$\hat{r} = \sqrt{\hat{\rho}^2 - \hat{v}^2}$

Then the measurement matrix, H, is formed by:

$$\mathbf{H} = \begin{bmatrix} \mathbf{U} & \mathbf{0}_{3\times3} \\ \mathbf{H}_{10} & \mathbf{H}_{11} \end{bmatrix} \tag{F5.34}$$

where

$\mathbf{0}_{3\times3} =$ 3×3 matrix of zeros,

and

$$\boldsymbol{H}_{10} = [h_{30} \quad h_{31} \quad h_{32}]$$
$$h_{30} = \frac{1}{\hat{\rho}}\left(\Delta\hat{e} - \frac{\hat{e}}{\hat{\rho}}\hat{\dot{\rho}}\right) \tag{F5.35}$$

$$h_{31} = \frac{1}{\hat{\rho}}\left(\Delta\hat{n} - \frac{\hat{n}}{\hat{\rho}}\hat{\dot{\rho}}\right)$$

$$h_{32} = \frac{1}{\hat{\rho}}\left(\Delta\hat{u} - \frac{\hat{u}}{\hat{\rho}}\hat{\dot{\rho}}\right)$$

$$\boldsymbol{H}_{11} = [h_{33} \quad h_{34} \quad h_{35}]$$

$$h_{33} = \frac{\hat{e}}{\hat{\rho}}$$

$$h_{34} = \frac{\hat{n}}{\hat{\rho}}$$

$$h_{35} = \frac{\hat{u}}{\hat{\rho}}$$

F.4.3.4.2 Innovation Covariance Matrix

The innovation covariance matrix, $\boldsymbol{S}$, found from:

$$\mathbf{S} = \mathbf{H}\widehat{\mathbf{P}}\mathbf{H}' + \mathbf{R} \tag{F5.36}$$

where

$\widehat{\mathbf{P}} =$ predicted state error covariance

$$\mathbf{R} = \begin{bmatrix} \sigma_\rho^2 & 0 & 0 & 0 \\ 0 & \sigma_\beta^2 & 0 & 0 \\ 0 & 0 & \sigma_\epsilon^2 & 0 \\ 0 & 0 & 0 & \sigma_{\dot{\rho}}^2 \end{bmatrix} \tag{F5.37}$$

F.4.3.4.3 Gain Matrix

The gain matrix, **W**, is calculated from

$$\mathbf{W} = \widehat{\mathbf{P}}\mathbf{H}'\mathbf{S}^{-1} \tag{F5.38}$$

F.4.3.5 State Update

The innovation vector is found from

$$\begin{bmatrix} \Delta\rho \\ \Delta\beta \\ \Delta\epsilon \\ \Delta\dot{\rho} \end{bmatrix} = \begin{bmatrix} \rho - \hat{\rho} \\ \beta - \hat{\beta} \\ \epsilon - \hat{\epsilon} \\ \dot{\rho} - \hat{\dot{\rho}} \end{bmatrix} \tag{F5.39}$$

where

$\rho =$ range measurement (m)

$\beta =$ bearing measurement (rad)

$\epsilon =$ elevation measurement (rad)

$\dot{\rho} =$ range rate measurement (m/s)

$\hat{\rho} =$ predicted range (m)

$\hat{\beta} =$ predicted bearing measurement (rad)

$\hat{\epsilon} =$ predicted elevation measurement (rad)

$\hat{\dot{\rho}} =$ predicted range rate measurement (m/s)

The state vector is updated as,

$$\begin{bmatrix} e \\ n \\ u \\ \dot{e} \\ \dot{n} \\ \dot{u} \end{bmatrix} = \begin{bmatrix} \hat{e} \\ \hat{n} \\ \hat{u} \\ \hat{\dot{e}} \\ \hat{\dot{n}} \\ \hat{\dot{u}} \end{bmatrix} + \mathbf{W} \begin{bmatrix} \Delta\rho \\ \Delta\beta \\ \Delta\epsilon \\ \Delta\dot{\rho} \end{bmatrix} \tag{F5.40}$$

where

$(\hat{e}, \quad \hat{n}, \quad \hat{u}) =$ predicted position of track in ownship local ENU (m)

$(\hat{\dot{e}}, \quad \hat{\dot{n}}, \quad \hat{\dot{u}}) =$ predicted velocity of track in ownship local ENU (m/s)

$(e, \quad n, \quad u) =$ updated position of track in ownship local ENU (m)

$(\dot{e}, \quad \dot{n}, \quad \dot{u}) =$ updated velocity of track in ownship local ENU (m/s)

F.4.3.6 Geodetic Coordinates Calculation

Next, track's relative position in ECEF coordinate system is calculated using (F5.5) and (F5.6). Track's absolute position in ECEF coordinate is calculated using (F5.7). The geodetic position of the track, $(\phi_t, \quad \lambda_t, \quad h_t)$ is calculated following the 15-step process given in (F5.8).

F.4.3.7 Velocity Update

Velocity of the track in target's local ENU is calculated from:

$$\begin{bmatrix} \dot{e}_t \\ \dot{n}_t \\ \dot{u}_t \end{bmatrix} = \mathbf{L}(\phi_t, \lambda_t, \phi_s, \lambda_s) \begin{bmatrix} \dot{e} \\ \dot{n} \\ \dot{u} \end{bmatrix} \tag{F5.41}$$

where

$(\dot{e}, \quad \dot{n}, \quad \dot{u}) =$ updated velocity of track in ownship local ENU (m/s)

$(\dot{e}_t, \quad \dot{n}_t, \quad \dot{u}_t) =$ updated velocity of track in target local ENU (m/s)

$\phi_t =$ track's estimated latitude (rad)

$\lambda_t =$ track's estimated longitude (rad)

$\phi_s =$ ownship's current latitude (rad)

$\lambda_s =$ ownship's current longitude (rad)

and $\boldsymbol{L}(\phi_t, \lambda_t, \phi_s, \lambda_s)$ is found from (F5.13).

F.4.3.8 State Error Covariance Update

The state error covariance matrix in ownship local ENU coordinates is calculated from:

$$\mathbf{P}_1 = [\mathbf{I}_{6\times6} - \mathbf{WH}]\widehat{\mathbf{P}}[\mathbf{I}_{6\times6} - \mathbf{WH}]' + \mathbf{WRW}' \tag{F5.42}$$

where

$\mathbf{P}_1 =$ updated state error covariance in ownship local ENU

$\widehat{\mathbf{P}} =$ predicted state error covariance in ownship local ENU

$\mathbf{W} =$ gain matrix calculated in (F5.38)

$\mathbf{H} =$ measurement matrix calculated in (F5.34)

$\mathbf{R} =$ measurement error covariance matrix calculated (F5.37)

$\mathbf{I}_{6\times6} =$ Identity matrix of size 6×6

The state error covariance in local ENU coordinates of target's updated position is calculated from:

$$\mathbf{P} = \mathbf{VP_1V}' \tag{F5.43}$$

where

$$\mathbf{V} = \begin{bmatrix} \mathbf{L}(\phi_t, \lambda_t, \phi_s, \lambda_s) & \mathbf{0}_{3\times3} \\ \mathbf{0}_{3\times3} & \mathbf{L}(\phi_t, \lambda_t, \phi_s, \lambda_s) \end{bmatrix} \tag{F5.44}$$

where

$\phi_t =$ track's estimated latitude (rad)

$\lambda_t =$ track's estimated longitude (rad)

$\phi_s =$ ownship's current latitude (rad)

$\lambda_s =$ ownship's current longitude (rad)

$\mathbf{0}_{3\times3} =$ 3 × 3 matrix of zeros

and $\mathbf{L}(\phi_t, \lambda_t, \phi_s, \lambda_s)$ is found from (F5.13)

F.4.3.9 Time of Update

Time of update in the track record is set to the time of measurement.

F.5 AST Tracker

The Active Surveillance Transponder tracker in the TPS processes the measurements from the AST sensor and maintains a track for each target detected by the AST sensor. The overall tracker architecture is shown in Figure F-4. The AST tracker has the following functionalities:

1. Track/Measurement Association
2. Track Initiation
3. Track Establishment
4. Polar Filter Update
5. Extended Kalman Filter Update

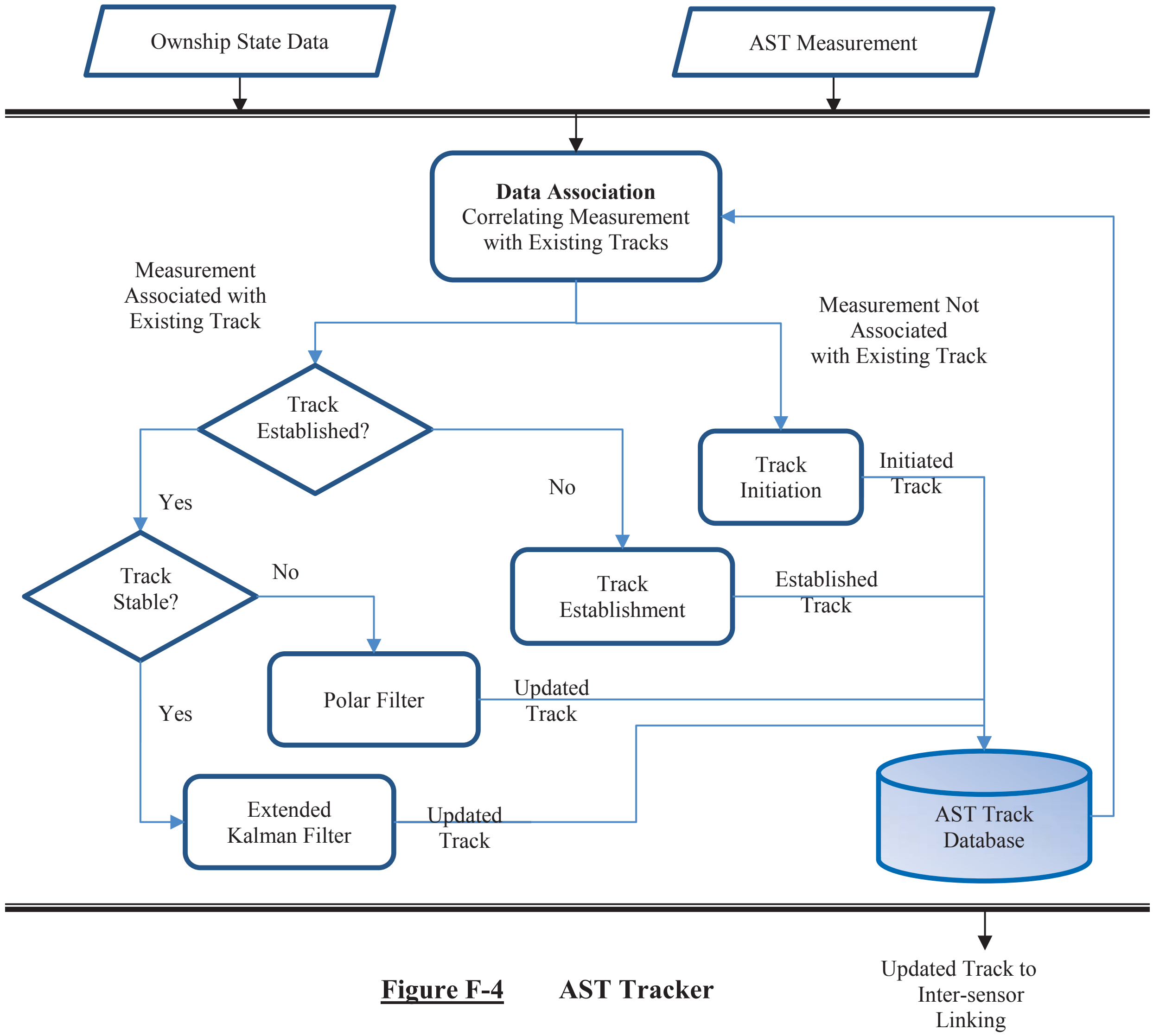


Figure F-4 **AST Tracker**

The measurements, at minimum, will contain the following parameters:

1. Track Number
2. Range (ρ)
3. Azimuth (θ)
4. Barometric pressure altitude (h)
5. Time of measurement (t)

The range and azimuth are measured by the AST radar with respect to the ENU coordinate system at the ownship position. The barometric pressure altitude above mean sea level is obtained from the information received from the target replies in response to the AST interrogations. At the receipt of a measurement, the Track/Measurement Association function searches the track records in the AST track database to find the track record that has the same track number as that in the measurement. If the measurement can be associated with a track, the Track/Measurement pair is sent to the Track Establishment module if the track is not established, or to one of two filters depending on the number of updates that the track has received. If a track is not found the measurement is sent to the Track Initiation function to start a track record.

The AST tracker updates a track's horizontal state and vertical state separately. A Polar filter is used to update the horizontal state during the initial stages of the track and an Extended Kalman filter is used afterwards. After track establishment, the vertical state is always updated using a simple Kalman filter.

F.5.1 Track Initiation

The track Initiation function initializes the horizontal state of the track in Polar coordinates that consists of the track's ground range from the ownship and its rate of change, and the track's azimuth and its rate of change. It also initializes the vertical state parameters that consist of the track's altitude above MSL and its rate of change. These parameters are then used to obtain the target's ENU coordinates with respect to the ENU coordinate system at the ownship position and geodetic coordinates. Thus, Track Initiation function starts a track record containing the following parameters:

1. Horizontal state in Polar coordinates
2. Vertical state and vertical state vector error covariance matrix (P_v)
3. Position in ownship ENU (East, North, Up)
4. Velocity in target local ENU (East velocity, North velocity, Up velocity)
5. Position in WGS-84 geodetic coordinates (latitude, longitude, altitude)
6. Track Time
7. Track Number

F.5.1.1 Horizontal State in Polar Coordinates

The horizontal state of the track in polar coordinates is initialized as follows:

$$\begin{aligned} \Delta h &= h - h_s \\ r &= \sqrt{\rho^2 - \Delta h^2} \\ \vartheta &= \theta \\ \dot{r} &= 0 \\ \dot{\vartheta} &= 0 \end{aligned} \tag{F5.45}$$

where

$h =$ barometric pressure altitude measurement (m)

$h_s =$ ownship barometric pressure altitude (m)

$\rho =$ measured slant range (m)

$r =$ estimated horizontal range of target from the ownship (m)

$\theta =$ measured azimuth (rad)

$\vartheta =$ estimated azimuth of target (rad)

$\dot{r} =$ estimated rate of change of range (m/s)

$\dot{\vartheta} =$ estimated rate of change of azimuth (rad/s)

F.5.1.2 Vertical State and Error Covariance

The vertical state and the error covariance are initialized using

$$z = h$$
$$\dot{z} = 0$$
$$\mathbf{P}_{\mathrm{v}} = \begin{bmatrix} \sigma_h^2 & 0 \\ 0 & 0 \end{bmatrix} \tag{F5.46}$$

where

$h =$ Barometric pressure altitude measurement (m)

$z =$ estimated altitude of the track (m)

$\dot{z} =$ estimated altitude rate of the track (m/s)

$\boldsymbol{P}_v =$ vertical state error covariance matrix

$\sigma_h =$ altitude measurement error standard deviation

F.5.1.3 Position in Ownship ENU

The position in ownship ENU is initialized as follows:

$$e = r \sin \vartheta$$
$$n = r \cos \vartheta \tag{F5.47}$$
$$u = h - h_s$$

where

$(e, \quad n, \quad u) =$ position of track in ownship local ENU (m)

$r =$ target's estimated range with respect to the ownship position (m)

$\vartheta =$ target's estimated azimuth with respect to North (rad)

$h =$ Barometric pressure altitude measurement (m)

$h_s =$ Barometric pressure altitude of the ownship (m)

Note: *Although $(h - h_s)$ is not really equal to the Up coordinate of the target, it is assumed that the error incurred by this approximation is negligible.*

F.5.1.4 Velocity in Target Local ENU

The velocity vector in target local ENU is set as $[0 \quad 0 \quad 0]'$.

F.5.1.5 Position in Geodetic Coordinates

Starting with the ownship's geodetic coordinates and target's ENU coordinates $(e, \quad n, \quad u)$, the position of target in geodetic coordinates is obtained following the steps presented by equations (F5.3) – (F5.8).

F.5.1.6 Time of Update

Time of update in the track record is set to the time of measurement.

F.5.1.7 Track Number

Track number of the track record is set to the track number in the measurement.

F.5.2 Track Establishment

If a measurement is associated with a track, then the Track/Measurement pair is sent to the Track Establishment module if the track has not been established yet.

The track establishment module performs the following functions:

1. Update track's horizontal state in Polar coordinates
2. Update track's vertical state and error covariance
3. Update track's position in ownship local ENU
4. Initialize track's velocity in target local ENU
5. Update track's geodetic coordinates
6. Time of update

F.5.2.1 Horizontal State in Polar Coordinates Update

The horizontal state in polar coordinates is updated using the new measurement as follows:

$$
\begin{aligned}
\Delta h &= h - \ h_s \\
r &= \sqrt{\rho^2 - \Delta h^2} \\
\vartheta &= \theta \\
\dot{r} &= \frac{r - r_o}{\Delta t} \\
\dot{\vartheta} &= 0
\end{aligned}
\tag{F5.48}
$$

where

$\Delta t =$ measurement time – last update time

$r_o =$ track's last estimated horizontal range (m)

***Note**: The azimuth change rate is set to zero for the established Polar coordinate track assuming that change in azimuth when the target is far from the ownship is negligible.*

F.5.2.2 Vertical State and Error Covariance

The track's vertical state and error covariance are established using the following steps:

$$z = h$$
$$\dot{z} = \frac{z - z_o}{\Delta t}$$
$$\mathbf{P}_\mathrm{v} = \begin{bmatrix} \sigma_h^2 & \frac{\sigma_h^2}{\Delta t} \\ \frac{\sigma_h^2}{\Delta t} & 2\frac{\sigma_h^2}{\Delta t^2} \end{bmatrix} \tag{F5.49}$$

where

$\Delta t =$ measurement time – last update time

$z_o =$ track's last estimated altitude (m)

F.5.2.3 Position in Ownship Local ENU

The track's position in ownship local ENU is calculated using (F5.47).

F.5.2.4 Geodetic Coordinates Update

Starting with the ownship's geodetic coordinates and target's ENU coordinates $(e, \quad n, \quad u)$, the position of target in geodetic coordinates is obtained following the steps presented by equations (F5.3) – (F5.8).

F.5.2.5 Velocity in Target Local ENU

Track's horizontal velocity in ownship local ENU is calculated as shown below:

$$\dot{e} = r\,\dot{\vartheta}\cos\vartheta + \dot{r}\sin\vartheta + \dot{e}_s$$
$$\dot{n} = -r\,\dot{\vartheta}\sin\vartheta + \dot{r}\cos\vartheta + \dot{n}_s \tag{F5.50}$$

where

$(\dot{e}, \quad \dot{n}) =$ estimated horizontal velocity in ownship local ENU (m/s)

$\dot{e}_s =$ ownship's East velocity (m/s)

$\dot{n}_s =$ ownship's North velocity (m/s)

<u>Note:</u> *Although the altitude rate $\dot{z}$ estimated by the vertical tracker is not strictly equal to the Up velocity of target in ownship ENU coordinate system $\dot{u}$, it is assumed that error introduced by this approximation is negligible.*

The horizontal velocity of the track in target's local ENU is calculated from:

$$\begin{bmatrix} \dot{e}_t \\ \dot{n}_t \end{bmatrix} = \mathbf{L}(\phi_t, \lambda_t, \phi_s, \lambda_s) \begin{bmatrix} \dot{e} \\ \dot{n} \end{bmatrix} \tag{F5.51}$$

The matrix $\boldsymbol{L}$ is given by

$$\begin{aligned}
\mathbf{L}(\phi_t, \lambda_t, \phi_s, \lambda_s) &= \begin{bmatrix} l_{00} & l_{01} \\ l_{10} & l_{11} \end{bmatrix} \\
l_{00} &= \cos(\lambda_t - \lambda_s) \\
l_{01} &= \sin\phi_s \sin(\lambda_t - \lambda_s) \\
l_{10} &= -\sin\phi_t \sin(\lambda_t - \lambda_s) \\
l_{11} &= \sin\phi_t \sin\phi_s \cos(\lambda_t - \lambda_s) + \cos\phi_t \cos\phi_s
\end{aligned} \tag{F5.52}$$

where

$\phi_t =$ track's estimated latitude (rad)

$\lambda_t =$ track's estimated longitude (rad)

$\phi_s =$ ownship latitude (rad)

$\lambda_s =$ ownship longitude (rad)

F.5.2.6 Time of Update

Time of update in the track record is set to the time of measurement.

F.5.3 Polar Filter Update

If a track has been established and it has not had more than N number of updates, the track is updated using a Polar filter. A typical value for N is 15. The Polar filter update functionality entails the following steps:

1. Track's range and azimuth update
2. Track's vertical state and error covariance update
3. Track's position in ownship ENU calculation
4. Track's velocity in target's local ENU calculation
5. Track's position in geodetic coordinates calculation
6. Time of update

F.5.3.1 Range and Azimuth Update

The Polar coordinate range of the track is updated according to the following steps:

$$\begin{aligned}
&\alpha = 0.5\\
&\beta = 2(2-\alpha) - 4\sqrt{1-\alpha}\\
&\Delta h = h - h_s\\
&\hat{r} = r_o + \dot{r}_o \Delta t\\
&r = \hat{r} + \alpha\left(\hat{r} - \sqrt{\rho^2 - \Delta h^2}\right)\\
&\dot{r} = \dot{r}_o + \frac{\beta}{\Delta t}\left(\hat{r} - \sqrt{\rho^2 - \Delta h^2}\right)
\end{aligned} \tag{F5.53}$$

where

$r_o =$ track's last estimated horizontal range (m)

$\dot{r}_o =$ track's last estimated horizontal range rate (m/s)

$\Delta t =$ measurement time – track's last update time

$\rho =$ slant range measurement (m)

$h =$ Barometric pressure altitude measurement (m)

$h_s =$ ownship's pressure altitude (m)

$r =$ track's updated horizontal range (m)

$\dot{r} =$ track's updated horizontal range rate (m/s)

The polar coordinate azimuth is updated using the following steps:

$$\begin{aligned}
&\alpha = \begin{cases} 0.6 & \text{if } r < 6 \text{ nmi AND number of updates} > 5 \\ 0.2 & \text{otherwise} \end{cases}\\
&\beta = 2(2-\alpha) - 4\sqrt{1-\alpha}\\
&\hat{\vartheta} = \vartheta_o + \dot{\vartheta}_o \Delta t\\
&\vartheta = \hat{\vartheta} + \alpha\left(\hat{\vartheta} - \theta\right)\\
&\dot{\vartheta} = \dot{\vartheta}_o + \frac{\beta}{\Delta t}\left(\hat{\vartheta} - \theta\right)
\end{aligned} \tag{F5.54}$$

where

$\vartheta_o =$ track's last estimated azimuth (rad)

$\dot{\vartheta}_o =$ track's last estimated azimuth change rate (rad/s)

$\Delta t =$ measurement time – track's last update time

$\theta =$ azimuth measurement (rad)

$\vartheta =$ track's updated azimuth (rad)

$\dot{\vartheta} =$ track's updated azimuth change rate (rad/s)

F.5.3.2 Vertical State and Covariance Update

The vertical state and covariance are updated following the steps below:

$$\begin{aligned}
&\hat{z} = z_o + \dot{z}_o\,\Delta t \\
&\mathbf{Q} = \sigma_u^2 \begin{bmatrix} \frac{1}{4}\Delta t^4 & \frac{1}{2}\Delta t^3 \\ \frac{1}{2}\Delta t^3 & \Delta t^2 \end{bmatrix} \\
&\mathbf{F} = \begin{bmatrix} 1 & \Delta t \\ 0 & 1 \end{bmatrix} \\
&\widehat{\mathbf{P}} = \mathbf{F}\mathbf{P}_{\mathrm{vo}}\mathbf{F}' + \mathbf{Q} \\
&\mathbf{H} = [1 \quad 0] \\
&s = \mathbf{H}\widehat{\mathbf{P}}\mathbf{H}' + \sigma_h^2 \\
&\mathbf{W} = \frac{1}{s}\widehat{\mathbf{P}}\mathbf{H}' \\
&\begin{bmatrix} z \\ \dot{z} \end{bmatrix} = \begin{bmatrix} \hat{z} \\ \dot{z}_o \end{bmatrix} + \mathbf{W}[h - \hat{z}] \\
&\mathbf{P}_{\mathrm{v}} = [\mathbf{I}_{2\times2} - \mathbf{W}\mathbf{H}]\widehat{\mathbf{P}}[\mathbf{I}_{2\times2} - \mathbf{W}\mathbf{H}]' + \sigma_h^2\mathbf{W}\mathbf{W}'
\end{aligned} \tag{F5.55}$$

where

$z_o =$ track's last estimated altitude (m)

$\dot{z}_o =$ track's last estimated altitude rate (m/s)

$\mathbf{P}_{\mathrm{vo}} =$ track's last estimated vertical error covariance matrix

$\Delta t =$ measurement time – track's last update time

$\sigma_u =$ standard deviation of altitude process noise (m/s^2)

$\sigma_h =$ standard deviation of altitude measurement error (m)

$z =$ track's estimated altitude (m)

$\dot{z} =$ track's estimated altitude rate (m/s)

$\mathbf{P}_{\mathrm{v}} =$ track's updated vertical state error covariance matrix

F.5.3.3 Position in Ownship ENU

The track's position in ownship local ENU is calculated using (F5.47).

F.5.3.4 Geodetic Coordinates Update

Starting with the ownship's geodetic coordinates and target's ENU coordinates $(e, \quad n, \quad u)$, the position of target in geodetic coordinates is obtained following the steps presented by equations (F5.3) – (F5.8).

F.5.3.5 Velocity in Target Local ENU

The velocity of track in target local ENU is calculated using (F5.50) and (F5.51).

F.5.3.6 Time of Update

Time of update in the track record is set to the time of measurement.

F.5.4 Extended Kalman Filter Update

If the track has had more than N updates, the Track/Measurement pair is sent to the EKF module. The EKF update entails one of two methods:

1. EKF Track Establishment
2. EKF Track Update

F.5.4.1 EKF Track Establishment

If it is the first time for this track to reach this module, EKF state parameters of the track are established by following the steps:

1. Initialize the last estimated horizontal state in ownship local ENU
2. Initialize the last estimated horizontal state error covariance in ownship local ENU
3. Update the state and error covariance with the current measurement
4. Update the vertical state
5. Update the geodetic position, velocity and state error covariance

After the EKF is initialized and updated using the above steps, the vertical state and error covariance is updated using the steps in (F5.55).

F.5.4.1.1 Initialize the Last Estimated Horizontal State in Ownship Local ENU

The last estimated horizontal state of the track in current ownship local ENU is represented by $[e_o \quad n_o \quad \dot{e}_o \quad \dot{n}_o]'$ which is found by following two steps.

1. Calculate the last updated position of the target with respect to the ownship local ENU as follows:
   a. Ownship's current ECEF coordinates $[\mathrm{X_s} \quad \mathrm{Y_s} \quad \mathrm{Z_s}]'$ are found using (F5.3).
   b. Starting with track's last geodetic coordinates, the track's last position ECEF coordinates $[\mathrm{X_t} \quad \mathrm{Y_t} \quad \mathrm{Z_t}]'$ is also found using (F5.3).
   c. The relative position of track's last position with respect to the ownship's current position in ECEF coordinates is given by (F5.15)
   d. Track's last position $[\mathrm{e_o} \quad \mathrm{n_o} \quad \mathrm{u_o}]'$ in current ownship local ENU coordinates is calculated from (F5.16).

2. Calculate the last updated velocity of the target with respect to the ownship local ENU as follows:

$$\begin{bmatrix} \dot{e}_o \\ \dot{n}_o \end{bmatrix} = \mathbf{L}'(\phi_t, \lambda_t, \phi_s, \lambda_s) \begin{bmatrix} \dot{e}_t \\ \dot{n}_t \end{bmatrix} \tag{F5.56}$$

where

$\mathbf{L}(\phi_t, \lambda_t, \phi_s, \lambda_s)$ is found from (F5.52) and

$\phi_t =$ track's last estimated latitude (rad)

$\lambda_t =$ track's last estimated longitude (rad)

$\phi_s =$ ownship's current latitude (rad)

$\lambda_s =$ ownship's current longitude (rad)

$\dot{e}_t =$ track's last estimated East velocity in track's last local ENU (m/s)

$\dot{n}_t =$ track's last estimated North velocity in track's last local ENU (m/s)

$\dot{e}_o =$ track's last estimated East velocity in current ownship local ENU (m/s)

$\dot{n}_o =$ track's last estimated North velocity in current ownship local ENU (m/s)

F.5.4.1.2 Initialize the Last Estimated State Error Covariance in Ownship Local ENU

The measurement error covariance with respect to ENU coordinates at the last ownship position is given by:

$$\mathbf{R_1} = \mathbf{M} \begin{bmatrix} \sigma_\rho^2 & 0 \\ 0 & \sigma_\theta^2 \end{bmatrix} \mathbf{M}' \tag{F5.57}$$

where

$\sigma_\rho =$ range measurement error standard deviation (m)

$\sigma_\theta =$ azimuth measurement error standard deviation (rad)

The matrix $\mathbf{M}$ is given by

$$\begin{aligned} \mathbf{M} &= \begin{bmatrix} m_{00} & m_{01} \\ m_{10} & m_{11} \end{bmatrix} \\ \Delta h &= z_o - h_{so} \\ \rho_o &= \sqrt{r_o^2 + \Delta h^2} \\ m_{00} &= \left(\frac{\rho_o}{r_o}\right) \sin\vartheta_o \\ m_{01} &= r_o \cos\vartheta_o \end{aligned} \tag{F5.58}$$

$$m_{10} = \left(\frac{\rho_o}{r_o}\right)\cos\vartheta_o$$

$$m_{11} = -r_o \sin\vartheta_o$$

where

$z_o =$ last estimated altitude of the track (m)

$h_{so} =$ last altitude of the ownship (m)

$r_o =$ last estimated horizontal range of the track (m)

$\vartheta_o =$ last estimated azimuth of the track (rad)

The measurement error covariance in ENU of the current ownship position is given by:

$$\mathbf{R} = \mathbf{L}(\phi_s, \lambda_s, \phi_{so}, \lambda_{so})\mathbf{R}_1\mathbf{L}'(\phi_s, \lambda_s, \phi_{so}, \lambda_{so}) \tag{F5.59}$$

where

$\mathbf{L}(\phi_s, \lambda_s, \phi_{so}, \lambda_{so})$ is found from (F5.52) and

$\phi_s =$ ownship's current latitude (rad)

$\lambda_s =$ ownship's current longitude (rad)

$\phi_{so} =$ ownship's last latitude (rad)

$\lambda_{so} =$ ownship's last longitude (rad)

Then the horizontal state error covariance in ENU coordinate system at the current ownship position is initialized as:

$$\mathbf{P}_o = \begin{bmatrix} \mathbf{R} & \frac{1}{\Delta t}\mathbf{R} \\ \frac{1}{\Delta t}\mathbf{R} & \frac{2}{\Delta t^2}\mathbf{R} \end{bmatrix} \tag{F5.60}$$

where

$\Delta t =$ measurement time – track's last update time

F.5.4.1.3 Update the State and Error Covariance with the Current Measurement

The horizontal state and covariance are updated using the following steps:

1. Predict the state and covariance using

$$\mathbf{F} = \begin{bmatrix} \mathbf{I}_{2\times2} & \Delta t\mathbf{I}_{2\times2} \\ \mathbf{0}_{2\times2} & \mathbf{I}_{2\times2} \end{bmatrix}$$
$$\begin{bmatrix} \hat{e} \\ \hat{n} \\ \hat{\dot{e}} \\ \hat{\dot{n}} \end{bmatrix} = \mathbf{F}\begin{bmatrix} e_o \\ n_o \\ \dot{e}_o \\ \dot{n}_o \end{bmatrix} \tag{F5.61}$$
$$\mathbf{Q} = \mathbf{G\Gamma G}'$$
$$\widehat{\mathbf{P}} = \mathbf{FP}_o\mathbf{F}' + \mathbf{Q}$$

where

$$\mathbf{G} = \begin{bmatrix} \frac{1}{2}\Delta t^2 & 0 \\ 0 & \frac{1}{2}\Delta t^2 \\ t & 0 \\ 0 & t \end{bmatrix}$$ and
$$\mathbf{\Gamma} = \begin{bmatrix} \sigma_e^2 & 0 \\ 0 & \sigma_n^2 \end{bmatrix}$$

$\sigma_e =$ process noise standard deviation in East direction (m/s^2)

$\sigma_n =$ process noise standard deviation in North direction (m/s^2)

2. Find the predicted measurement as follows:

$$\Delta h = h - h_s$$
$$\hat{\rho} = \sqrt{\hat{e}^2 + \hat{n}^2 + \Delta h^2} \tag{F5.62}$$
$$\hat{\theta} = \tan^{-1}\left(\frac{\hat{e}}{\hat{n}}\right)$$

where

$h =$ altitude measurement (m)

$h_s =$ altitude of the ownship (m)

$\hat{\rho} =$ predicted slant range (m)

$\hat{\theta} =$ predicted azimuth (rad)

3. Find the gain of the filter, W, using

$$\boldsymbol{H} = \begin{bmatrix} h_{00} & h_{01} & 0 & 0 \\ h_{10} & h_{11} & 0 & 0 \end{bmatrix} \tag{F5.63}$$
$$h_{00} = \frac{\hat{e}}{\hat{\rho}}$$

$$h_{01} = \frac{\hat{n}}{\hat{\rho}}$$

$$h_{10} = \frac{\hat{n}}{(\hat{\rho}^2 - \Delta h^2)}$$

$$h_{11} = -\frac{\hat{e}}{(\hat{\rho}^2 - \Delta h^2)}$$

$$\mathbf{R} = \begin{bmatrix} \sigma_\rho^2 & 0 \\ 0 & \sigma_\theta^2 \end{bmatrix}$$

$$\mathbf{S} = \mathbf{HPH}' + \mathbf{R}$$

$$\mathbf{W} = \mathbf{PH}'\mathbf{S}^{-1}$$

where

$\sigma_\rho =$ range measurement error standard deviation (m)

$\sigma_\theta =$ azimuth measurement error standard deviation (rad)

4. Update the state and covariance

$$\begin{bmatrix} e \\ n \\ \dot{e} \\ \dot{n} \end{bmatrix} = \begin{bmatrix} \hat{e} \\ \hat{n} \\ \hat{\dot{e}} \\ \hat{\dot{n}} \end{bmatrix} + \mathbf{W} \begin{bmatrix} \rho - \hat{\rho} \\ \theta - \hat{\theta} \end{bmatrix}$$

$$\mathbf{P}_1 = [\mathbf{I}_{4\times4} - \mathbf{WH}]\hat{\mathbf{P}}[\mathbf{I}_{4\times4} - \mathbf{WH}]' + \mathbf{WRW}' \qquad \text{(F5.64)}$$

F.5.4.1.4 Update the Vertical State

Vertical state of the track is updated using the steps in (F5.55).

F.5.4.1.5 Update Geodetic Position, Velocity and Error Covariance

Starting with the ownship geodetic position and the position of the track in ownship ENU coordinate system, $(e \quad n \quad z - h_s)$, where h_s is the altitude of the ownship, the geodetic position of the track is found following the steps (F5.3) – (F5.8).

The horizontal velocity of the track in target's local ENU is calculated from:

$$\begin{bmatrix} \dot{e}_t \\ \dot{n}_t \end{bmatrix} = \mathbf{L}(\phi_t, \lambda_t, \phi_s, \lambda_s) \begin{bmatrix} \dot{e} \\ \dot{n} \end{bmatrix} \qquad \text{(F5.65)}$$

The matrix $\mathbf{L}(\phi_t, \lambda_t, \phi_s, \lambda_s)$ is given by (F5.52)

where

$\phi_t =$ track's estimated latitude (rad)

$\lambda_t =$ track's estimated longitude (rad)

$\phi_s =$ ownship latitude (rad)

$\lambda_s =$ ownship longitude (rad)

The updated horizontal state error covariance in target local ENU coordinates is given by

$$\mathbf{P} = \mathbf{L}(\phi_t, \lambda_t, \phi_s, \lambda_s)\mathbf{P_1}\mathbf{L}'(\phi_t, \lambda_t, \phi_s, \lambda_s) \tag{F5.66}$$

F.5.4.2 EKF Track Update

If it is not the first time this Track/Measurement pair reaches the EKF Update module, the horizontal state and error covariance of the track are updated using the following steps:

1. Calculate the last updated position of the target with respect to the ownship local ENU as follows:
   a. Ownship's current ECEF coordinates $[X_s \quad Y_s \quad Z_s]'$ is found using (F5.3).
   b. Starting with track's last geodetic coordinates, track's last position ECEF coordinates $[X_t \quad Y_t \quad Z_t]'$ is also found using (F5.3).
   c. The relative position of track's last position with respect to the ownship's current position in ECEF coordinates is given by (F5.15)
   d. Track's last position $[e_o \quad n_o \quad u_o]'$ in current ownship local ENU coordinates is calculated from (F5.16).

2. Calculate the last updated velocity of the target with respect to the ownship local ENU as follows:

$$\begin{bmatrix} \dot{e}_o \\ \dot{n}_o \end{bmatrix} = \mathbf{L}(\phi_s, \lambda_s, \phi_t, \lambda_t) \begin{bmatrix} \dot{e}_t \\ \dot{n}_t \end{bmatrix} \tag{F5.67}$$

where

$\mathbf{L}(\phi_s, \lambda_s, \phi_t, \lambda_t)$ is found from (F5.52), and

$\phi_t =$ track's last estimated latitude (rad)

$\lambda_t =$ track's last estimated longitude (rad)

$\phi_s =$ ownship's current latitude (rad)

$\lambda_s =$ ownship's current longitude (rad)

$\dot{e}_t =$ track's last estimated East velocity in track's last local ENU (m/s)

$\dot{n}_t =$ track's last estimated North velocity in track's last local ENU (m/s)

$\dot{e}_o =$ track's last estimated East velocity in current ownship local ENU (m/s)

$\dot{n}_o =$ track's last estimated North velocity in current ownship local ENU (m/s)

3. Calculate the last updated horizontal covariance in ownship local ENU as follows

$$\mathbf{P_o} = \mathbf{L}(\phi_s, \lambda_s, \phi_t, \lambda_t)\mathbf{PL}'(\phi_s, \lambda_s, \phi_t, \lambda_t) \qquad \text{(F5.68)}$$

4. Predict the horizontal state and covariance using (F5.61).
5. Predict the measurement using (F5.62).
6. Find the gain of the filter using (F5.63).
7. Update the state and covariance using (F5.64).
8. The vertical state and error covariance are updated using the steps in (F5.55).

F.5.4.3 Geodetic Coordinates Update

Starting with the ownship's geodetic coordinates and target's ENU coordinates $(e, \quad n, \quad z - h_s)$, the position of target in geodetic coordinates is obtained following the steps presented by equations (F5.3) – (F5.8).

Note: *Although $(z - h_s)$ is not really equal to the Up coordinate of the target, it is assumed that the error incurred by this approximation is negligible.*

F.5.4.4 Velocity in Target Local ENU

Velocity of the track in target's local ENU is calculated using (F5.65).

F.5.4.5 Horizontal State Error Covariance in Target Local ENU

The horizontal state error covariance in target local ENU is found from (F5.66).

F.5.4.6 Time of Update

Time of update in the track record is set to the time of measurement.

F.6 ADS-B Tracker

The horizontal position and velocity of an ADS-B target are directly obtained from the ADS-B messages from the target. The vertical position and vertical rate are derived from tracking the Barometric altitude measurement from the ADS-B messages. The altitude track is initialized, established and tracked using the steps shown in (F5.46), (F5.49) and (F5.55), respectively.

F.7 Inter Sensor Linking

The linking module links the sensor tracks for the same intruder from multiple sources (ADS-B, radar, AST) to a single central track or fused track belonging to the intruder. The linking is based on the nearest neighbor paradigm using various parameters, namely, 24-bit International Civil Aviation Organization (ICAO) address, time-aligned sensor track positions, and time-aligned sensor measurements.

Let $[e_s \quad n_s \quad u_s]'$ be the position of the sensor track and $[e_f \quad n_f \quad u_f]'$ be the extrapolated position of the central track in the ENU coordinate system at the ownship. Let $[\rho_s \quad \beta_s \quad \epsilon_s]'$ and $[\rho_f \quad \beta_f \quad \epsilon_f]'$ be the position of the sensor track and the extrapolated position of the central track in the ownship frame respectively. Figure F-5 shows the sensor track and the extrapolated central track in order to illustrate the linking parameters calculation. The following parameters are calculated for track linking:

$$
\begin{aligned}
&\Delta x = e_f - e_s \\
&\Delta y = n_f - n_s \\
&\Delta s = \sqrt{\Delta x^2 + \Delta y^2} \;:\; \text{lateral position difference} \\
&\Delta z = \left| u_f - u_s \right| \;:\; \text{vertical position difference} \\
&\Delta \rho = \left| \rho_f - \rho_s \right| :\; \text{range difference} \\
&\Delta \beta = \left| \beta_f - \beta_s \right| :\; \text{bearing difference} \\
&\Delta \epsilon = \left| \epsilon_f - \epsilon_s \right| :\; \text{elevation difference}
\end{aligned}
\qquad \text{(F5.69)}
$$

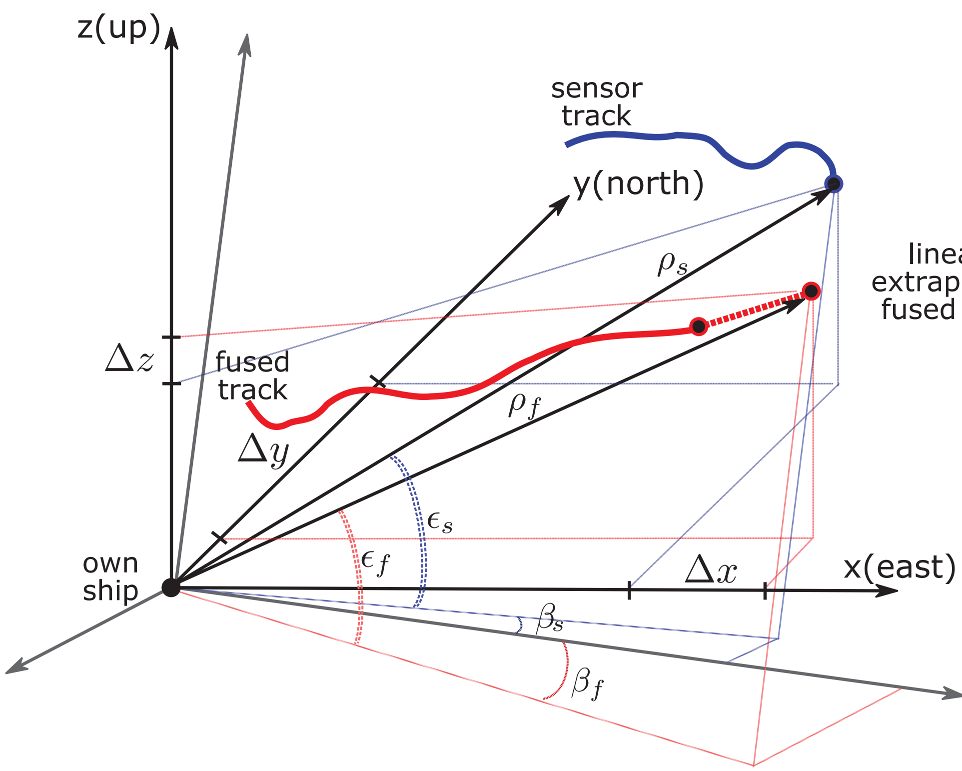


Figure F-5 **Linking Parameters**

The links between the sensor tracks and the central tracks are updated in the following way:

1. If any two existing central tracks have a matched ICAO address or the central tracks are close to each other such that: $\Delta\rho < 0.25$ NM, $\Delta\beta < 45^\circ$, and $\Delta\epsilon < 2.5^\circ$ or $\Delta z < 250'$, remove the central track with a larger position uncertainty.
2. Remove sensor tracks that have not been updated longer than the specified time
3. Remove central tracks that have no sensor tracks linked to them.
4. Update ADS-B, radar, and AST links, as described in Paragraphs F.7.1, F.7.2, and F.7.3, respectively.

F.7.1 ADS-B Link Update

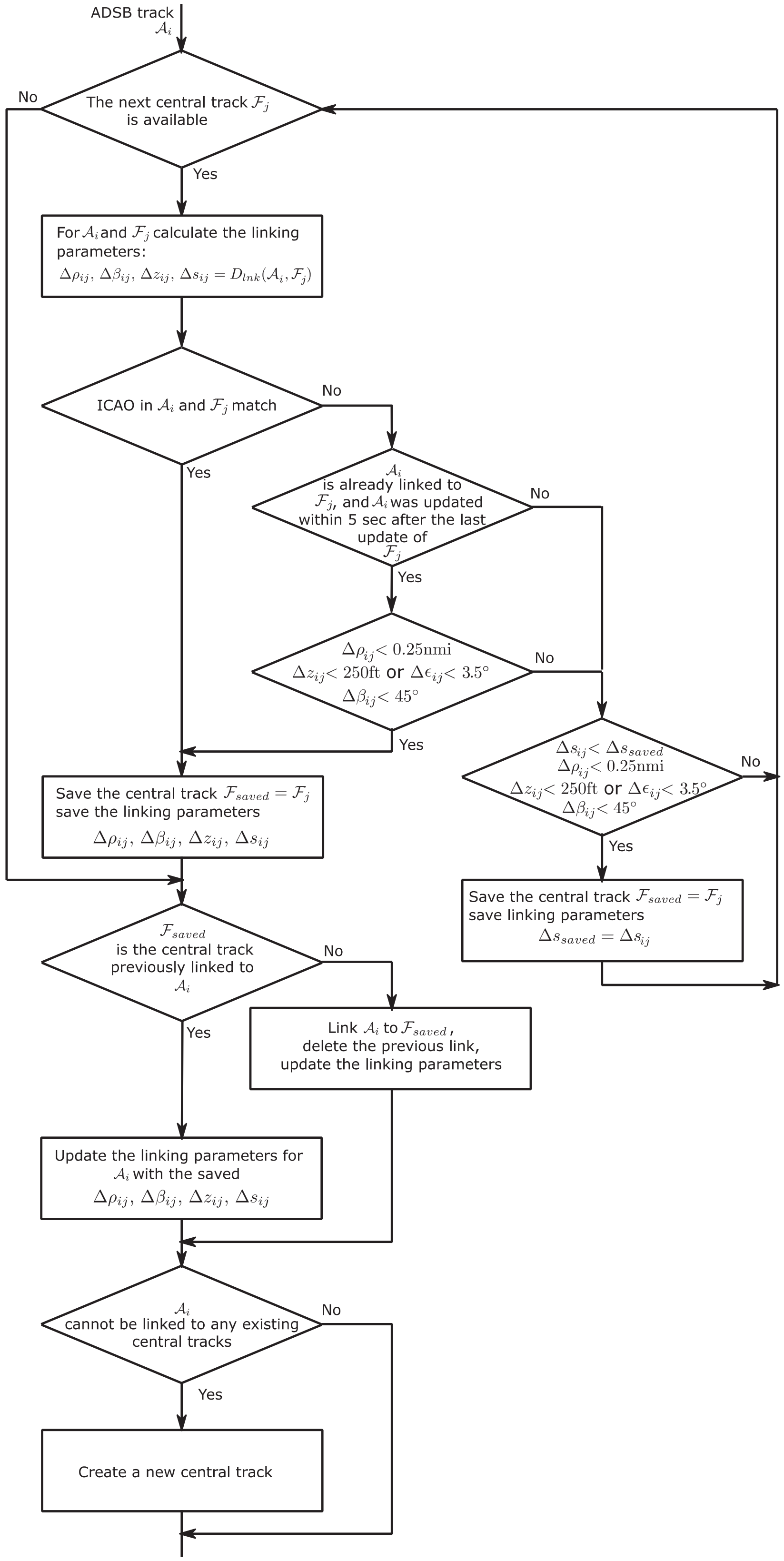
A flowchart in Figure F-6 demonstrates the link update algorithm between the ADS-B sensor track A_i and the central track F_j. First the function $D_{lnk}(R_i, F_j)$ is used to calculate the linking parameters shown in Figure F-5 and described above for A_i and linearly extrapolated F_j. If A_i and F_j have matching ICAO address, A_i is linked to F_j if the tracks have not been previously linked, and the linking parameters are updated for this link. Otherwise, if A_i is already linked to F_j, and if A_i has been updated within 5 seconds after the last update of F_j, such that $\Delta\rho < 0.25$ NM, $\Delta\beta < 45^\circ$, and $\Delta z < 250'$ (or $\Delta\epsilon < 3.5^\circ$ for a fused track linked only to non-cooperative sensor), the link between A_i and F_j is updated with the new values of the linking parameters. Finally, if neither of the above conditions are satisfied, a central track F_j is chosen such that $\Delta\rho < 0.25$ NM, $\Delta\beta < 45^\circ$, and $\Delta z < 250'$ (or $\Delta\epsilon < 3.5^\circ$ for a fused track linked only to non-cooperative sensor), and the lateral position difference,Δs, is the lowest among all existing central tracks. If such a central track cannot be found, a new central track is created based on the ADS-B sensor track A_i. The bearing difference test is kept large for validation against AST that may have a large bearing error. Unless it is validated, an ADS-B sensor track is not eligible to update/initiate a central track.

F.7.2 Radar Link Update

A flowchart in Figure F-7 demonstrates the link update algorithm between the radar sensor track R_i and the central track F_j. First the function $D_{lnk}(R_i, F_j)$ is used to calculate the linking parameters shown in Figure F-5 and described above for R_i and linearly extrapolated F_j. If R_i is already linked to F_j, and if R_i has been updated within 5 seconds after the last update of F_j, such that $\Delta\rho < 0.25$ NM, $\Delta\beta < 45^\circ$, and $\Delta\epsilon < 3.5^\circ$, the link between A_i and F_j is updated with the new values of the linking parameters. Otherwise a central track F_j is chosen such that $\Delta\rho < 0.25$ NM, $\Delta\beta < 45^\circ$, and $\Delta\epsilon < 3.5^\circ$, and the lateral position difference, Δs, is the lowest among all existing central tracks. If such a central track cannot be found, a new central track is created based on the radar sensor track R_i. The bearing difference test for radar track is kept tight as the radar bearing error is small.

F.7.3 AST Link Update

A flowchart in Figure F-8 demonstrates the link update algorithm between the AST sensor track T_i and the central track F_j. First the function $D_{lnk}(T_i, F_j)$ is used to calculate the linking parameters shown in Figure F-5 and described above for T_i and linearly extrapolated F_j. If T_i and F_j have matching ICAO addresses, T_i is linked to F_j if the tracks have not been previously linked, and the linking parameters are updated for this link. Otherwise, if T_i is already linked to F_j, and if T_i has been updated within 5 seconds after the last update of F_j, such that $\Delta\rho < 0.25$ NM, $\Delta\beta < 45^\circ$, and $\Delta z < 250'$ (or $\Delta\epsilon < 3.5^\circ$ for a fused track linked only to a non-cooperative sensor), the link between T_i and F_j is updated with the new values of the linking parameters. Finally, if neither of the above conditions are satisfied, a central track F_j is chosen such that $\Delta\rho < 0.25$ NM, $\Delta\beta < 45^\circ$, and $\Delta z < 250'$ (or $\Delta\epsilon < 3.5^\circ$ for a fused track linked only to a non-cooperative sensor), and the lateral position difference, Δs, is the lowest among all existing central tracks. If such a central track cannot be found, a new central track is created based on the AST sensor track T_i.



<u>Figure F-6</u> **ADS-B Sensor Track Linking Update Algorithm**

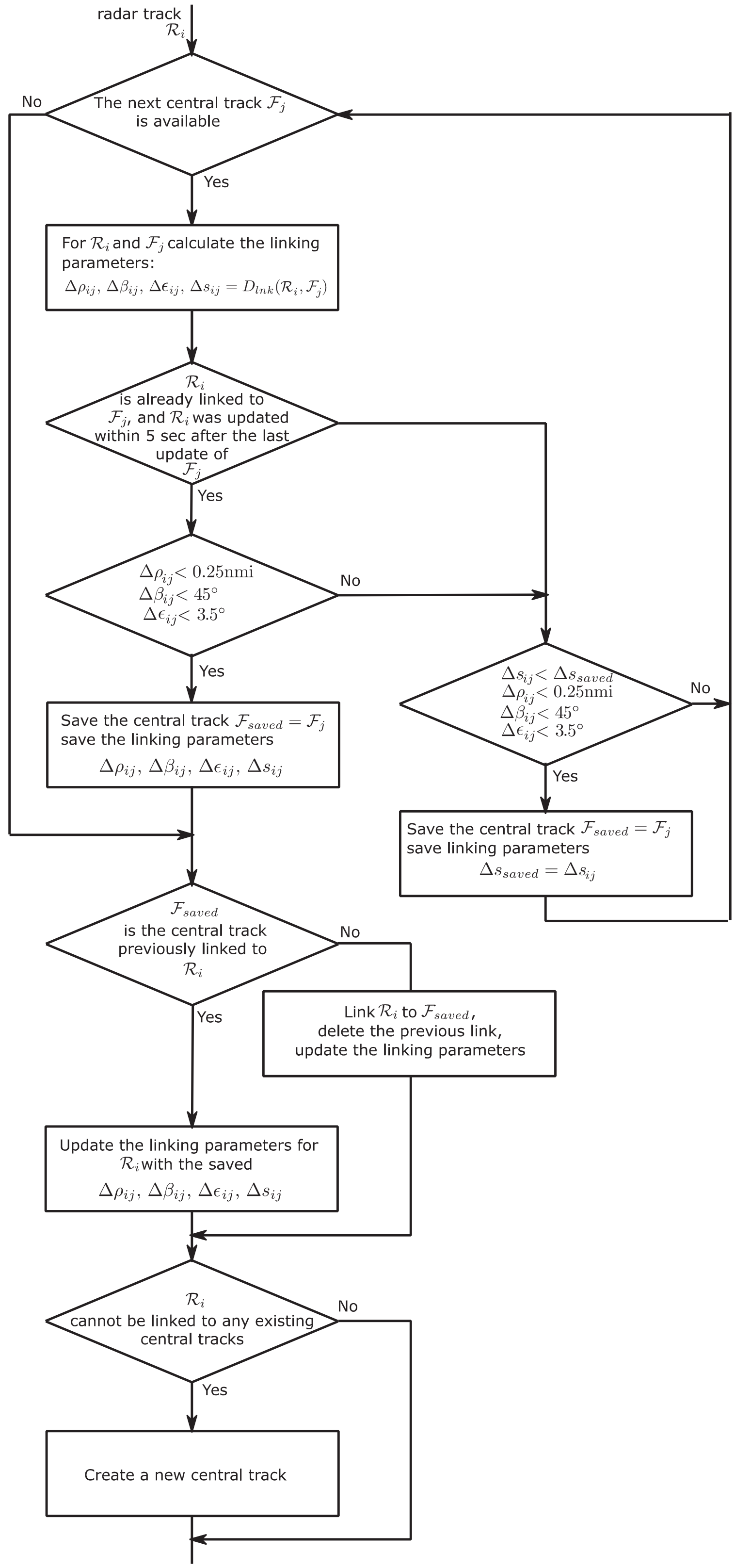
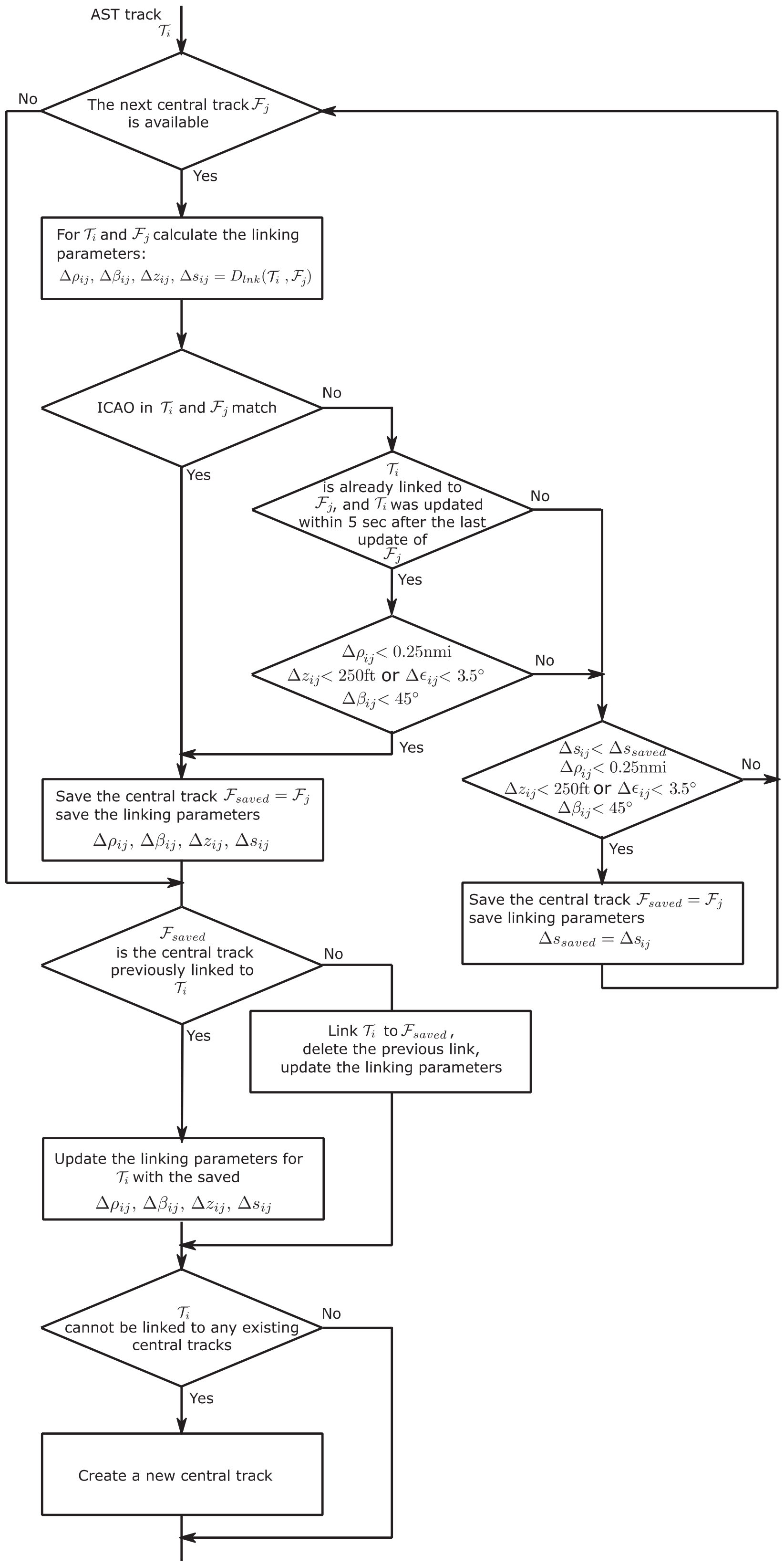


Figure F-7 Radar Sensor Track Linking Update Algorithm



<u>Figure F-8</u> **AST Sensor Track Linking Update Algorithm**

F.8 Best Sensor Selection

Once linked, the central tracker performs a preferred or best sensor selection for the estimated horizontal position and velocity based on sensor track's propagated horizontal position uncertainty at the time of linking, which is the circular error bound computed from the elliptical track propagated horizontal covariance, and best sensor track for estimated vertical position and velocity based on vertical rate uncertainty.

The preferred sensor is maintained separately for the horizontal and vertical estimates. To avoid toggling of the preferred sensor, the preferred sensor is switched only if the alternate sensor track has better uncertainty for at least 2.5 seconds (an adaptable parameter). The uncertainty refers to propagated positional uncertainty for the horizontal estimates and vertical rate uncertainty for the vertical estimates. For the preferred sensor for vertical estimates, cooperative sensors are prioritized over non-cooperative sensors, and this sensor prioritization precedes the vertical rate uncertainty. To avoid extended periods without track update, the preferred sensor is switched if no track updates have been received for the preferred sensor for at least 5.5 seconds. This is done to avoid the stale track estimates being used during extrapolation at each one-second epoch, as the intruder may have maneuvered during this interval, or the intruder may have moved outside the sensor field of view, or the sensor may have become offline.

The propagated horizontal position uncertainty is computed from the tracker estimated position and velocity variances, for the prediction duration δt as follows, ignoring the uncertainty in target dynamics for simplicity of implementation and runtime efficiency.

$$\acute{\sigma}^2_{east} = \sigma^2_{east} + \delta_t^2 \times \sigma^2_{v,east}$$

$$\acute{\sigma}^2_{north} = \sigma^2_{north} + \delta_t^2 \times \sigma^2_{v,north}$$

$$\acute{\sigma}^2_{east,north} = \sigma^2_{east,north}$$

Next, the algorithm for selecting the best sensor and updating the central track with the best sensor track are presented. Figure F-9 illustrates the best sensor selection algorithm flowchart.

The following definitions and variables are used in the best sensor selection algorithm:

$\boldsymbol{A}$, $\boldsymbol{R}$, $\boldsymbol{T}$ are the sets of the ADS-B, radar, and AST sensor tracks respectively

$A_j \in \boldsymbol{A}$ is a jth Automatic Dependent Surveillance-Broadcast (ADS-B) track

$R_j \in R$ is a jth radar track

$T_j \in \boldsymbol{T}$ is a jth AST track

$\mathcal{L}$ is a map that stores key-value pairs of the form sensor-sensor track for each fused track. For example $\mathcal{L}[ADSB]$==A_j if the ADSB track, A_j, was stored in $\mathcal{L}$. If $\mathcal{L}$ does not contain an ADSB track, the map returns an empty set, $\mathcal{L}[ADSB] = = \{\}$.

t is a current time

Each sensor track S_j has the following attributes:

$S_j.s$ is an update sensor for the sensor track S_j, i.e., $A_j.s == ADSB$, $R_j.s == RADAR$, and $T_j.s == AST$

$S_j.t$ is the time of the last update of the sensor track S_j

The fused track F_i has the following attributes:

$F_i.s^h$ is the last update sensor for the horizontal position and velocity states of the central track F_i ($F_i.s^h = \{ADSB, RADAR, AST\}$)

$F_i.t^h$ is the time of the last update of $F_i.s^h$

$F_i.s_p^h$ is a selected preferred sensor track for the horizontal position and velocity update. The preferred sensor track selection is based on the current best values of the horizontal positional uncertainty

$F_i.t_p^h$ is the time when $F_i.s_p^h$ was selected as the preferred sensor for the horizontal position and velocity

$F_i.s^v$ is the last update sensor for the vertical position and the vertical rate of the central track F_i ($F_i.s^v = \{ADSB, RADAR, AST\}$)

$F_i.t^v$ is the time of the last update of $F_i.s^v$

$F_i.s_p^v$ is a selected preferred sensor track for the vertical position and the vertical rate update. The preferred sensor track selection is based on the current best values of the vertical rate uncertainty. Note that the cooperative sensors are prioritized over non-cooperative sensors, and this sensor prioritization precedes the vertical rate uncertainty.

$F_i.t_p^v$ is the time when $F_i.s_p^v$ was selected as the preferred sensor for the horizontal position and velocity

$T_S = 2.5$ sec is a constant that defines switching to the selected preferred sensor track based on the uncertainty

$T_D = 5.5$ sec is a constant that defines switching to the preferred sensor track based on the track update interval

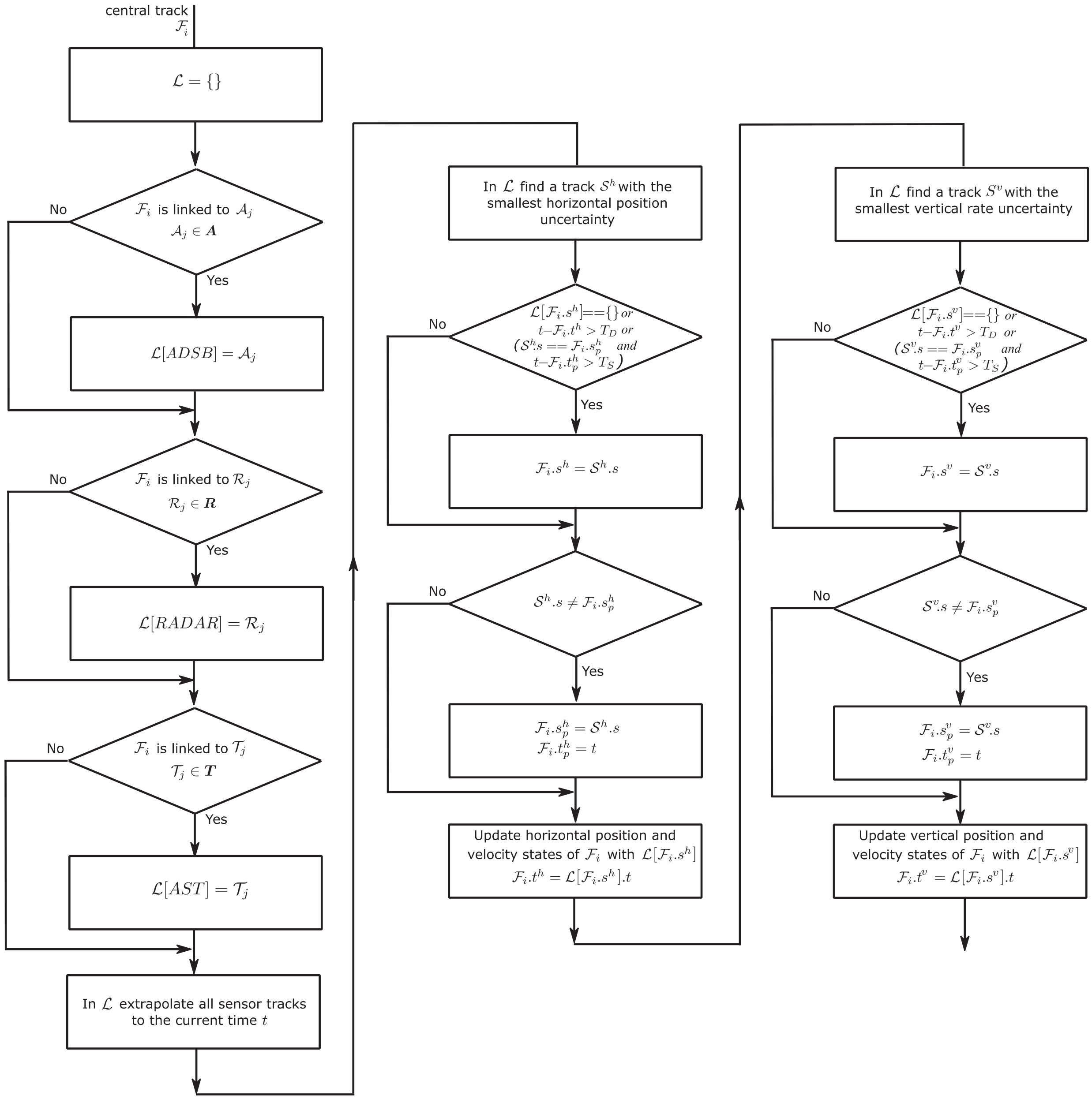


Figure F-9 **Best Sensor Selection Algorithm Flowchart**

F.9 Track Management

The sensor tracks are managed by removing sensor tracks that have not been updated longer than the specified time. The ADS-B track, radar track, and AST track are terminated after coasting for 10 seconds, 4 seconds, and 10 seconds respectively.

The central tracks are managed in the following way:

1. If any two existing central tracks have a matched ICAO address or the central tracks are close to each other such that: $\Delta\rho < 0.15$ NM, $\Delta\beta < 30^{\circ}$, and $\Delta\epsilon < 3.5^{\circ}$ or $\Delta z < 250'$ remove the central track with a larger position uncertainty.
2. Remove central tracks that have no sensor tracks linked to them (i.e., all the sensor tracks linked to the central tracks have terminated).

The tracker sends the linearly extrapolated central track state from the preferred or best sensor track at each one-second epoch for each intruder to the DAA algorithm. The ownship track information obtained from the sensor emulator is also passed along at each one-second epoch. The following information for each track is sent once per second to the DAA algorithm: time, track ID, ICAO Address, latitude, longitude, east-north velocity, altitude, altitude rate, position variance, velocity variance, speed, speed variance, heading, heading variance, range, range variance, bearing, bearing variance, elevation, elevation variance, range rate, and range rate variance.

F.9.1 Common Time Track Extrapolation

The central track state (position and velocity) and uncertainty (represented by the variance) are linearly extrapolated from the last track update time to the next one second epoch time at which the track information is sent out to the DAA algorithm. The extrapolation is performed in the ENU coordinate system local to the intruder.

Position and velocity of the central track in the ENU coordinate system local to the intruder at the time of the last update are $[0 \quad 0 \quad 0]'$ and $[\dot{e}_t \quad \dot{n}_t \quad \dot{u}_t]'$ respectively. The time difference between the current epoch time and the last track update of the central track is found by,

$$\Delta t = \text{ current epoch time – central track update time}$$

The extrapolated position of the central track in the ENU coordinate system local to the intruder can be found by

$$\begin{bmatrix} e_x \\ n_x \\ u_x \end{bmatrix} = \Delta t \begin{bmatrix} \dot{e}_t \\ \dot{n}_t \\ \dot{u}_t \end{bmatrix} \tag{F5.70}$$

Let $[\phi_t \quad \lambda_t \quad h_t]'$ be the geodetic position of the central track at the time of the last update. The extrapolated central track position in the ECEF coordinate system with respect to the position at the time of the central track update is calculated as

$$\begin{bmatrix} X_{x-t} \\ Y_{x-t} \\ Z_{x-t} \end{bmatrix} = \boldsymbol{T}(\phi_t, \lambda_t) \begin{bmatrix} e_x \\ n_x \\ u_x \end{bmatrix} \tag{F5.71}$$

where the transformation matrix $\mathbf{T}(\phi_t, \lambda_t)$ is given by (F5.6). The extrapolated central track position in the ECEF is further calculated as

$$\begin{bmatrix} X_x \\ Y_x \\ Z_x \end{bmatrix} = \begin{bmatrix} X_{x-t} \\ Y_{x-t} \\ Z_{x-t} \end{bmatrix} + \begin{bmatrix} X_t \\ Y_t \\ Z_t \end{bmatrix} \tag{F5.72}$$

where $[X_t \quad Y_t \quad Z_t]'$ is the central track's position in the ECEF coordinate system at the time of the update. Starting with $[X_x \quad Y_x \quad Z_x]'$ as input, the extrapolated central track position in WGS-84 geodetic coordinates (ϕ_x, λ_x, h_x) is obtained following the 15-step process presented in (F5.8).

Due to the linear extrapolation, the ENU velocity of the central track does not change from the time of the last update to the current epoch time. However, this velocity needs to be expressed with respect to the new geodetic coordinates (ϕ_x, λ_x, h_x). Hence, the extrapolated velocity $[\dot{e}_x \quad \dot{n}_x \quad \dot{u}_x]'$ at the epoch time is given by

$$\begin{bmatrix} \dot{e}_x \\ \dot{n}_x \\ \dot{u}_x \end{bmatrix} = \mathbf{L}(\phi_x, \lambda_x, \phi_t, \lambda_t) \begin{bmatrix} \dot{e}_t \\ \dot{n}_t \\ \dot{u}_t \end{bmatrix} \tag{F5.73}$$

where matrix $\mathbf{L}(\phi_x, \lambda_x, \phi_t, \lambda_t)$ is given by (F5.13).

Position and velocity variances after extrapolation can be found as the diagonal elements of the matrix

$$\mathbf{P}_x = \mathbf{L}(\phi_x, \lambda_x, \phi_t, \lambda_t)\mathbf{F}\mathbf{P}_{\mathrm{t}}\mathbf{F}'\mathbf{L}'(\phi_x, \lambda_x, \phi_t, \lambda_t) \tag{F5.74}$$

where $\mathbf{P}_t$ is a state covariance matrix of the central track at the time of the last update specified with respect to the ENU coordinate system located at the intruder, and $\boldsymbol{F}$ is given in (F5.25).

The extrapolated track position, velocity, and covariance in (F5.72), (F5.73), and (F5.74) are used to derive the other estimates; speed, speed variance, heading, heading variance, range, range variance, bearing, bearing variance, elevation, elevation variance, range rate, and range rate variance.

F.10 Adding Bias Effects to Error Covariance

The measurements from a sensor are affected by additive random noise that change from measurement to measurement and bias that remains constant or vary slowly. The tracker described in this appendix is designed to estimate the target state by minimizing the effects of random noise contained in the measurements. While doing so it outputs an error covariance estimate which is representative of residual noise errors in the estimated state. However, when the estimated state and its uncertainty estimates derived from the covariance are used by the applications downstream, the estimated state needs to be corrected for bias or the uncertainty estimates need to reflect the actual error in the estimated state. Thus, since the tracker in this appendix has no means to estimate the bias and correct the state, it is proposed to add the effects of the bias to the uncertainty estimate. The values added to the estimated covariance to include the sensor bias effects are calculated as described below.

F.10.1 Radar Tracker

The radar measurements can be modelled by the following equation:

$$\rho = \rho_0 + \rho_\Delta + n_\rho$$
$$\beta = \beta_0 + \beta_\Delta + n_\beta \quad \text{(F5.75)}$$
$$\epsilon = \epsilon_0 + \epsilon_\Delta + n_\epsilon$$

where $\rho_0, \theta_0, \epsilon_0$ are the true range, bearing and elevation of the target with respect to the ownship body frame, respectively. The noise terms are modeled as Gaussian random variables $n_\rho \sim N\left(0, \sigma_{n_\rho}^2\right)$, $n_\beta \sim N\left(0, \sigma_{n_\beta}^2\right)$ and $n_\epsilon \sim N\left(0, \sigma_{n_\epsilon}^2\right)$. The EKF tracker is designed to minimize this noise. Additionally, the measurements also contain bias terms which are uniformly random for a particular installation.

$$\rho_\Delta \sim U(-\rho_B, \rho_B)$$
$$\beta_\Delta \sim U(-\beta_B, \beta_B) \quad \text{(F5.76)}$$
$$\epsilon_\Delta \sim U(-\epsilon_B, \epsilon_B)$$

where ρ_Δ, β_Δ and ϵ_Δ are the maximum bias in range, bearing and elevation respectively. The sampled bias is a constant for an installation. However, if the tracker used data from multiple installations and its output is used to drive a single downstream application, the estimated variance in each measured parameter due to bias can be quantified by the ensemble quantity "bias variances" defined as

$$\sigma_{\rho,\Delta}^2 = \frac{{\rho_B}^2}{3}$$
$$\sigma_{\beta,\Delta}^2 = \frac{{\beta_B}^2}{3} \quad \text{(F5.77)}$$
$$\sigma_{\epsilon,\Delta}^2 = \frac{{\epsilon_B}^2}{3}$$

The radar measurements can be transformed into coordinates with respect to the ownship frame using the transformation

$$\begin{bmatrix} l \\ a \\ v \end{bmatrix} = \begin{bmatrix} \rho \cos\epsilon \sin\beta \\ \rho \cos\epsilon \cos\beta \\ \rho \sin\epsilon \end{bmatrix} \quad \text{(F5.78)}$$

Based on the above transformation, the bias variance for each of the ownship frame coordinates are

$$\sigma_l^2 = (\cos\epsilon_0 \sin\beta_0)^2 \sigma_{\rho,\Delta}^2 + (\rho_0 \cos\epsilon_0 \cos\beta_0)^2 \sigma_{\beta,\Delta}^2 + (\rho_0 \sin\epsilon_0 \sin\beta_0)^2 \sigma_{\epsilon,\Delta}^2$$

$$\sigma_a^2 = (\cos\epsilon_0 \cos\beta_0)^2 \sigma_{\rho,\Delta}^2 + (\rho_0 \cos\epsilon_0 \sin\beta_0)^2 \sigma_{\beta,\Delta}^2 + (\rho_o \sin\epsilon_0 \cos\beta_0)^2 \sigma_{\epsilon,\Delta}^2 \qquad \text{(F5.79)}$$

$$\sigma_v^2 = (\sin\epsilon_0)^2 \sigma_{\rho,\Delta}^2 + (\rho_o \cos\epsilon_0)^2 \sigma_{\epsilon,\Delta}^2$$

The bias covariance in ENU coordinates of the ownship is given by

$$\mathbf{R} = \mathbf{M}(\alpha,\gamma,\eta) \begin{bmatrix} \sigma_l^2 & 0 & 0 \\ 0 & \sigma_a^2 & 0 \\ 0 & 0 & \sigma_v^2 \end{bmatrix} \mathbf{M}'(\alpha,\gamma,\eta) \qquad \text{(F5.80)}$$

where $\mathbf{M}(\alpha,\gamma,\eta)$ is given by (F5.2). The position error variance in each direction of the ENU coordinate system of the ownship is inflated as follows,

$$\begin{aligned} \acute{\sigma}_e^2 &= \sigma_e^2 + \mathbf{R}_{00} \\ \acute{\sigma}_n^2 &= \sigma_n^2 + \mathbf{R}_{11} \\ \acute{\sigma}_{en}^2 &= \sigma_{en}^2 + \mathbf{R}_{01} \\ \acute{\sigma}_u^2 &= \sigma_u^2 + \mathbf{R}_{22} \end{aligned} \qquad \text{(F5.81)}$$

where

$\acute{\sigma}_e^2$ = inflated position error variance in east direction (m^2)

$\acute{\sigma}_n^2$ = inflated position error variance in north direction (m^2)

$\acute{\sigma}_{en}^2$ = inflated position error cross covariance of east and north directions (m^2)

$\acute{\sigma}_u^2$ = inflated position error variance in up direction (m^2)

σ_e^2 = extrapolated (Paragraph F.9.1) position error variance in east direction (m^2)

σ_n^2 = extrapolated (Paragraph F.9.1) position error variance in north direction (m^2)

σ_{en}^2 = extrapolated (Paragraph F.9.1) position error cross covariance of east and north directions (m^2)

σ_u^2 = extrapolated (Paragraph F.9.1) position error variance in up direction (m^2)

$\acute{\sigma}_e^2, \acute{\sigma}_n^2, \acute{\sigma}_{en}^2$ and $\acute{\sigma}_u^2$ are then used to calculate the 95% position uncertainty estimate in the output of the tracker.

F.10.2 AST Tracker – Horizontal

The AST sensor is modelled such that it has no bias for bearing measurements and there is a fixed 125' and 250' range bias for Mode S and Mode C respectively. These bias values are directly added to the 95% positional uncertainty of the AST tracker.

F.10.3 Altitude Tracker

AST and ADS-B sensors are modelled to have altitude bias depending on the altitude tier that the target is in as stipulated in Altitude Error Model of ICAO Annex 10, §4.4.2.4. Thus, the altitude error variance estimated by the altitude tracker described in this appendix needs to be inflated based on the altitude tier that the target is in. However, it is assumed that the downstream application would employ necessary tolerances to mitigate the effects of bias in the altitude estimates. Hence, altitude error uncertainty estimate is not inflated.

This Page Intentionally Left Blank

G APPENDIX G DAA ALERTING LOGIC AND MANEUVER GUIDANCE FOR UAS REFERENCE IMPLEMENTATION

G.1 Conceptual Overview of the DAIDALUS Reference Implementation

Detect and Avoid Alerting Logic for Unmanned Aircraft Systems (DAIDALUS) is a software reference implementation intended to satisfy the Detect and Avoid (DAA) functional requirements detailed in this document. This appendix discusses the high-level architecture and the underlying logic and assumptions that went into the DAIDALUS reference implementation. The DAIDALUS software library is released under the National Aeronautics and Space Administration (NASA)'s Open Source Agreement and it is available for download at http://www.github.com/nasa/wellclear in Java and C++. The DAIDALUS software library is not intended to be used as an actual industrial-ready implementation of Detect and Avoid functionality. It should be used as a reference implementation of the DAA algorithms described in this appendix. The code is provided "as is" with supporting documentation but without any express warranty. The formal models of the algorithms implemented in DAIDALUS are written in the mathematical notation of the Prototype Verification System (PVS).

The top-level functionality of DAIDALUS provides traffic awareness and maneuver guidance to Unmanned Aircraft Systems (UAS) operators to detect and avoid other aircraft having the potential to cause Loss of Well Clear (LoWC). This functionality is intended to aid the pilot in command (PIC) to perform a safe maneuver to maintain well clear, or return to DAA well clear (DWC) if a LoWC has already occurred (or is unavoidable). Traffic awareness is achieved through increasing alert levels, which correspond to increasing potential for LoWC. Maneuver guidance is provided in the form of ranges of maneuvers, which the pilot in command may execute to avoid or recover from LoWC.

G.2 High-Level Functional Block Diagram of the DAIDALUS Reference Implementation

The high-level functional architecture of DAIDALUS is depicted in Figure G-1, together with a high-level depiction of data and external processing requirements. The DAIDALUS software computes: (1) predictions of LoWC between the ownship and a given traffic aircraft, (2) maneuver guidance for the ownship pilot in command to maintain or return to DWC with respect to all traffic aircraft, and (3) an alert level representing the severity of a potential LoWC between the ownship and a given traffic aircraft. The functionalities provided in (1), (2), and (3) are referred to as detection logic, guidance-processing logic, and alerting logic, respectively. Together, these functionalities make up the DAIDALUS Algorithms module, as illustrated in Figure G-1.

The scope of the reference software implementation provided in this appendix is limited to the DAIDALUS Algorithms. All pre-processing of surveillance input data and all post-processing for crew interface is performed by external modules. An example of a preprocessing element is an altitude adjustment when a radar-only surveillance source is provided. It is assumed that the inputs to DAIDALUS are within accepted ranges of accuracy and integrity as required by this document. In particular, the DAIDALUS software does not track or filter the aircraft state information, and does not apply time lags or delays to the output data. Additionally, the choice of crew interface symbology and display design is assumed to be part of the external post-processing modules. All visualizations presented here are for illustrative purposes only.

The guidance-processing logic described is only intended to fulfill the requirements in Subparagraphs 2.2.4.4.1 and 2.2.4.4.2, although pre-processing and post-processing of data may allow the algorithms to fulfill some of the requirements in Subparagraphs 2.2.4.4.3 and 2.2.4.4. For example, the requirements of Subparagraph2.2.4.4.4.1.3.2 can be met for an intruder with no altitude information by setting the intruder's altitude and vertical velocity to be the same as that of the ownship before sending it to DAIDALUS. The alerting logic described is only intended to fulfill the requirements in Subparagraphs 2.2.4.3.4.2, 2.2.4.3.4.3, and 2.2.4.3.4.4, excluding the requirement that alerts must persist for a minimum of 4 seconds. Similar to the guidance-processing logic, pre-processing and post-processing of the data may allow for the alerting logic to meet some requirements of Subparagraph 2.2.4.3.5.

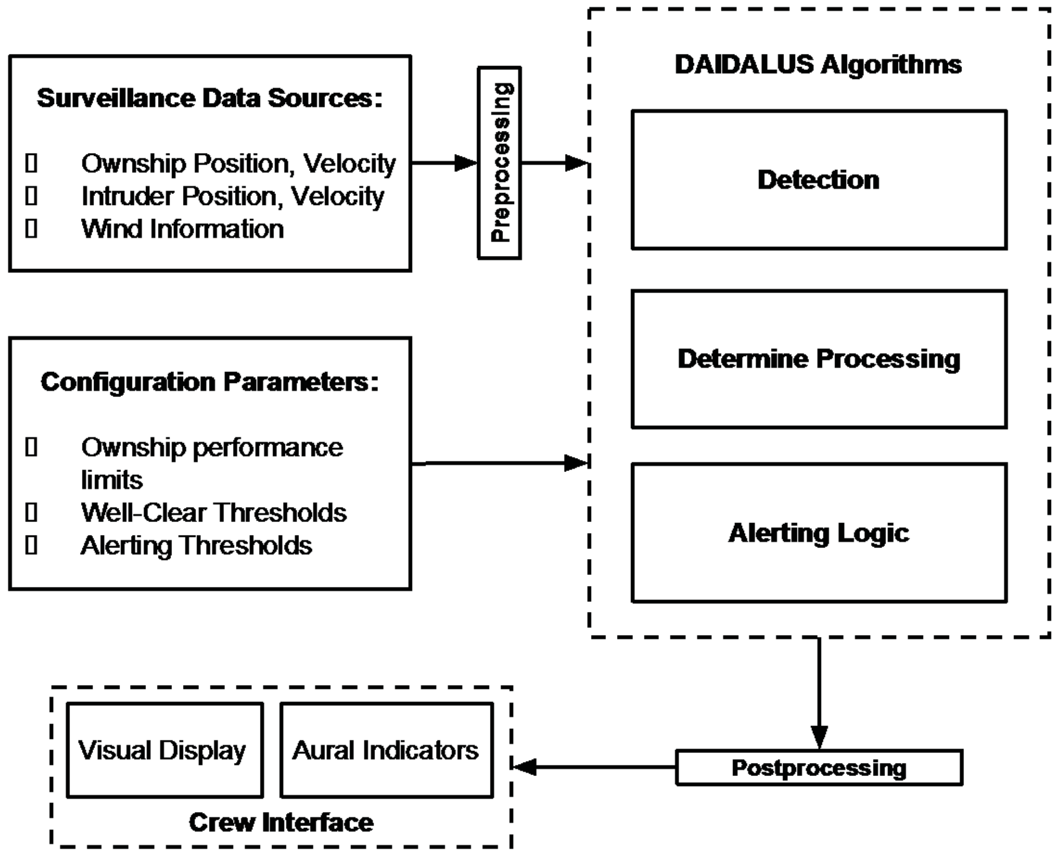


Figure G-1 **Notional Functional Block Diagram of DAIDALUS**

G.2.1 Alerter Settings

The DAIDALUS reference implementation computations are based on an Alerter. This Alerter is a list of three sets of DWC thresholds labeled "FAR," "MID," and "NEAR," and an indicator as to which set of thresholds is to be used for the computation of Well Clear Recovery guidance processing. Each set of thresholds consists of values that describe a volume similar to the Well Clear volume, along with a pair of time parameters. The time parameters are referred to as *alert time* and *early alert time*. The FAR, MID, and NEAR threshold values and times are intended to correspond (respectively) to the preventive, corrective, and warning Hazard Volumes and times described in Table 2-21 and described in the Subparagraph 2.2.4.3.2 of this document. For the purposes of this document, a *predicted Hazard (HAZ) violation* of an alert level (preventive, corrective, or warning) means that the associated volume is predicted to be violated prior to the indicated alert time. Both the guidance processing and the alerting logic use this Alerter for determining output.

G.2.2 Detection Logic

The DAIDALUS detection logic predicts a time interval of LoWC between the ownship and a traffic aircraft within a specified look-ahead time, assuming constant-velocity (linear) projections of the aircraft current states. An illustration of these projections is given in Figure G-2 for a notional horizontal encounter at a particular time instant t_0 and for a given look-ahead time T. Thus, the detection logic assumes constant-velocity trajectories for the ownship and the intruder for the purpose of LoWC interval computation at any particular time instant.

As the aircraft states are updated and become available at some subsequent time instant, a new interval is computed which is based on constant-velocity projections from that particular time instant. Thus, the predicted interval for LoWC evolves as the encounter evolves, and the accuracy of the predicted interval for LoWC improves with the accuracy of the projected positions. For example, in the depicted scenario, if the ownship comes out of the maneuver at time $t = t_0 + T$ and follows a constant velocity trajectory thereafter, the predictions from that time forward will coincide with the actual positions from that time forward (assuming accurate state information and no maneuvering by the intruder).

The detection logic is used as both a stand-alone function, and as a subroutine in the alerting logic and guidance-processing computations described below, when configured using parameters from the alerter.

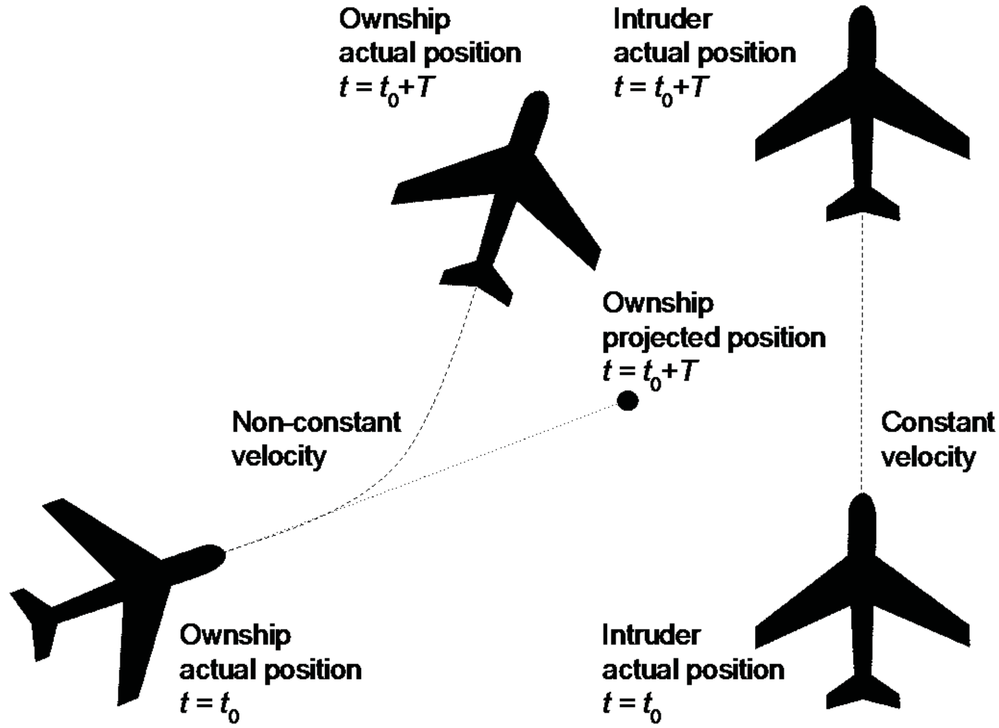


Figure G-2 **Constant Velocity Aircraft Projection**

G.2.3 Guidance-Processing Logic

The guidance-processing logic computes maneuver guidance in the form of intervals that may be used by a pilot in command to maintain DWC of traffic aircraft, or aid in returning to DWC in a timely manner and within the ownship performance limits. The maneuver guidance computed by the guidance-processing logic has the form of maneuver ranges (intervals) referred to as *bands*. These bands are computed for the MID and NEAR threshold values provided in the Alerter. A band corresponds to a predicted HAZ violation at the alerter level, assuming constant turn rate and constant acceleration of the ownship and constant-velocity projections of traffic aircraft. Both MID and NEAR bands are computed, with a maneuver being labeled NEAR when both labels are applicable (i.e., the more severe band is given priority). In the event that every available maneuver is predicted to lead to a HAZ violation at the alerter level indicated for recovery, a third type of band, labeled "RECOVERY," is computed. These bands correspond to ranges of ownship maneuvers that are predicted to exit the HAZ zone in a timely manner.

Four dimensions of bands are provided by DAIDALUS: (1) horizontal maneuver ranges (i.e., heading ranges, if wind information is provided; otherwise, track ranges), (2) horizontal speed ranges (i.e., air speed ranges, if wind information is provided; otherwise, ground speed ranges), (3) vertical velocity ranges, and (4) altitude ranges. Figure G-3 illustrates a conceptual horizontal encounter where state projections for the ownship and the intruder aircraft are used in the computation of heading ranges to avoid in order to remain outside of the warning and corrective HAZ zones.

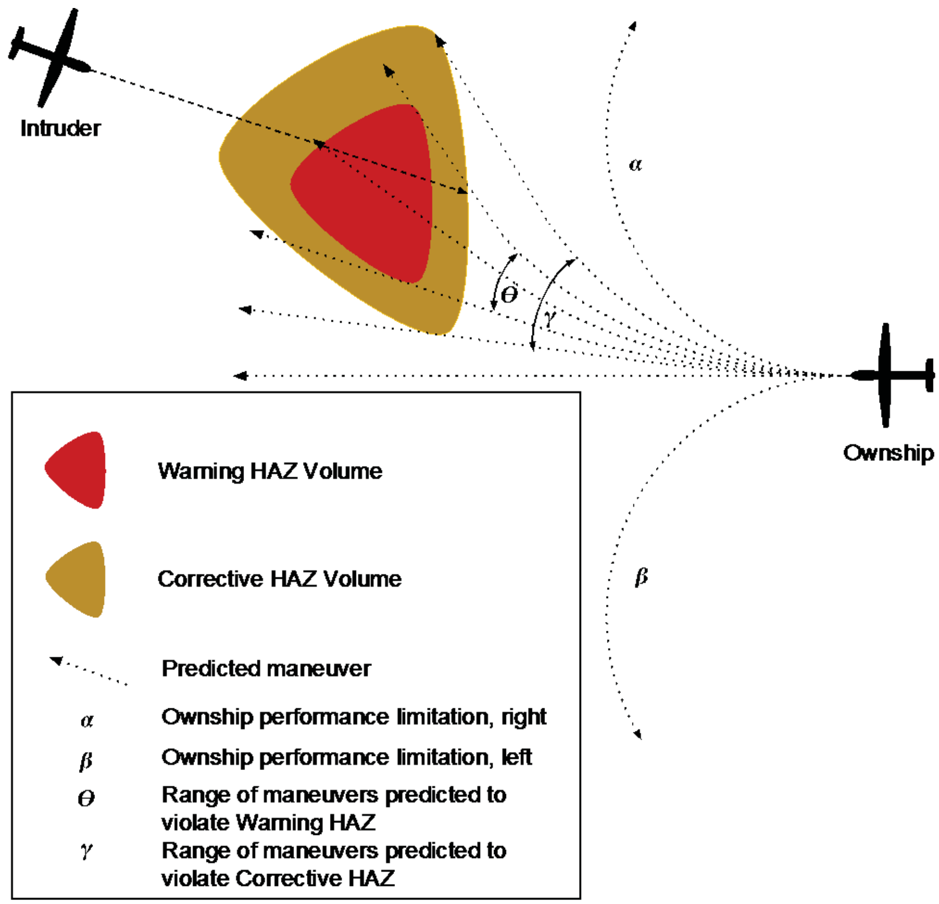


Figure G-3 **Concept of DAIDALUS Horizontal Maneuver Guidance to Maintain DWC**

In this figure, the range of headings indicated by γ represents the set of horizontal maneuvers for the ownship that are predicted to lead to a corrective HAZ violation. The range of headings indicated by θ represent the set of horizontal maneuvers for the ownship that are predicted to lead to a warning HAZ violation. To illustrate how bands are computed taking into account the ownship performance limitations, the limit of possible horizontal maneuvers the ownship may take are indicated by α and β. Thus, the range of horizontal maneuvers which would allow the pilot in command to remain free of any HAZ violation in this scenario consist of

- those horizontal maneuvers between the upper bound of γ and α (maneuvers to the ownship's right), and
- those horizontal maneuvers between the lower bound of γ and β (maneuvers to the ownship's left).

DAIDALUS returns maneuver guidance as ranges of maneuvers with one of four possible labels. In the illustrated scenario, the arc represented by θ would be labeled as NEAR, the two arcs within γ but outside of θ would be labeled as MID, and the remaining arcs are labeled as "NONE." In the event of a current or unavoidable HAZ violation at the alerter level indicated for recovery, (not depicted), the bands corresponding to maneuvers exiting the indicated HAZ violation in a timely manner are labeled RECOVERY, and all other ranges of maneuvers are labeled as the indicated recovery alerter level (i.e., NEAR or MID).

Figure G-4 depicts a conceptual view of track guidance bands for an example encounter evolving over four discrete times. This illustration is notional and does not necessarily represent how maneuver guidance is presented to a UAS operator.

- At time $t = t_0$, the ownship and the intruder aircraft are depicted in their initial configuration with the Alert Threshold and HAZ Volume shown around the ownship, where there is initially no predicted HAZ violation as the intruder is outside the alerting time threshold. No bands are shown at this time.
- At time $t = t_1$, the intruder is inside the Alerting time threshold of the ownship. The maneuver guidance computed by DAIDALUS is presented as *NEAR and MID bands* (shown as red and amber arcs, respectively, in Figure G-4), signifying the range of horizontal maneuvers the ownship should *avoid*, as they would lead to either a warning or corrective HAZ violation within the alerting time threshold.
- At time $t = t_2$, the intruder has maneuvered towards the ownship and, as a result, the encounter has evolved such that a warning HAZ violation is predicted for the ownship's and the intruder's current paths within the alerting time. The illustrated *NEAR band* is computed indicating that unless the ownship maneuvers outside the band, a warning HAZ violation will occur.
- At time $t = t_3$, the intruder is now within the warning HAZ volume of the ownship, and a LoWC has likely occurred. Thus, a recovery band, which is shown in Figure G-4 as a dashed green arc, is computed to indicate the ranges of maneuvers that the ownship may take to exit the warning HAZ volume, if it maneuvers within this range in a timely manner.

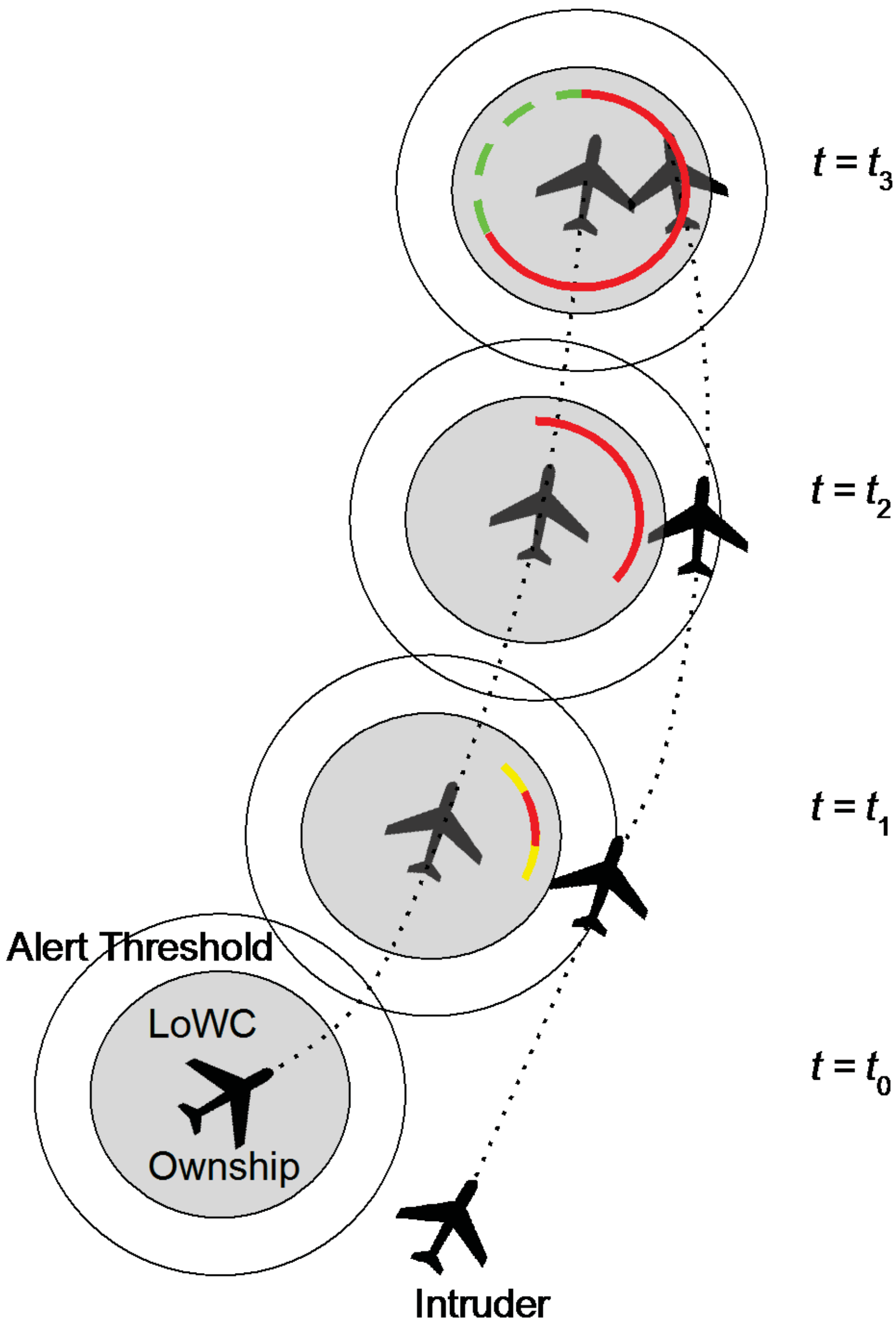


Figure G-4 Notional Illustration of Maneuver Guidance Evolution for an Example Encounter

G.2.4 Alerting Logic

The DAIDALUS alerting logic computes a pairwise alert level for each traffic aircraft according to the hierarchical alerting schema specified in Subparagraph 2.2.4.3.4 of this document. The alerting schema comprises multiple alert levels representing the severity of the ownship-intruder encounter condition. A higher alert level corresponds to a higher severity of the threat represented by the traffic aircraft. DAIDALUS assigns a numerical value to each traffic aircraft indicating its current alert level based on the set of time and distance boundaries provided as input configuration parameters in the alerter. Using these threshold values for both bands and alerting provides a consistency between the bands algorithm and the alerting logic. Traffic aircraft outside the bounds of these alerting parameters are given the alert level 0 indicating "no alert." As there are three levels given in the alerter, there are (including the level 0 alert) four alert levels in the hierarchy.

G.3 Data Requirements for DAIDALUS Reference Implementation

Table G-1 specifies the input requirements for the ownship state, and Table G-2 includes the requirements for specifying all traffic states. Optionally, wind information for the ownship can be provided. In this case, the wind information is uniformly applied to all traffic states. Note that all wind information is assumed to contain only horizontal components, i.e., no vertical wind information is considered.

Table G-1 Ownship Input State

State Field	Units	Data Type[60]	Sign Convention
Identifier		String	
Latitude	Degrees (Decimal) Radians	Double	North Positive, South Negative
Longitude	Degrees (Decimal) Radians	Double	East Positive, West Negative
Altitude	Feet Meters	Double	
Ground Speed	Knots Kilometers per Hour Meters per Second	Double	
Ground Track	Degrees Radians	Double	Clockwise from True North
Vertical Velocity	Feet per Minute Meters per Second	Double	
Wind Speed (Optional)	Knots Kilometers per Hour Meters per Second	Double	
Wind Track (Optional)	Degrees Radians	Double	Clockwise from True North

[60] The Data Type column used in tables G-1 through G-6 refers to types and data structures used in modern programming languages to represent numerical and textual data. For example, Double refers to large floating point numbers usually represented in 64 bits and String refers to an array of characters.

Table G-2 Traffic Input State

State Field	Units	Data Type	Sign Convention
Identifier	N/A	String	N/A
Latitude	Degrees (Decimal) Radians	Double	North Positive, South Negative
Longitude	Degrees (Decimal) Radians	Double	East Positive, West Negative
Altitude	Feet Meters	Double	N/A
Ground Speed	Knots Kilometers per Hour Meters per Second	Double	N/A
Ground Track	Degrees Radians	Double	Clockwise from True North
Vertical Velocity	Feet per Minute Meters per Second	Double	

Table G-3 specifies the data requirements for the ownship performance limits. The parameters MinHorizontalSpeed and MaxHorizontalSpeed are based on airspeed when wind information is provided; otherwise, they are based on ground speed.

Table G-3 Ownship Performance Limits

Parameter	Units	Data Type
MaxTurnRate	Degrees per Second Radians per Second	Double
MinHorizontalSpeed	knots Kilometers per Hour Meters per Second	Double
MaxHorizontalSpeed	Knots Kilometers per Hour Meters per Second	Double
MaxHorizontalAcceleration	Meters per Second per Second the Acceleration of Gravity (g)-Force	Double
MinVerticalSpeed	Feet per Minute Meters per Second	Double
MaxVerticalSpeed	Feet per Minute Meters per Second	Double
MaxVerticalAcceleration	Meters per Second per Second g-Force	Double

Table G-4 specifies the data types of DAIDALUS outputs. Table G-5 specifies the output requirements of DAIDALUS functionalities. The outputs corresponding to the horizontal dimension are based on airspeed when wind information is provided; otherwise, they are based on ground speed.

Table G-4 Output Data Types

Data Type Name	Units	Definition
TimeInterval	[Seconds, Seconds]	Pair<Double, Double>
BandsType		Enumeration {NONE, MID, NEAR, RECOVERY}
DoubleInterval		Pair<Double, Double>
HorizontalDir	Degrees Radians	Double
HorizontalDirInterval	[Degrees, Degrees] [Radians, Radians]	DoubleInterval
HorizontalDirRegions		List<Pair<HorizontalDirInterval, BandsType>>
HorizontalSpeedInterval	[Knots, Knots] [Kilometers per Hour, Kilometers per Hour] [Meters per Second, Meters per Second]	DoubleInterval
HorizontalSpeedRegions		List<Pair<HorizontalSpeedInterval, BandsType>>
VerticalSpeed	Feet per Minute Meters per Second	Double
VerticalSpeedInterval	[Feet per Minute, Feet per Minute] [Meters per Second, Meters per Second]	DoubleInterval
VerticalSpeedRegions		List<Pair<VerticalSpeedInterval, BandsType>>
AltitudeInterval	[Feet, Feet] [Meters, Meters]	DoubleInterval
AltitudeRegions		List<Pair<AltitudeInterval, BandsType>>
RecoveryTime	Seconds	Double
AlertLevel		Integer

Table G-5 Output Requirements

Functionality	Function Name	Output Data Type
Well Clear Detection Logic	WCD	TimeInterval
Guidance-Processing Logic (Track or Heading Maneuvers)	HorizontalDirBands	Pair<HorizontalDirRegions, RecoveryTime>

Functionality	Function Name	Output Data Type
Guidance-Processing Logic (Ground Speed or Airspeed Maneuvers)	HorizontalSpeedBands	Pair<HorizontalSpeedRegions, RecoveryTime>
Guidance-Processing Logic (Vertical Velocity Maneuvers)	VerticalSpeedBands	Pair<VerticalSpeedRegions, RecoveryTime>
Guidance-Processing Logic (Altitude Maneuvers)	AltitudeBands	Pair<AltitudeRegions, RecoveryTime>
Recovery Directional Guidance	RecoveryGuidance	Pair<HorizontalDir, VerticalSpeed>
Alerting Logic	Alerting	AlertLevel

Table G-6 specifies DAIDALUS configuration parameters and their default values.

Table G-6 Configuration Parameters

Parameter	Units	Data Type	Default Value
RecoveryLevel		Integer	2
$DMOD_1$ (Alert Level 1)	Nautical Miles Feet Meters	Double	1.0 Nautical Miles
$ZTHR_1$ (Alert Level 1)	Feet Meters	Double	750’
$TAUMOD_1$ (Alert Level 1)	Seconds	Double	35 Seconds
$TCOA_1$ (Alert Level 1)	Seconds	Double	20 Seconds
$AlertTime_1$ (Alert Level 1)	Seconds	Double	60 Seconds
$EarlyAlertTime_1$ (Alert Level1)	Seconds	Double	75 Seconds
$DMOD_2$ (Alert Level 2)	Nautical Miles Feet Meters	Double	1.0 Nautical Miles
$ZTHR_2$ (Alert Level 2)	Feet Meters	Double	450’
$TAUMOD_2$ (Alert Level 2)	Seconds	Double	35 Seconds
$TCOA_2$ (Alert Level 2)	Seconds	Double	20 Seconds
$AlertTime_2$ (Alert Level 2)	Seconds	Double	60 Seconds

Parameter	Units	Data Type	Default Value
$EarlyAlertTime_2$ (Alert Level 2)	Seconds	Double	75 seconds
$DMOD_3$ (Alert Level 3)	Nautical Miles Feet Meters	Double	1.0 Nautical Miles
$ZTHR_3$ (Alert Level 3)	Feet Meters	Double	450'
$TAUMOD_3$ (Alert Level 3)	Seconds	Double	35 Seconds
$TCOA_3$ (Alert Level 3)	Seconds	Double	20 Seconds
$AlertTime_3$ (Alert Level 3)	Seconds	Double	30 Seconds
$EarlyAlertTime_3$ (Alert Level 3)	Seconds	Double	60 Seconds
TurnStep	Degrees Radians	Double	1 Degree
HorizontalSpeedStep	Knots Kilometers per Hour Meters per Second	Double	1 Knot
VerticalSpeedStep	Feet per Minute Meters per Second	Double	100 Feet per Minute (fpm)
AltitudeStep	Feet Meters	Double	100'

G.4 Mathematical Description of the DAIDALUS Reference Implementation

This subsection describes the underlying logic of the DAIDALUS reference implementation. All of the algorithms associated with DAIDALUS have been implemented in Java and C++, and these implementations are publicly available under NASA's Open Source Agreement. All of the underlying algorithms implemented in DAIDALUS have corresponding formal specifications written in the mathematical notation of the PVS. In this document, pseudo-code is used to provide the functional specification of these algorithms.

G.4.1 Nomenclature

Table G-7 lists the nomenclature for equations in this paragraph.

Table G-7 Nomenclature Unique to This Appendix

Symbol	Definition
$[B,T]$	Look-ahead time interval, where $0 \leq B < T$
$[t_{in},t_{out}]$	Time interval of LoWC, i.e., t_{in} is time to LoWC and t_{out} is time to exit LoWC
D	Horizontal distance
d_{cpa}	Distance at Closest Point of Approach (CPA)
H	Vertical distance

Symbol	Definition
Kpos	Kinematic Position function at constant acceleration
Kvel	Kinematic Velocity function at constant acceleration
NMAC_D	Diameter of Near Mid-Air Collision cylinder
NMAC_H	Height of Near Mid-Air Collision cylinder
R	Range
s, v	Two-dimensional aircraft state, i.e., position and velocity
s_z, v_z	Vertical aircraft state, i.e., altitude and vertical velocity
T	Time
T	Time of Detection
t_{coa}	Time to Co-altitude
t_{cpa}	Time to CPA
τ_{mod}	Modified Tau (time function over states)
ϵ	Numerical parameter with a value of ±1
Subscripts	**Definition**
o, i	Ownship and intruder information of a position or velocity vector
x, y, z	Northern, eastern, and altitude component of a position or velocity vector
Acronyms	**Definition**
CAT	Collision Avoidance Threshold
DAA	Detect and Avoid
DMOD	Modified Distance Threshold
HMD	Horizontal Miss Distance
NAS	National Airspace System
NMAC	Near Mid-Air Collision
RA	Resolution Advisory
TAUMOD	Modified Tau Threshold
TCAS	Traffic Alerting and Collision Avoidance System
TCOA	Vertical Time Threshold
TTHR	Time of Detection Threshold
UAS	Unmanned Aircraft System
ZTHR	Vertical Distance Threshold

G.4.2 Geometrical Assumptions

The algorithms presented in this paragraph assume a Euclidean three-dimensional coordinate system, i.e., a local East, North, Up (ENU) Cartesian coordinate system. In particular, this coordinate system is based on the orthogonal projection of the ownship and traffic geodesic coordinates onto a plane tangent to the projected ownship position on the surface of the earth. Moreover, when wind information is provided, the velocity component of the aircraft states is assumed to be relative to the wind.

For convenience, formulas are presented in a relative coordinate system where the intruder aircraft is at the origin and the ownship is moving relatively to the intruder, i.e., $\mathbf{s} = \mathbf{s}_{\text{o}} - \mathbf{s}_{\text{i}}, s_z = s_{oz} - s_{iz}$, $\mathbf{v} = \mathbf{v}_{\text{o}} - \mathbf{v}_{\text{i}}$, and $v_z = v_{oz} - v_{iz}$. If $\mathbf{u}$ and $\mathbf{u}'$ are two-dimensional vectors, then $\| \mathbf{u} \|$ denotes the norm of $\mathbf{u}$, $\mathbf{u} \cdot \mathbf{u}'$ denotes the dot product of $\mathbf{u}$ and $\mathbf{u}'$, $\mathbf{u}^2$ denotes the scalar $\mathbf{u} \cdot \mathbf{u}$, which is equivalent to the square of the norm of $\mathbf{u}$, and $\mathbf{u}^{\perp}$ represents the right perpendicular of $\mathbf{u}$, i.e., the two-dimensional vector $(u_y, -u_x)$. Furthermore, the following definitions are assumed:

Horizontal Range:

$$r(t) \equiv \| \mathbf{s} + t \cdot \mathbf{v} \| = \sqrt{\mathbf{s}^2 + 2t \cdot (\mathbf{s} \cdot \mathbf{v}) + t^2 \cdot \mathbf{v}^2}.$$

Time to Horizontal C (t_{cpa}):

$$t_{\mathrm{cpa}}(\mathbf{s}, \mathbf{v}) \equiv \begin{cases} -\dfrac{\mathbf{s} \cdot \mathbf{v}}{\mathbf{v}^2} & \text{if } \mathbf{v} \neq \mathbf{0}, \\ 0 & \text{otherwise.} \end{cases}$$

Horizontal Distance at t_{cpa}:

$$d_{\mathrm{cpa}}(\mathbf{s}, \mathbf{v}) \equiv r\left(t_{\mathrm{cpa}}(\mathbf{s}, \mathbf{v})\right) = \left\| \mathbf{s} + t_{\mathrm{cpa}}(\mathbf{s}, \mathbf{v}) \cdot \mathbf{v} \right\|.$$

Vertical Range at time t:

$$r_z(t) \equiv |s_z + t \cdot v_z|.$$

Time to Co-Altitude:

$$t_{\mathrm{coa}}(s_z, v_z) \equiv \begin{cases} -\dfrac{s_z}{v_z} & \text{if } s_z \cdot v_z < 0, \\ -1 & \text{otherwise.} \end{cases}$$

Modified Tau:

$$\tau_{\mathrm{mod}}(s, v) \equiv \begin{cases} -\dfrac{DMOD^2 - s^2}{s \cdot v} & \text{if } s \cdot v < 0, \\ -1 & \text{otherwise.} \end{cases}$$

G.4.3 DWC Logic

The well clear logic is implemented by the Boolean function WCV defined below. This function has as inputs the relative position and velocity of the aircraft. The function returns the value TRUE if and only if the aircraft are in LoWC at the current time. It is assumed that HMD = DMOD. The threshold values are configurable parameters of the logic.

- $\mathrm{WCV}(\mathbf{s}, s_z, \mathbf{v}, v_z)$: Boolean $\equiv$ Horizontal_WCV$(\mathbf{s}, \mathbf{v})$ and Vertical_WCV(s_z, v_z).
- Horizontal_WCV$(\mathbf{s}, \mathbf{v})$: Boolean $\equiv$

  $$\|\mathbf{s}\| \leq \mathrm{DMOD} \text{ or } \left(d_{\mathrm{cpa}}(\mathbf{s}, \mathbf{v}) \leq \mathrm{HMD} \text{ and } 0 \leq \tau_{\mathrm{mod}} \leq \mathrm{TAUMOD}\right).$$
- Vertical_WCV(s_z, v_z): Boolean $\equiv |s_z| \leq$ ZTHR or $0 \leq t_{\mathrm{coa}}(s_z, v_z) \leq$ TCOA.

G.4.4 Detection Logic

The well clear detection logic is implemented by the function WCD defined below. This function has as inputs the relative position and velocity of the aircraft and a look-ahead time interval $[B, T]$. The function returns a time interval $[t_{\mathrm{in}}, t_{\mathrm{out}}]$ within $[B, T]$. If $t_{\mathrm{in}} \leq t_{\mathrm{out}}$, the time t_{in} represents time to first LoWC and t_{out} represents the time to last LoWC, assuming constant velocity. The returned time interval is empty, i.e., $t_{\mathrm{in}} > t_{\mathrm{out}}$, if the aircraft are not predicted to be in a LoWC state within the time interval $[B, T]$.

Usually, the value of B is set to 0 and the value of T is set to the configurable parameter LookaheadTime. The functions below allow for an arbitrary look-ahead time interval $[B,T]$, provided that $0 \leq B < T$.

- $\text{WCD}(\mathbf{s}, s_z, \mathbf{v}, v_z, B, T)\text{: TimeInterval} \equiv$
  let $[t_1, t_2] = \text{Vertical\_WCD}(s_z, v_z, B, T)$ in
  if $t_1 > t_2$ then $[T, B]$
  elseif $t_1 = t_2$ and $\text{Horizontal\_WCV}(\mathbf{s} + t_1 \cdot \mathbf{v}, \mathbf{v})$ then $[t_1, t_1]$
  elseif $t_1 = t_2$ then $[T, B]$
  else let $[t_{\text{in}}, t_{\text{out}}] = \text{Horizontal\_WCD}(\mathbf{s} + t_1 \cdot \mathbf{v}, \mathbf{v}, t_2 - t_1)$ in
  $[t_{\text{in}} + t_1, t_{\text{out}} + t_1]$
  endif .
- $\text{Vertical\_WCD}(s_z, v_z, B, T)\text{: TimeInterval} \equiv$
  if $v_z = 0$ and $|s_z| \leq \text{ZTHR}$ then $[B, T]$
  elseif $v_z = 0$ then $[T, B]$
  else let $[t_1, t_2] = \text{Vertical\_entry\_exit}(s_z, v_z)$ in
  if $T < t_1$ or $t_2 < B$ then $[T, B]$
  else $[\max(B, t_1), \min(T, t_2)]$
  endif
  endif.
- $\text{Vertical\_entry\_exit}(s_z, v_z)\text{: TimeInterval} \equiv$
  let $H = \max(\text{ZTHR}, \text{TCOA} \cdot |v_z|)$ in
  $$\left[\frac{-\text{sign}(v_z) \cdot H - s_z}{v_z}, \frac{\text{sign}(v_z) \cdot \text{ZTHR} - s_z}{v_z}\right].$$
- $\text{Horizontal\_WCD}(\mathbf{s}, \mathbf{v}, T)\text{: TimeInterval} \equiv$
  let $a = \mathbf{v}^2$,
  $b = 2(\mathbf{s} \cdot \mathbf{v}) + \text{TAUMOD} \cdot \mathbf{v}^2$,
  $c = \mathbf{s}^2 + \text{TAUMOD}(\mathbf{s} \cdot \mathbf{v}) - \text{DMOD}^2$ in
  if $a = 0$ and $\|\mathbf{s}\| \leq \text{DMOD}$ then $[0, T]$
  elseif $\|\mathbf{s}\| \leq \text{DMOD}$ then $[0, \min(T, \Theta(\mathbf{s}, \mathbf{v}, \text{DMOD}))]$
  elseif $\mathbf{s} \cdot \mathbf{v} \geq 0$ or $b^2 - 4ac < 0$ then $[T, 0]$
  else let $t = \dfrac{-b - \sqrt{b^2 - 4ac}}{2a}$ in
  if $\Delta(\mathbf{s}, \mathbf{v}) \geq 0$ and $t \leq T$ then $[\max(0, t), \min(T, \Theta(\mathbf{s}, \mathbf{v}, \text{DMOD}))]$
  else $[T, 0]$
  endif
  endif.

- $\Theta(\mathbf{s}, \mathbf{v}, D)$: Double $\equiv \frac{-\mathbf{s}\cdot\mathbf{v}+\sqrt{\Delta(\mathbf{s},\mathbf{v},D)}}{\mathbf{v}^2}$.
- $\Delta(\mathbf{s}, \mathbf{v}, D)$: Double $\equiv D^2 \cdot \mathbf{v}^2 - (\mathbf{s} \cdot \mathbf{v}^{\perp})^2$.

G.4.5 Guidance-Processing Logic

The well clear determine-processing function is implemented in DAIDALUS by algorithms that compute maneuver guidance bands. Generic Algorithms for computing conflict and recovery bands are described in Subparagraphs G.4.5.1 and G.4.5.2. The instantiation of these algorithms for computing bands for horizontal and vertical maneuvers is described in Subparagraph G.4.5.3.

As stated in Paragraph G.2.3, the guidance processing logic runs twice, instantiated with the parameters given in the MID and NEAR levels of the alerter. The resulting bands are then merged, overlaying NEAR bands on MID bands where applicable.

Bands are computed by incrementally projecting the maneuvers the ownship may take, within its specified performance limits, up to the time t when such a maneuver is achieved. From time t to a look-ahead time T, the ownship state is projected along a constant velocity. Each traffic aircraft is projected along a constant-velocity trajectory over the entire look-ahead time. Ownship and traffic trajectory projections are checked for HAZ violation. Those maneuvers that lead to a violation make up a list of bands.

The recovery bands algorithm is used when the previous process results in a single saturated band for the alert level specified in the alerter for recovery. In this case, a HAZ violation is unavoidable assuming the ownship performance limits. Recovery bands are computed by finding the time t less than a look-ahead time T, such that the range of possible ownship maneuvers, when considered only in the time interval from t to T, do not all lead to HAZ violations. The time t, called the *recovery time,* is a time at which the ownship can feasibly recover from an unavoidable HAZ violation. The well clear recovery bands algorithm also guarantees that for any band determined to be a recovery band, the aircraft do not violate a minimum value of horizontal distance D and a minimum value of vertical distance H for all times before time t. The value of T is set to the configurable parameter EarlyAlertTime. The values of D and H are usually set to the DMOD and ZTHR threshold values corresponding to the TCAS II Resolution Advisory (RA) logic.

G.4.5.1 Generic Conflict Bands

Bands represent ranges of horizontal and vertical maneuvers predicted to result in a HAZ violation. The list of bands is computed as the union of the list of pairwise bands computed for each traffic aircraft with respect to the ownship. At the core of the algorithms that compute horizontal and vertical bands, there is a generic pairwise algorithm, namely GenericBands_1x1, which computes the list of intervals that yield a HAZ violation for a given maneuver. This algorithm has as inputs the relative state of the aircraft, the look-ahead time interval [B,T], a current maneuver value *cval* for the ownship, minimum and maximum values *min* and *max* for the maneuvers, a step value *step* for computing each maneuver, a constant acceleration, *accel*, for the maneuver, horizontal and vertical distances D and H, and position and velocity functions *Pos* and *Vel* that project the relative state of the aircraft for a given time using the constant acceleration.

```
GenericBands_1x1(s,v,s_z,v_z,B,T,cval,min,max,step,accel,D,H,Pos,Vel):
List<DoubleInterval>≡
  tstep := step/accel;
  t := 0;
  val := cval;
  bands := EmptyList<DoubleInterval>;
  while val < max and t < T do
    (s′,s_z′) := Pos(s,v,accel,t);
    (v′,v_z′) := Vel(s,v,accel,t);
    if t < B then
      if ‖ s′‖ < D and |s_z′ | < H then
        bands := Union(bands,[val,max]);
        val := max;
      endif
    elseif WCV(s′,s_z′,v′,v_z′) then
        bands := Union(bands,[val,max]);
        val := max;
    elseif  not IsEmptyInterval(WCD(s′,s_z′,v′,v_z′,0,T-t)) then
       bands := Union(bands,[val,val+step]);
       val := val+step;
   endif
   t := t+tstep;
 endwhile
 t := 0;
 val := cval;
 while val > min and t < T do
    (s′,s_z′) := Pos(s,v, −accel,t);
    (v′,v_z′) := Vel(s,v, −accel,t);
    if t < B then
      if ‖ s′‖ < D and |s_z′ | < H then
        bands := Union(bands,[min,val]);
        val := min;
      endif
    elseif WCV(s′,s_z′,v′,v_z′) then
        bands := Union(bands,[min,val]);
```

val := *min*;

elseif not IsEmptyInterval(WCD($\mathbf{s}', s_z', \mathbf{v}', v_z'$,0,*T*-*t*)) then

bands := Union(*bands*,[*val*-*step*,*val*]);

val := *val*-*step*;

endif

t := *t*+*tstep*;

endwhile

return *bands*

From GenericBands_1x1, the generic algorithm that computes bands for an ownship and a list of traffic aircraft can be defined as follows. In this function, the parameters *ownship* and *traffic* represent the state of the ownship and a list of states for all intruder aircraft, respectively.

GenericBands(ownship,traffic,B,T,cval,min,max,step,accel,D,H,Pos,Vel) :

List<DoubleInterval>≡

bands := EmptyList<DoubleInterval>;

foreach *intruder* in *traffic* do

($\mathbf{s}, s_z$) := Position(*ownship*)-Position(*intruder*);

($\mathbf{v}, v_z$):= Velocity(*ownship*)-Velocity(*intruder*);

bands := Union(*bands*,

GenericBands_1x1($\mathbf{s}, s_z, \mathbf{v}, v_z$,B,T,cval,min,max,step,accel,D,H,Pos,Vel);

endforeach

return *bands*;

G.4.5.2 Recovery Guidance

Recovery Guidance is computed in the case that the bands computed for the alerter level specified by RecoveryLevel returns completely saturated bands. In this event, the system predicts that there is no way to avoid entering the associated HAZ volume. The guidance provided is in the form of ranges of maneuvers which will quickly exit the HAZ volume while avoiding a protected cylinder (recovery bands), and in the case of horizontal direction and vertical velocity, a preferred direction for the resolution (resolution direction).

Generic recovery bands are computed using the algorithm RecoveryBands. This algorithm assumes that the algorithm GenericBands has returned a saturated conflict band, i.e., the single interval [*min, max*]. The algorithm RecoveryBands has as inputs the state of the ownship, a set of states for all intruder aircraft, a look-ahead time *T*, a current maneuver value *cval* for the ownship, minimum and maximum values *min* and *max*, for the maneuvers, a step value *step* for the maneuvers, a constant acceleration *accel* for the maneuver, horizontal and vertical distances *D* and *H*, and position and velocity functions, *Pos* and *Vel*, that project the relative state of the aircraft for a given time using a constant acceleration (*accel*). It returns a list of intervals and a time.

```
RecoveryBands(ownship,traffic,T,cval,min,max,step,accel,D,H,Pos,Vel) :
Pair<List<DoubleInterval>,RecoveryTime> ≡
 B := 0;
 repeat
   B := B+1;
   bands := GenericBands(ownship,traffic,B,T,cval,min,max,step,accel,D,H,Pos,Vel);
 until not [min,max] in bands;
 return (bands,B);
```

The intervals computed by the RecoveryBands correspond to bands that result in a HAZ violation. The complement of this these intervals with respect to [*min,max*] corresponds to bands of type RECOVERY.

When computing a resolution direction, it is assumed that the current heading *cval* is in a conflict band. Hence the upper and lower bounds of the band containing *cval* are the closest maneuvers that lead to recovery, unless the maneuver corresponds to the *min* or *max* value, in which case there is no recovery in that direction. The following function computes these two values, returning a 0 value if a direction has no resolution.

```
Resolutions(ownship,traffic,T,cval,min,max,step,accel,D,H,Pos,Vel) :
Pair<Double,Double> ≡
 L := 0;
 U := 0;
 Bands := RecoveryBands(ownship,traffic,T,cval,min,max,step,accel,D,H,Pos,Vel)(1)
 for i<length(Bands);
   if Bands(i)(0)<cval and cval<Bands(i)(1);
      if Bands(i)(0)>min;
         L := Bands(i)(0);
      if Bands(i)(1)<max;
      U := Bands(i)(1);
 return (L,U);
```

Due to the way recovery bands are computed, in the majority of cases, Resolutions finds only one direction with a possible maneuver, which is then returned as the preferred maneuver. In the case that both directions have a possible resolution, the maneuver that incrementally increases the distance at time of closest point of approach throughout the maneuver (referred to as the *repulsive* direction) is chosen. The following chooses this maneuver.

```
ResolutionDirection(ownship,traffic,T,cval,min,max,step,accel,D,H,Pos,Vel) :
Double ≡
 Dir :=cval;
 (L,U) := Resolutions(ownship,traffic,T,cval,min,max,step,accel,D,H,Pos,Vel);
```

```
if L /= 0 and U /=0;
  if Repulsive?(ownship,traffic,cval,step,accel,Pos,Vel,L);
    Dir := L;
  else;
    Dir := U;
elseif L /= 0;
  Dir :=L;
else;
  Dir :=U;
return Dir;
```

Here, Repulsive? is a function that computes whether a maneuver increases, at each time step, the distance at the time of closest point of approach.

G.4.5.3 Horizontal and Vertical Guidance

The algorithms that compute horizontal direction bands (i.e., heading bands, if wind information is provided; otherwise, track bands), horizontal speed bands (i.e., airspeed bands, if wind information is provided; otherwise, ground speed bands), and vertical bands for a given look-ahead time *T*, minimum horizontal separation *D*, and minimum vertical separation *H* are defined using the following functions.

HorizontalDirBands(*ownship,traffic,T,D,H*) : Pair<HorizontalDirRegions,RecoveryTime>≡
ColorBands (*ownship*,*traffic*,*T*,HorizontalDir(*ownship*),-π, π,TurnStep,TurnRate,*D*,*H*,TurnRatePos,TurnRateVel)),

HorizontalSpeedBands(*ownship,traffic,T,D,H*) : Pair<HorizontalSpeedRegions,RecoveryTime>≡
ColorBands (*ownship*,*traffic*,*T*,HorizontalSpeed(*ownship*),MinHorizontalSpeed, MaxHorizontalSpeed, HorizontalSpeedStep,HorizontalAcceleration,*D*,*H*,HorizontalAccelPos,HorizontalAccelVel),

VerticalSpeedBands(*ownship,traffic,T,D,H*) : Pair<VerticalSpeedRegions,RecoveryTime>≡
ColorBands (*ownship*,*traffic*,*T*,VerticalSpeed(*ownship*),MinVerticalSpeed, MaxVerticalSpeed, VerticalSpeedStep,VerticalAcceleration,*D*,*H*,VerticalAccelPos,VerticalAccelVel),

where

```
ColorBands(ownship,traffic,T,cval,min,max,step,accel,D,H,Pos,Vel):
Pair<Pair<List<Double>,List<BandsTypes>>,RecoveryTime>≡
  bands := GenericBands(ownship,traffic,0,T,cval,min,max,step,accel,0,0,Pos,Vel);
  noconflictband := NONE;
  recovery_time := 0;
```

```
 if [min,max] in bands then
     noconflictband := RECOVERY;
    (bands,recovery_time): =
 RecoveryBands(ownship,traffic,T,cval,min,max,step,accel,D,H,Pos,Vel);
 endif
 intervals := EmptyList<DoubleInterval>;
 types := EmptyList<BandsType>;
 prev := min;
 foreach [low,up] in bands do
   if prev < low then
     intervals :=Add(intervals,[prev,low]);
     types := Add(types,noconflictband);
   endif
   intervals :=Add(intervals,[low,up]);
   types := Add(types,CONFLICT);
   prev := up;
 endforeach
 if prev < max then
   intervals :=Add(intervals,[prev,max]);
   types := Add(types,noconflict);
 endif
 return ((intervals,types),recovery_time);
```

Furthermore,

- HorizontalDir, HorizontalSpeed, and VerticalSpeed are functions that return the current horizontal direction (i.e., heading, if wind information is provided; otherwise, track), horizontal speed (i.e., airspeed, if wind information is provided; otherwise, ground speed), and vertical velocity of an aircraft, respectively;
- TurnRatePos, TurnRateVel are functions that return the projected relative position and velocity of the aircraft for a given time and constant turn rate;
- HorizontalAccelPos, HorizontalAccelVel are functions that return the projected relative position and velocity of the aircraft for a given time and constant horizontal acceleration;
- VerticalAccelPos, VerticalAccelVel are functions that return the projected relative position and velocity of the aircraft for a given time and constant vertical acceleration

The band type CONFLICT in the function ColorBands is set to either MID or NEAR depending on the type of bands being computed.

Recovery directional guidance is computed for horizontal directional maneuvers and for vertical velocity maneuvers with the following function.

```
RecoveryGuidance(ownship,traffic,T,D,H) : Pair<HorizontalDir,VerticalSpeed>≡
 HorizGuidance := ResolutionDirection(ownship,traffic,T,
HorizontalDir(ownship), -π, π,TurnStep,TurnRate,D,H,TurnRatePos,TurnRateVel));
```

VerticalGuidance := ResolutionDirection(*ownship*,*traffic*,*T*,VerticalSpeed(*ownship*), MinVerticalSpeed,MaxVerticalSpeed,VerticalSpeedStep,VerticalAcceleration,*D*,*H*,VerticalAccelPos,VerticalAccelVel);

return (*HorizontalGuidance, VerticalGuidance)*;

G.4.6 Alerting Logic

DAIDALUS implements an alerting schema based on the prediction of LoWC with respect to a traffic aircraft for different sets of increasingly conservative threshold values. The intent of the alerting logic is to provide an indication of the severity of the proximity of a particular traffic aircraft to the ownship. This indication is given as a numerical value, where zero represents no alert. The greater the numerical value, the greater the severity level. The function Alerting has as inputs the relative states of the ownship and a traffic aircraft. It returns a numerical value between 0 and 3.

Alerting($\mathbf{s}, s_z, \mathbf{v}, v_z$) : AlertLevel ≡

  i := 3;

  while $1 \leq i$ do

    (DMOD,ZTHR,TAUMOD,TCOA) := (DMOD$_i$,ZTHR$_i$,TAUMOD$_i$,TCOA$_i$);

    if not EmptyInterval(WCD($\mathbf{s}, s_z, \mathbf{v}, v_z$, 0,AlertingTime$_i$)) then

      return i;

   else

     i := i-1;

   endif

  endwhile

  return i;

Using the same volume for the computation of MID bands and Corrective alerts, as well as the same volume for the computation of NEAR bands and Warning alerts gives a tight integration between the alerting logic and the maneuver guidance logic. An aircraft that causes a Corrective alert will always cause a MID band to appear in the current path of the ownship. Similarly, an aircraft that causes a Warning alert will always cause a NEAR band to appear in the current path of the ownship.

G.5 Verification and Validation

The verification and validation of the software implementation of the DAIDALUS algorithms is a critical part of its development. The verification and validation effort consists of three elements. The first element is the verification of the formal models of the DAIDALUS algorithms against the functional requirements. The second element is the validation of the DAIDALUS software library against the formal models. The third element is the validation of the software library against the requirements as specified in this document. These elements are discussed below in more detail.

1. The formal verification of the DAIDALUS algorithms against the functional requirements involves several steps. The DAIDALUS algorithms are written in PVS, a formal verification system where mathematical statements can be rigorously and

mechanically proved. The functional requirements of the DAIDALUS algorithms are also written in PVS. It is formally proved in PVS that the algorithms adhere to the functional requirements. The formal proofs that these functional requirements are satisfied provide a high degree of confidence in the functional correctness of DAIDALUS algorithms.

2. The second element is the validation of the DAIDALUS software library against the formal models in PVS. The actual implementation of the DAIDALUS software in Java and C++ is done by manual translation of the formal models into each respective language. Being based on a formally verified specification, the software implementation should carry with it a high level of assurance that the code adheres to the functional requirements. But due to human error in the manual translation or numerical error inherent to the implementations of these kinds of algorithms, it is possible that this code fails to match the formal models. In order to mitigate this possibility, the technique of model animation is used to ensure that the software implementations and the formal models produce the same output (up to a given tolerance) on a large, curated set of test cases.

3. The third element of the verification and validation effort involves checking the algorithms against the requirements laid out in this document. The testable requirements are specified in PVS, and the DAIDALUS output from a particular time in a test scenario is checked against these requirements. This checking is done on the PVS, Java, and C++ versions of the DAIDALUS algorithms for a set of stressing scenarios.

When taken together, the intent of these three elements of verification and validation is to provide strong assurance that the algorithms do precisely what they are designed to do and that this design meets the requirements laid out in this document. However, the Verification and Validation (V&V) process described in this appendix does not include an assessment of the correctness of the requirements themselves, which are assumed to be adequate to support DAA functionality for UAS.

G.6 Sensor Uncertainty Mitigation

Sensor errors impose a requirement that the DAA system take account of the imprecision of sensed intruder position in order to provide better when providing alerts and maneuver guidance to the UAS operator. The mitigation approach used in the reference implementation uses the position and velocity standard deviations provided by the tracker to augment the sensed position of each intruder with additional “phantom” intruders to present the DAA algorithm with a block of intruders that span a sigma-multiple of the possible intruder location and velocity arrayed around the sensed position and velocity. See Figure G-5.

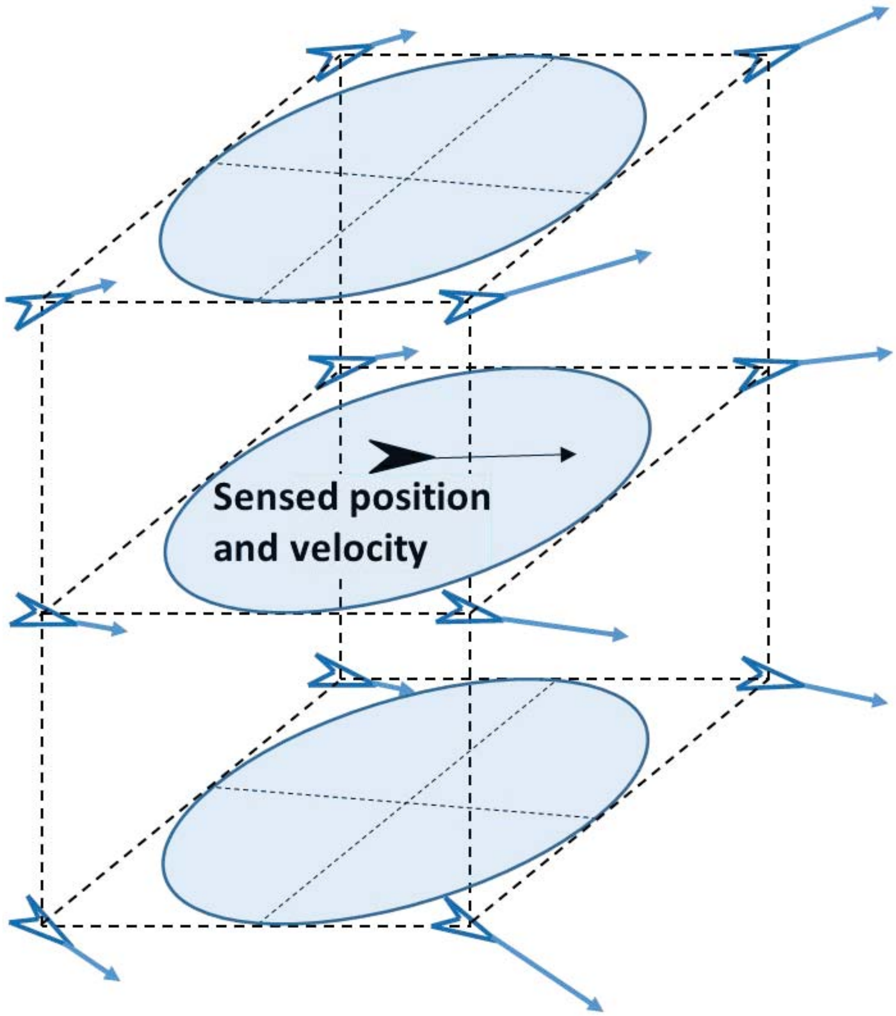


Figure G-5 **Notional Depiction of Sensor Uncertainty Mitigation**

In the north and east dimensions, the north, east, and north-east (covariance) standard deviation estimates are analyzed using eigenvalue/eigenvector decomposition to determine the major and minor error ellipse axes and magnitudes. The angle of the major/minor axes of the uncertainty ellipse is determined by the ratio of largest eigenvector. This is done because radar and AST sensors typically have much better accuracy in range than in azimuth, which makes the error ellipse highly elongated. Generally, the major and minor horizontal velocity error ellipse axes are closely aligned with those of the positional error, and for this mitigation algorithm they are assumed to be coincident.

For generating intruder input to the DAA algorithm, each intruder's sensed state (Three-Dimensional (3D) position and velocity) is passed to the DAA algorithm along with a set of "phantom" intruder states. These phantoms are generated by enumerating displacements of the sensed state (position and velocity) of the intruder in the positive and negative direction of each of the horizontal error ellipse axes and the vertical axis using a scaling factor multiplied by the appropriate standard deviation for that axis. This effectively puts an intruder at the vertices of a box bounding the error ellipses corresponding to the scale factors. The numeric values of the scaling factors are presented in Table G-8.

Table G-8 Sensor Uncertainty Mitigation Scaling Factors

Scaling Factor	Numeric Value
Horizontal Position	1.5
Horizontal Velocity	0.5
Vertical Position	1.0
Vertical Velocity	1.0

In performing the enumeration, an additional set of phantom intruders is placed either at the sensed intruder altitude and altitude rate, or, if the sensed altitude of the intruder could be coincident with the ownship's altitude within the look ahead time, at the ownship altitude and vertical rate (zero vertical displacement). This middle plane ensures that potential conflicts are not missed by propagating the ownship between the upper and lower surfaces, which in the case of radar can be widely spaced due to the large vertical uncertainty.

As a final processing step, the altitude and speed bands of the DAA algorithm are post-processed to remove any non-conflict regions that lie entirely within the upper and lower surfaces (as propagated out to the look ahead time) or that represent ownship vertical velocities that would not escape the upper or lower surface within the look ahead time.

This Page Intentionally Left Blank

H APPENDIX H RIGHT OF WAY

H.1 Introduction

Right Of Way (ROW) rules as specified in Code of Federal Regulations (CFR), Title 14 §91.113 have been a foundation of aviation safety. They provide implicit coordination to resolve conflicts by specifying which aircraft has the right of way for any given moment and recommended maneuvers for some special conditions. However, the rules as written are vague. For example, §91.113(e) specifies when aircraft are approaching each other head-on, or nearly so, the pilot of each aircraft shall alter course to the right. While pilots have no problem applying these rules and may even prefer their flexibility, the rules need to be quantified for development of the Detect and Avoid (DAA) algorithm for Unmanned Aircraft Systems (UAS) to either provide a suggestive display or enable an automatic DAA maneuver for UAS applications. This appendix summarizes the ongoing effort to quantify the ROW rules. The Special Committee 228 (SC-228) ROW Working Group has adopted the term "Quantified Right of Way" (QROW) to distinguish this parameter from 14 CFR §91.113, ROW rules.

It is important to point out that QROW does not apply to manned aircraft, for which CFR 14 91.113 ROW rules shall continue to apply. For UAS, Pilots In Command (PICs) will also comply with the manned ROW rules unless the PIC is no longer in control of the Unmanned Aircraft (UA). The QROW is intended for use in suggestive guidance and automatic maneuver algorithms to maintain DAA Well Clear (DWC). Note that automatic maneuvers are out of the scope of these Phase 1 Minimum Operational Performance Specifications, (MOPS) for UAS DAA equipment, but may be included in follow-on phases.

The following assumptions and limitations were used to bound the QROW study.

1. QROW is a component of DAA, but is not required for collision avoidance.
2. Landing operations are considered out of scope for this effort.
3. The focus of this study is on aerial encounters under Visual Flight Rules (VFR).
4. Applying right-of-way rules to aircraft in distress is considered out of scope. It is impractical for a DAA algorithm to identify an emergency aircraft that has, for example, invoked this priority thru an air traffic control radio call. However, although out of scope, it should be emphasized that DAA implementation of QROW and DAA should provide passage well clear of other aircraft regardless of emergency status. This situation is defined as "DAA Well Clear" (DWC) in these MOPS to distinguish it from the "well clear" in §91.113 of the CFR. If a point is reached where the intruder does not maneuver to attain or maintain DWC as expected (due to the emergency declaration), the DAA system should recognize a continuing DWC conflict and maneuver to achieve DWC – in effect yielding right of way to the emergency intruder.
5. Applying right-of-way rules to a balloon, glider, airship, or an aircraft towing or refueling another aircraft is considered out of scope for the same reason applied to aircraft in distress described in Item 4, above.

H.2 References

In this subsection, the reference documents for this appendix are identified. Additionally, reference materials used for ROW Modeling and Simulation (M&S) analyses are also listed.

H.2.1 ROW References

Reference 1: International Civil Aviation Organization (ICAO) Annex 2 to the Convention on International Civil Aviation "Rules of the Air." More specifically, Paragraph 3.2.2, Right of Way (Subparagraphs 3.2.2.1 to 3.2.2.4)

(http://www.icao.int/Meetings/anconf12/Document%20Archive/an02_cons%5B1%5D.pdf)

Reference 2: Code of Federal Regulations Title 14, §91.113, Part 91 General Operating and Flight Rules, Subpart B, Flight Rules.

http://www.ecfr.gov/cgi-bin/text-idx?SID=8dc0658a5e4ada26c0ce52278d083ca7&mc=true&node=se14.2.91_1113&rgn=div8

Reference 3: Federal Aviation Administration (FAA) Joint Order (JO) 7110.65W. "Air Traffic Control Procedures and Phraseology for Use by Personnel Providing Air Traffic Control Services."

H.2.2 References for Modeling & Simulation Analysis

Reference materials used by the M&S functional build-up are identified in this paragraph, grouped by their applications:

H.2.2.1 Lincoln Lab Uncorrelated Encounter Model

The SaRP based the DWC definition partly on their analysis of five million airborne encounters.[61] These files are stored on a secured web directory maintained by the Massachusetts Institute of Technology Lincoln Laboratory (MIT LL) at https://topa.atc.ll.mit.edu/lldata/EncounterData/, and access is available upon request. A detailed guide to using the files, Guide_to_the_Well_Clear_encounter_files.docx, is also available. For access to these files, please contact the RTCA Special Committee 228 (SC-228) Document Manager.

H.2.2.2 Intruder Pilot Visual Acquisition Model

Reference 4: "Air-to-Air Visual Acquisition Handbook," J.W. Andrews. ATC 151, Nov.1991.

Reference 5: "Unalerted Air-to-Air Visual Acquisition," J.W. Andrews. ATC 152, Nov.1991.

Reference 6: "Modeling of Air-to-Air Visual Acquisition." J.W. Andrews. The Lincoln Laboratory Journal, Vol. 2, No. 3, 1989.

[61] See Subsection C.2 for details on the SaRP established by the UAS Executive Committee Senior Steering Group.

Note: *Reference 4 contains the mathematical visual acquisition model used in the M&S software; References 5 and 6 contain background information used to better the ROW subgroup's understanding of Reference 4.*

H.2.2.3 Intruder Pilot Response Model

Reference 7: "Extended Flight Rules (EFR) to Apply to the Resolution of Encounters in Autonomous Airborne Separation." V. Duong, E. Hoffman, L. Floc'hic, J.P. Nicolaon, A.Bossu. 1996.

Reference 8: "Dynamic Protection Zone Alerting and Pilot Maneuver Logic for Ground Based Sense and Avoid of Unmanned Aircraft Systems." E. Maki, C. Parry, K. Noth, M. Molinario, and R. Miraor. American Institute of Aeronautics and Astronautics (AIAA) 2012-2505.

H.3 Quantified Right of Way

In this subsection, the encounter geometry in terms of bearing, relative headings, and Horizontal Miss Distance (HMD) will be used to determine:

1. The classification of the encounter geometry
2. If the UA has the right of way, and
3. If applicable, the maneuver direction that the DAA system should take or recommend to the PIC to maintain DWC.

With Reference 1 and Reference 2 addressing two-dimensional encounters, this subsection will broaden the premise and discuss considerations for generalized three-dimensional encounters. Geometric features, such as the encounter's vertical convergence profile, and the unmitigated HMD, should be taken into consideration for the direction of the maneuver to maintain DWC. "… approximately the same altitude…" referenced in §91.113(d) is assumed to be analogous to the altitude difference dropping below the DWC 450' altitude threshold between the UA and the intruder. This assumption extends to encounters with the UA and/or intruder in a climb and/or descent profile. It should be further noted that in this appendix, references to bearing and heading angles are based on the aircraft's inertial velocity vector (ground track) in the horizontal dimension, not based on the aircraft body-axis system.

Without specifying an algorithm for QROW or a DAA maneuver initiation point, it is expected that a DAA directive or suggestive guidance will require ROW determination at or before the DAA Execution Threshold (DET) (see Appendix D, Subsection D.2).

H.3.1 Vertically Converging Encounters

If the unmitigated encounter geometry is such that the DWC volume is anticipated to be penetrated through its vertical protection threshold, it is possible that such an encounter can be more efficiently resolved via a vertical maneuver. As illustrated in Figure H-1 and Figure H-2, if the UA is vertically converging toward the intruder's altitude and the DWC volume is expected to penetrate the vertical protection threshold (±450'), it is possible to resolve such an encounter by adjusting the UA's climb or descent profile to maintain DWC vertically. This vertical resolution can be generalized to all geometries with intruders situated at different approach angles such as head-on, overtaking, or converging. Therefore vertically converging encounters are not the focus of QROW and are considered out of scope for this appendix; however, resolving a co-altitude encounter with a vertical mitigation maneuver is considered to still be within scope.

Note: *In all the encounters diagramed in this appendix, the intruder aircraft is represented in red and the UA is shown in blue. In grey scale, the UA is the darker aircraft with a pusher propeller.*

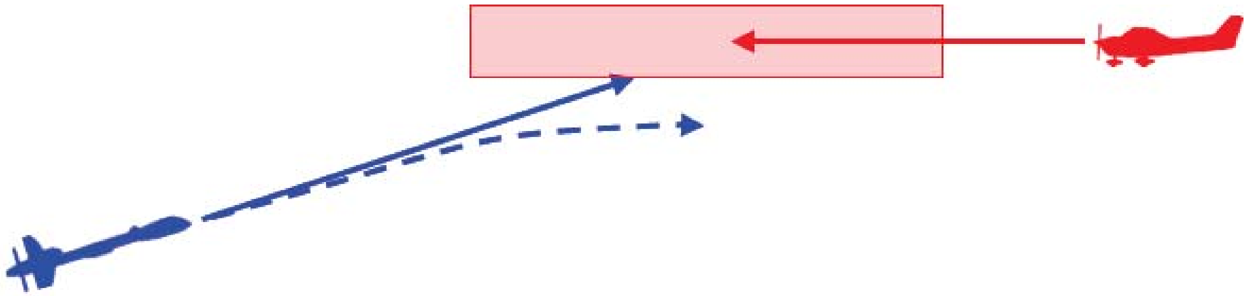


Figure H-1 Vertically Converging Encounter with the UA Climbing

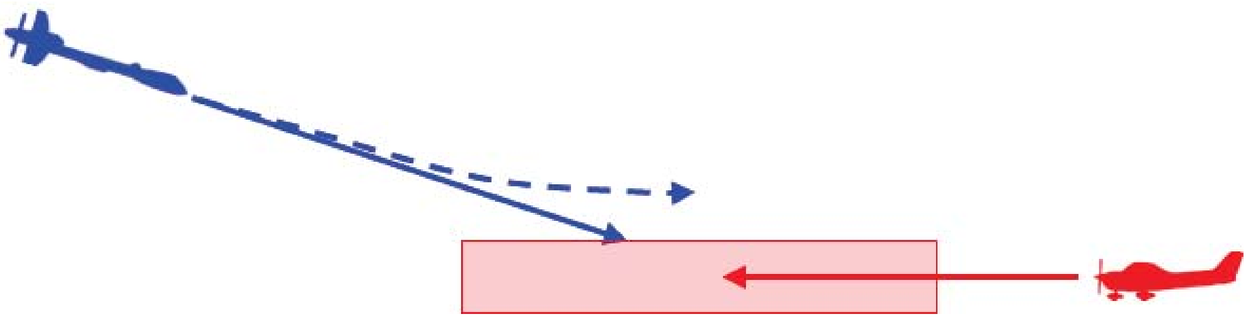


Figure H-2 Vertically Converging Encounter with the UA Descending

H.3.2 Horizontally Unambiguous Encounters

Horizontal (co-altitude) encounters with significantly large unmitigated HMDs are considered "unambiguous" encounters. In such geometries, if the UA does not have the right of way as determined by the geometric classifications in Paragraph H.3.3, it is expected to maneuver to maintain DWC, and is not required to follow the maneuver directions specified in Paragraph H.3.3.

As illustrated in Figure H-3, a 1000' HMD threshold is chosen to classify an encounter as horizontally unambiguous. This 1000' unmitigated HMD threshold is chosen based on an upper bound of 4000' (per the definition of DWC) and with a lower bound sufficiently large in magnitude that it can be reasonably estimated by the DAA system at the DAA Declaration Threshold (DDT). In this example of an unambiguous encounter, although classified as head-on according to Paragraph H.3.3.1, the UA, while not having the right of way, is expected to turn left to take advantage of the $HMD_{umitigated}$ and maintain DWC.

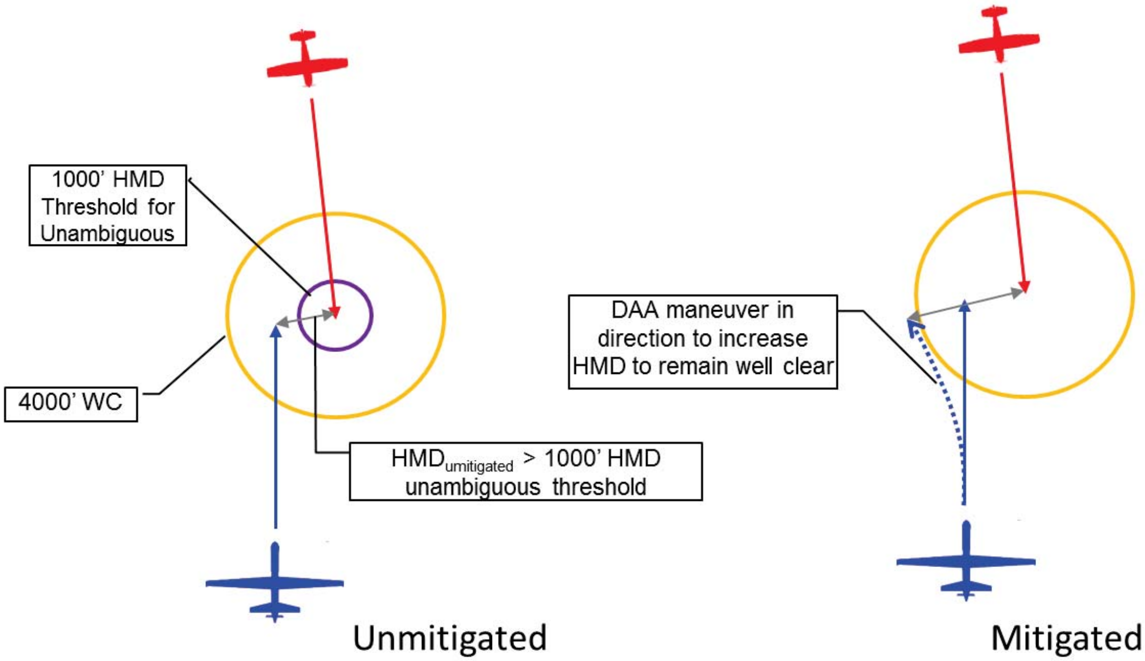


Figure H-3 **Horizontally Unambiguous Encounter with a Sufficiently Large HMD**

H.3.3 Horizontally Ambiguous Encounters

This paragraph addresses Loss of Well Clear (LoWC) encounters with sufficiently small projected HMD ($HMD_{unmitigated}$ < 1000'), thus requiring explicit geometric classification and ROW quantification. The following horizontally ambiguous encounters are described in detail in subsequent paragraphs.

- Head-on
- Overtaken
- Overtaking
- Right Oblique Overtaking
- Converging from Left
- Converging from Right

It should be noted that even though some geometries can be paired with their symmetric counterparts, such as overtaking and overtaken, the UA's right of way and the expected maneuver direction cannot always be inferred. Therefore, the geometric classification is individually identified and the expected maneuver, if any, is explicitly discussed for each. Additionally, this approach allows for development of comprehensive test cases for each corresponding geometric classification in Paragraph H.3.3

H.3.3.1 Head-On

For the head-on geometry, the intruder must be located within a ±10° bearing (inertial velocity vector or ground track), and the UA and the intruder traveling within ±10° of the intruder Heading (Δ(HDG)=180°±10°) as illustrated in Figure H-4. In this case, the UA does not have the right of way, and it is expected to turn right to maintain DWC.

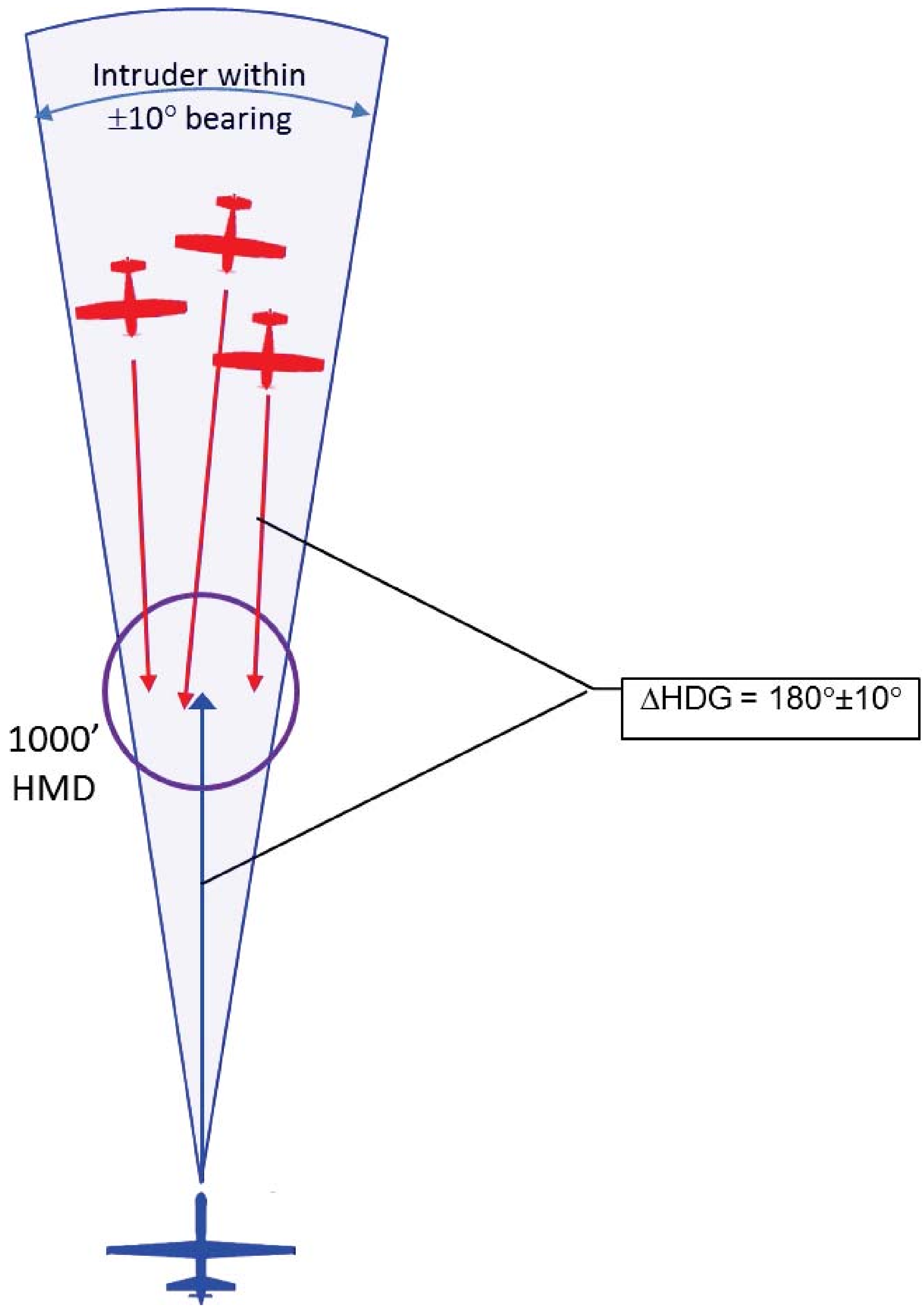


Figure H-4 **Head-On Geometry with Bearing and Relative Heading Criteria**

H.3.3.2 Overtaken

For the overtaken geometry, the UA is approached from astern as illustrated in Figure H-5 with the following criteria:

1. The intruder is behind the UA within ±90 degrees of the UA's direction of travel
2. The UA is within ±90 degrees of intruder's direction of travel

In this geometry, the UA has the right of way and is not expected to maneuver. However, if the risk of LoWC persists by the DAA warning alert, the UA may maneuver to maintain DWC without consideration for ROW.

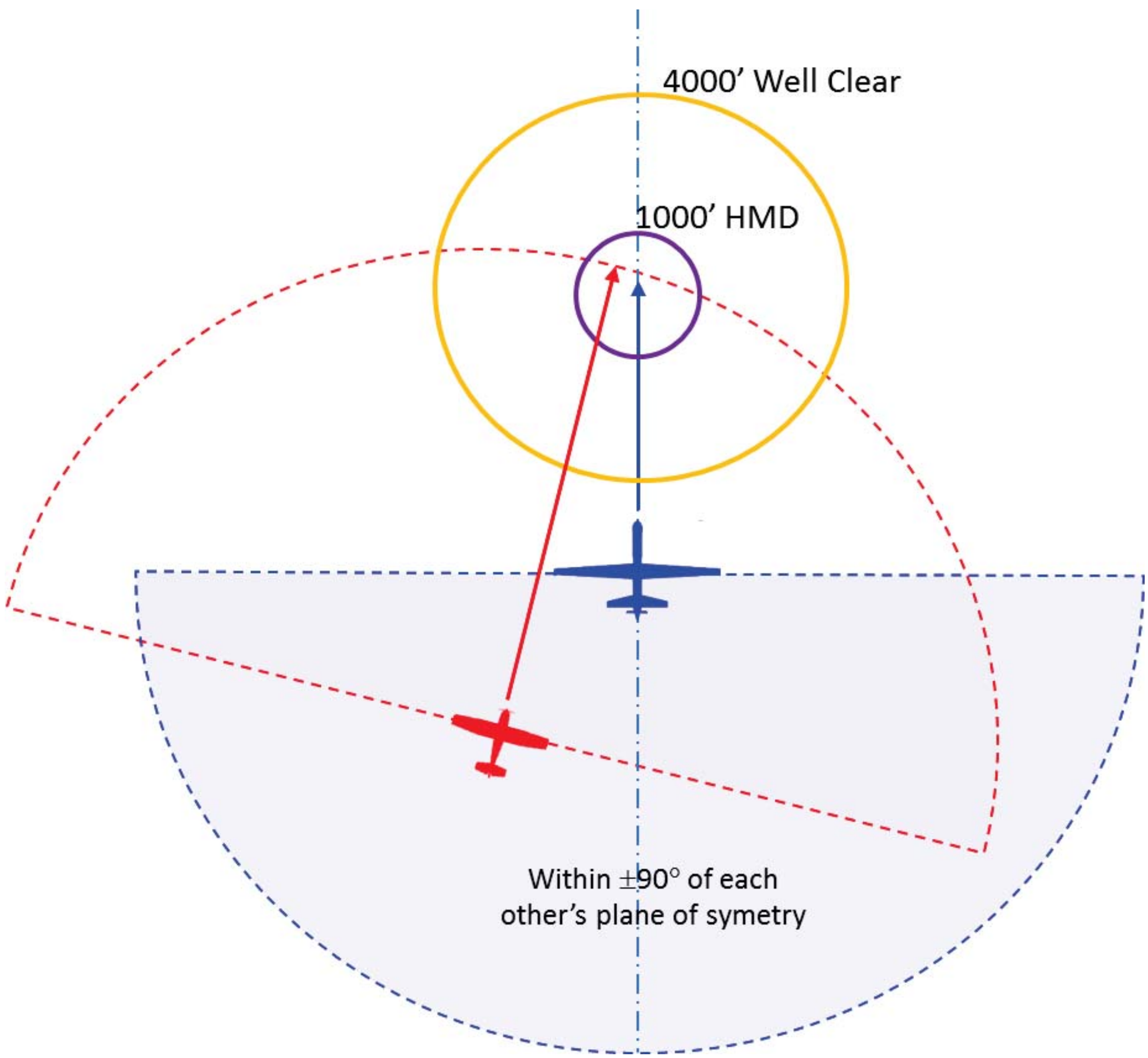


Figure H-5 **Overtaken Geometry with Bearing Criteria**

H.3.3.3 Overtaking

For the overtaking geometry, the UA is approaching the intruder from astern as illustrated in Figure H-6 with the following criteria:

1. The UA is behind the intruder
2. The relative heading between the UA and the intruder is within ±10°
3. The intruder is in front of the UA

In this geometry, the UA does not have the right of way and must maneuver to the right to maintain DWC.

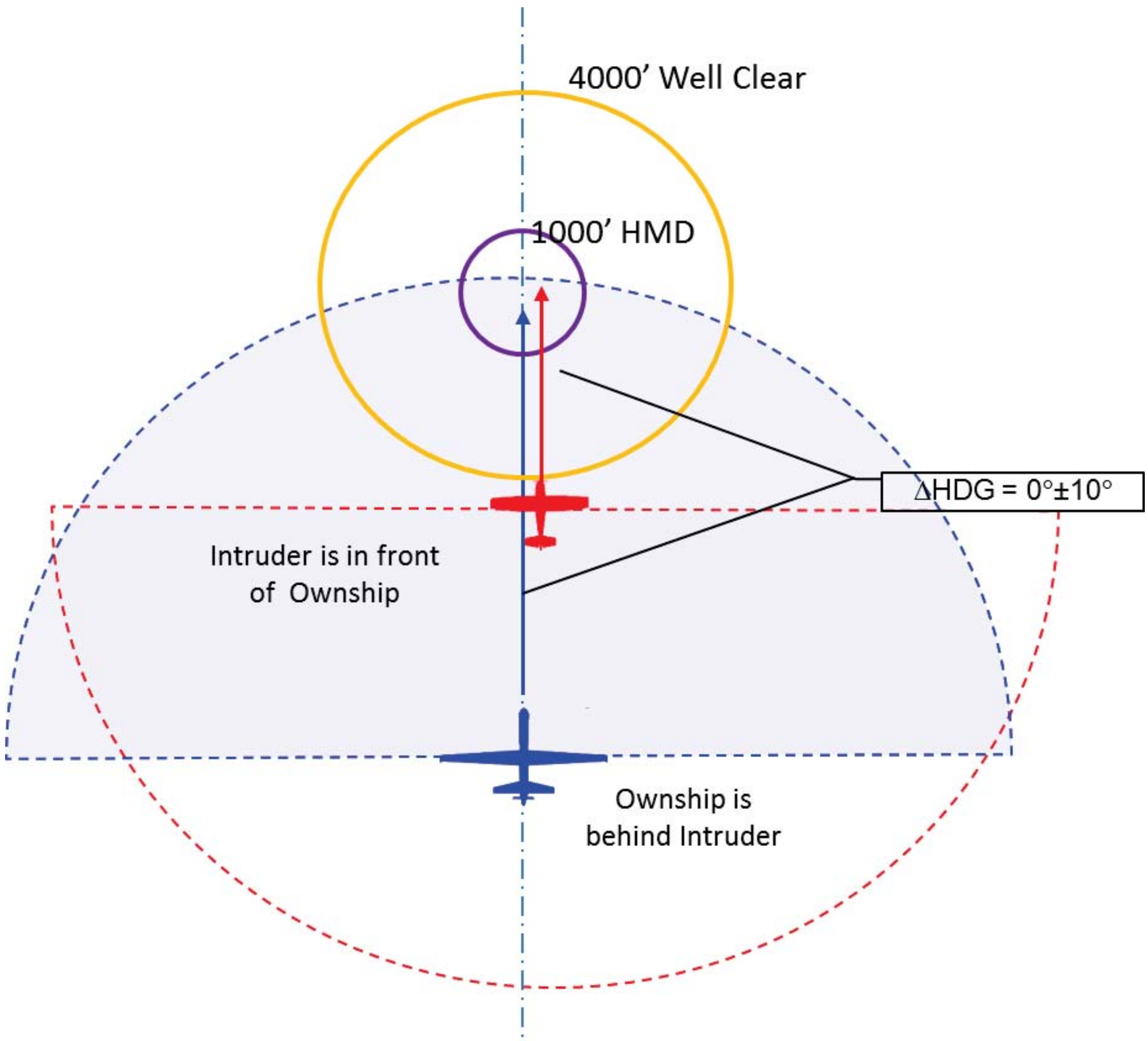


Figure H-6 Overtaking Geometry with Bearing and Relative Heading Criteria

H.3.3.4 Left Oblique Overtaking

For the left oblique overtaking geometry, the UA is approaching the intruder from astern as illustrated in Figure H-7 with the following criteria:

1. The UA is in the right-rear quadrant of the intruder.
2. The intruder is in the left-front quadrant of the UA.

In this geometry, the UA does not have the right of way and must maneuver to maintain DWC.

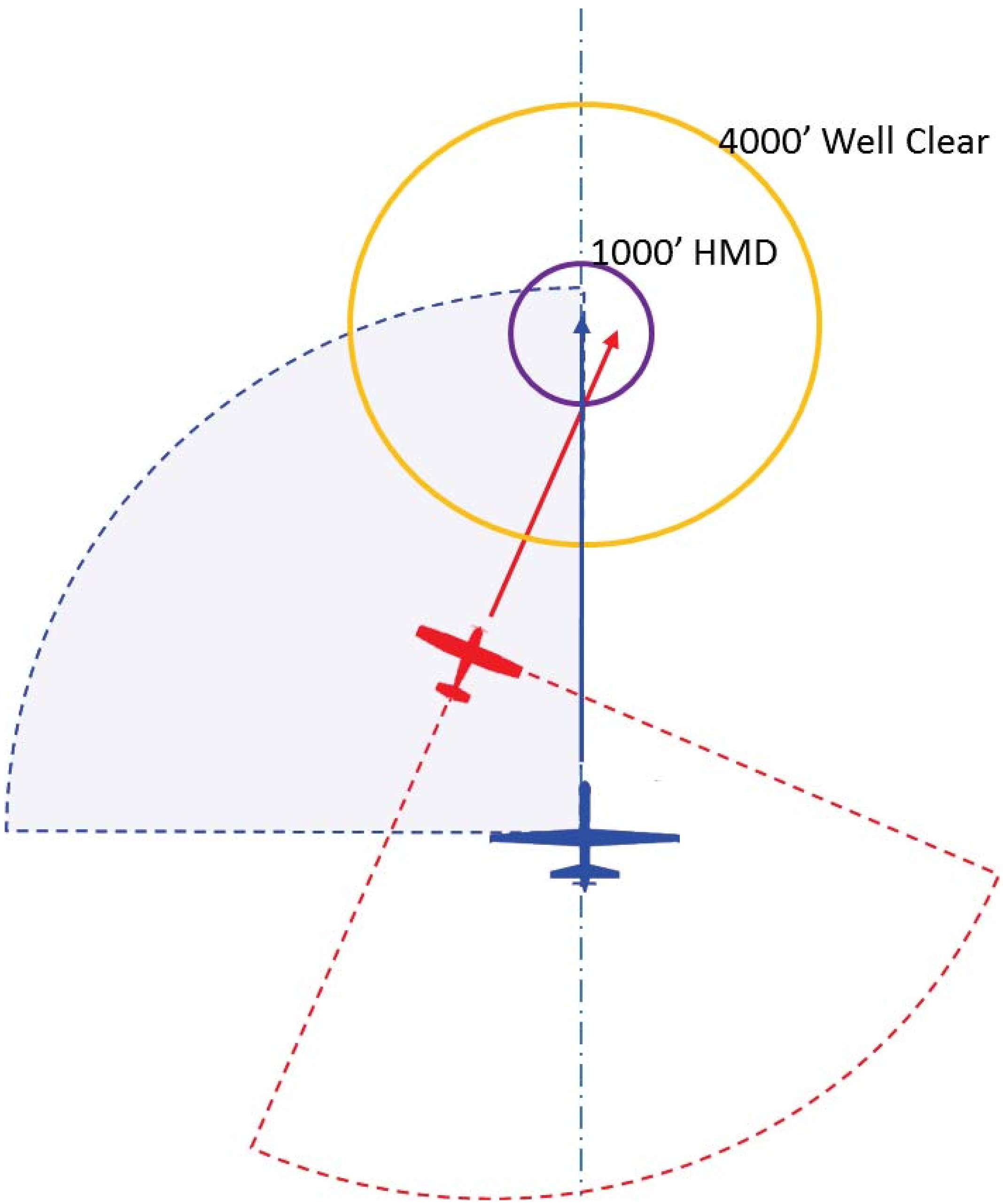


Figure H-7 **Left Oblique Overtaking Geometry with Bearing Criteria**

H.3.3.5 Right Oblique Overtaking

For the right oblique overtaking geometry, the UA is approaching the intruder from astern as illustrated in Figure H-8 with the following criteria:

1. The UA is in the left-rear quadrant of the intruder.
2. The intruder is in the right-front quadrant of the UA.

In this geometry, the UA does not have the right of way and must maneuver to maintain DWC.

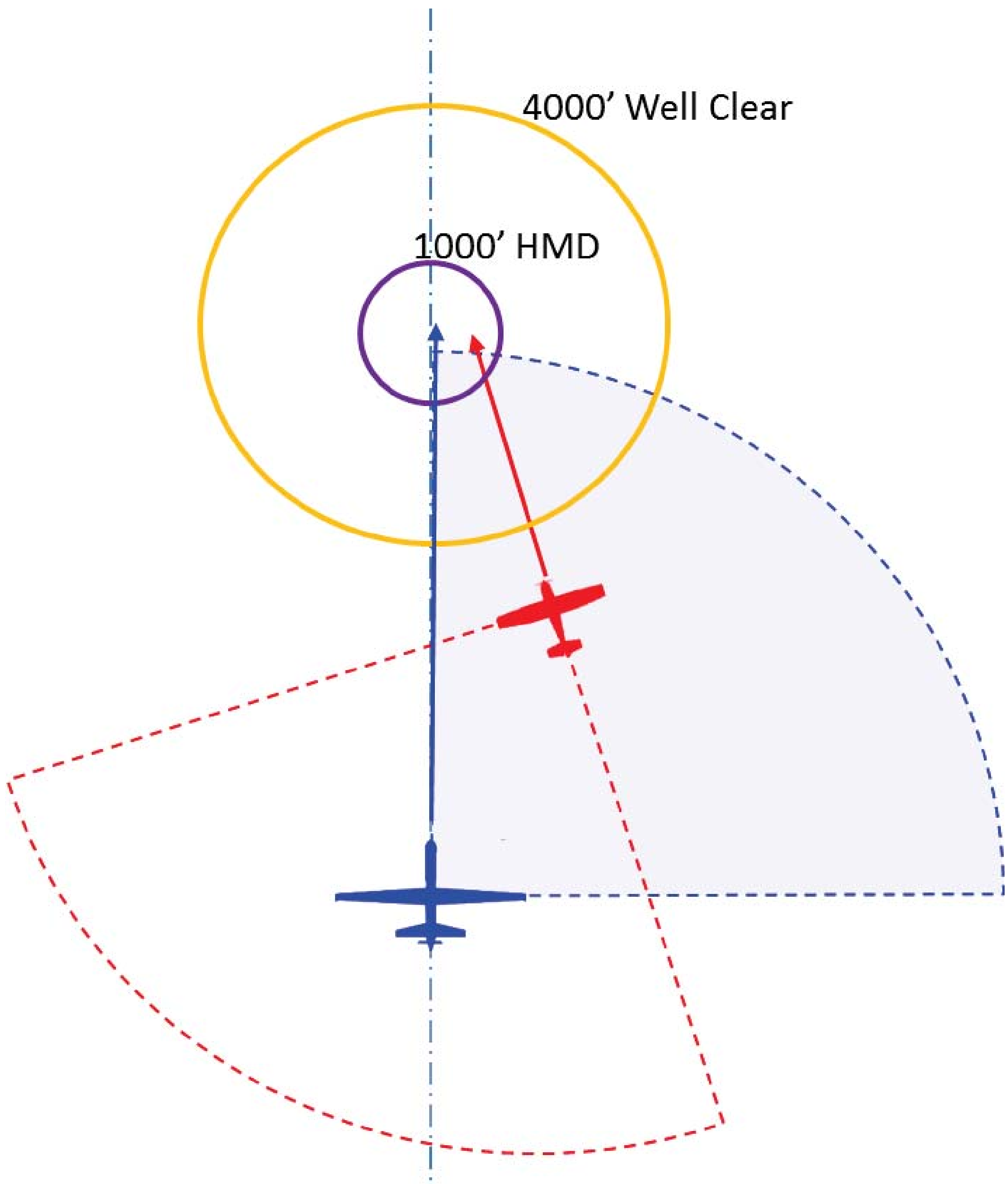


Figure H-8 Right Oblique Overtaking Geometry with Bearing Criteria

H.3.3.6 Converging from Left

For the converging from left geometry, the intruder is in the UA's left-front quadrant and the UA is in front of the intruder's wing as illustrated in Figure H-9 with the following criteria:

1. The intruder is to the left of the UA and in front of the UA (intruder is in the UA's left-front quadrant).
2. The UA is in front of the intruder.
3. The aircraft are not in a head-on geometry.

For this geometry, the UA has the right of way and is not expected to maneuver. However, if the risk of LoWC persists by the DAA Warning Alert, the UA may maneuver to maintain DWC without consideration of ROW rules.

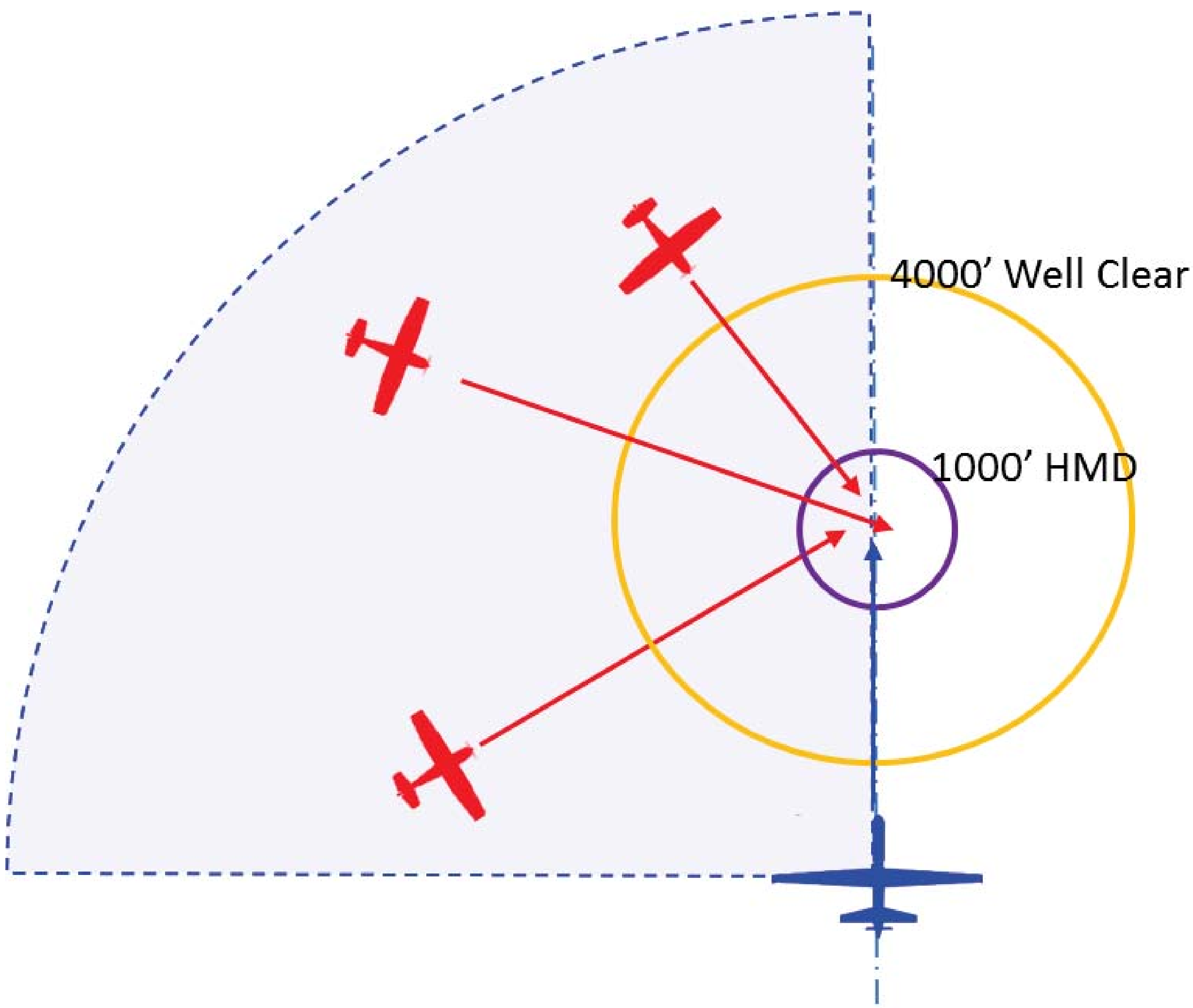


Figure H-9 **Converging from Left**

H.3.3.7 Converging from Right

For the converging from right geometry, the intruder is in the UA's right-front quadrant and the UA is in front of the intruder's wing as illustrated in Figure H-10, with the following criteria:

1. Intruder is to the right of the UA and in front of the UA (the intruder is in the UA's right front quadrant).
2. The UA is in front of the intruder.
3. The aircraft are not in a head-on geometry.

For this geometry, the intruder has the right of way, and the UA must maneuver to maintain DWC.

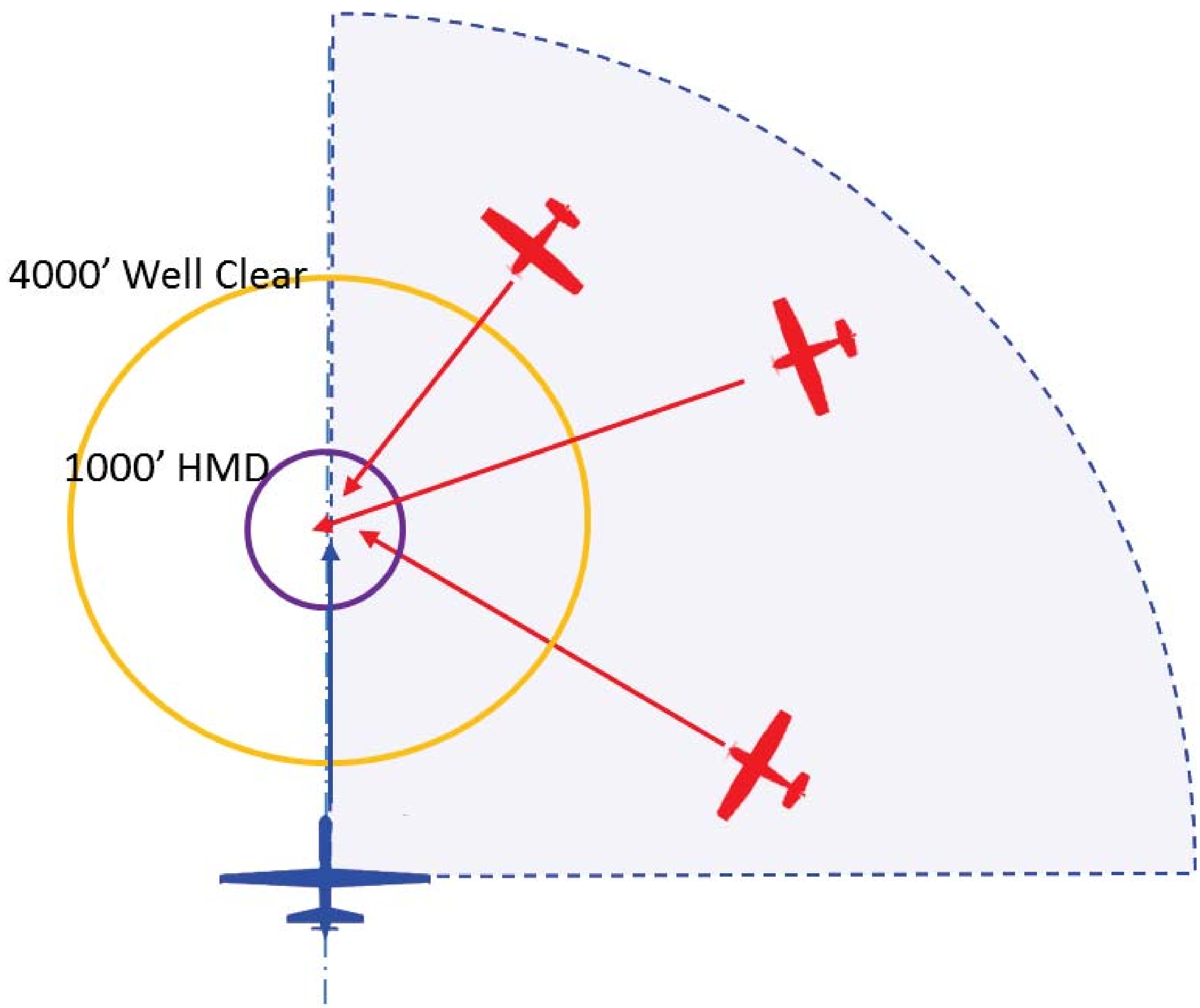
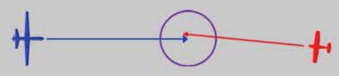
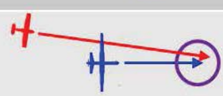
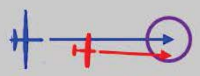
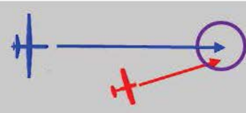
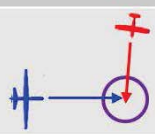
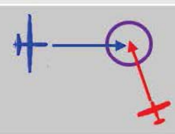


Figure H-10 Converging from Right

H.3.4 QROW Summary for Ambiguous Encounters

A summary of the QROW based on overall geometric classification is provided in Table H-1.

Table H-1 Summary of QROW for Ambiguous Geometries

Geometric Classification	Description	Ownship Has ROW?	Intruder Has ROW?	Ownship Maneuver Direction
Head-On		No	No	Turn Right
UA Overtaken		Yes	No	N/A
UA Overtaking		No	Yes	Turn Right
Left Oblique UA Overtaking		No	Yes	Maneuver to Remain DWC
Right Oblique UA Overtaking		No	Yes	Maneuver to Remain DWC
Intruder Converging from Left		Yes	No	N/A
Intruder Converging from Right		No	Yes	Maneuver to Remain DWC

H.4 ROW Modeling and Simulation and Analysis Results

M&S efforts were employed to investigate and validate QROW deliberation outlined in Paragraph H.4.2. This subsection will examine:

- Implementation, validation and integration of the major M&S components.
- Performance metrics employed by the SC-228 M&S Working Group to demonstrate the efficacy of the DAA system with QROW.
- Analysis results comparing DAA performance metrics with and without QROW.

The overall M&S framework is shown in Figure H-11 along with its role to support validating QROW.

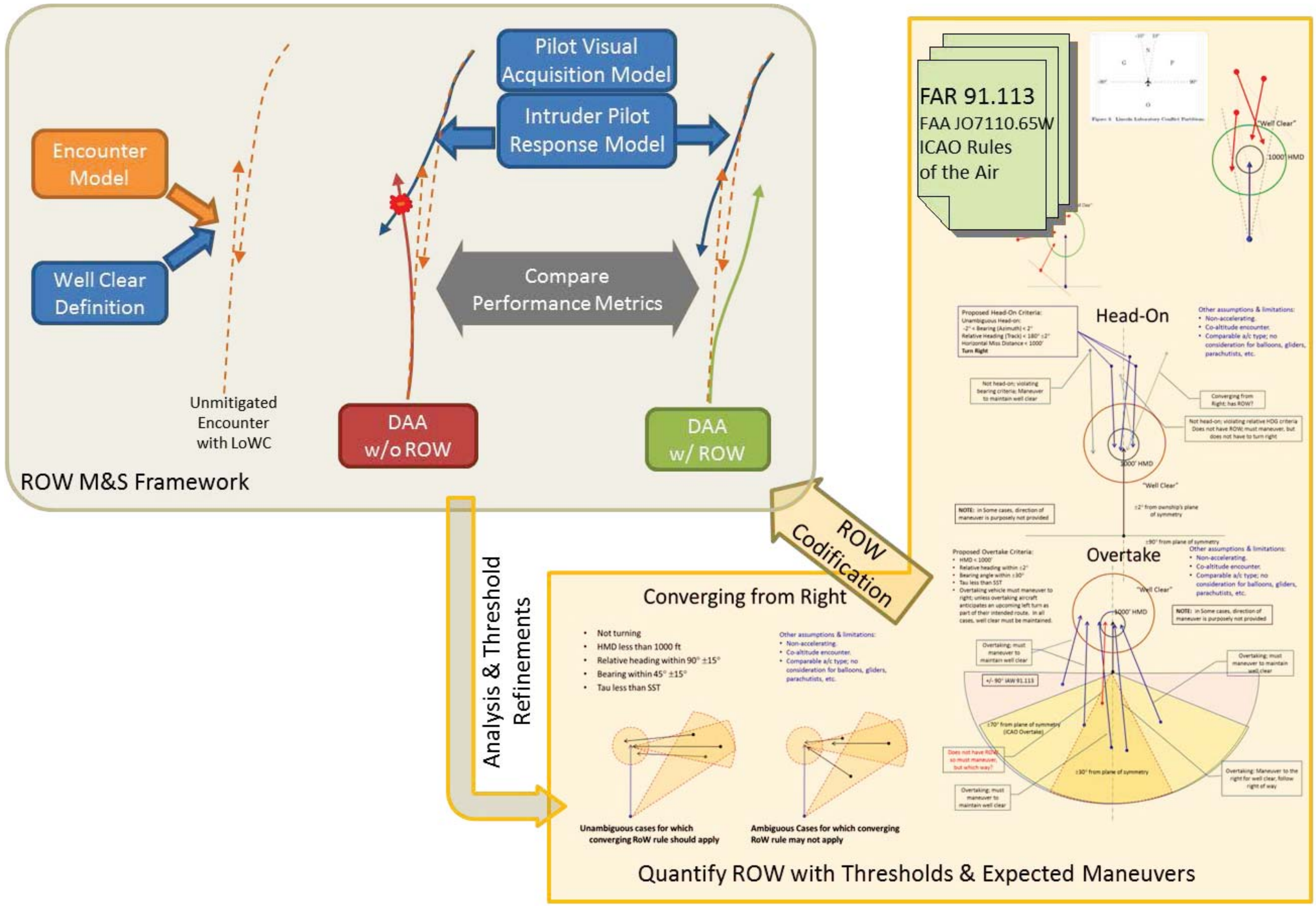


Figure H-11 M&S to Support Validating QROW

H.4.1 M&S Components

This paragraph examines the key components of the QROW M&S framework. Their functions and interactions with other components are identified, along with assumptions made for this QROW M&S effort.

H.4.1.1 Encounter Model

An encounter model was employed to generate statistically representative aircraft trajectories for the QROW M&S framework as shown in Figure H-12.

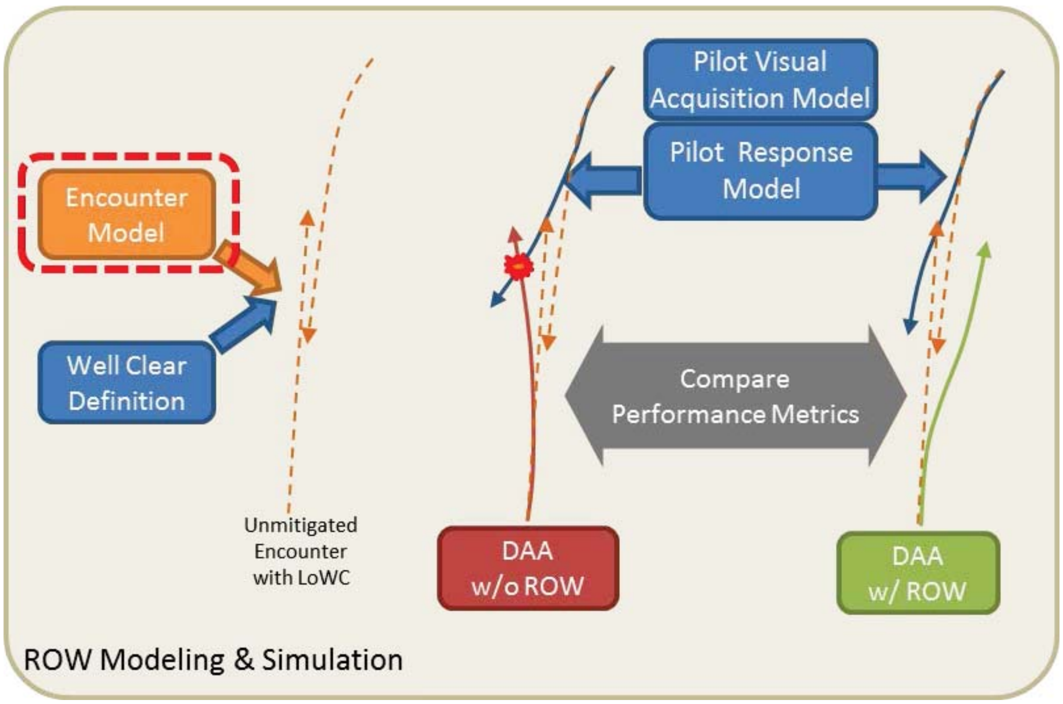


Figure H-12 Encounter Model to Generate Aircraft Trajectories for the M&S Framework

To demonstrate the efficacy of QROW with the DAA system, both the UA and manned intruder must be on representative flight paths prior to any mitigating maneuvers. MIT LL provided this representative model in the form of five million encounters between two aircraft. Therefore, each encounter used for QROW M&S involves one UA and a single intruder aircraft. The encounter sets were generated statistically, based on the observed behavior of non-cooperative general aviation aircraft within the National Airspace System (NAS) (Reference 2). The encounter set consists of five million initial condition pairs with each using one of one-hundred thousand command sets. The command sets specify the rate of change of speed, heading, and altitude as "time histories" for the duration of the encounter. Given the initial condition and rates of change, ground tracks and altitude profiles can be generated for each UA and the intruder in the five million encounters.

The encounter set represents uncorrelated encounters of general aviation aircraft within the NAS. This encounter set was used by the Science and Research Panel (SaRP) to analyze and quantify the DWC definition (see Appendix C). The ROW Working Group (WG) deemed it appropriate to represent encounter geometries and aircraft maneuvering characteristics subject to ROW rules as specified in CFR 14, §91.113. The encounter model does not address the effects of wind with the two aircraft states specified in a ground (inertial) reference frame. The encounter model's statistical breakdown of initial speed and altitude of each pair are shown in Figure H-13 as histograms.

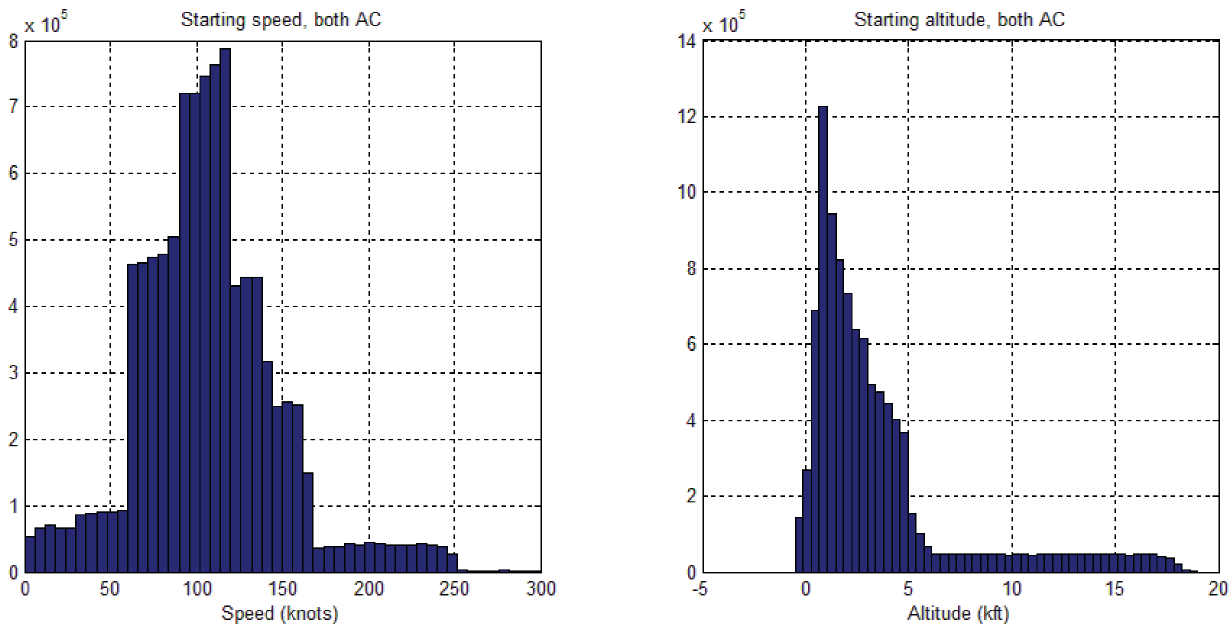


Figure H-13 **Aircraft Initial Speed and Altitude Histograms**

H.4.1.2 DWC Definition

See Appendices B and 0 for the definition of DWC.

H.4.1.3 Human Visual Acquisition Model

The ROW M&S effort focuses on encounters between the UA and non-cooperative VFR traffic. To model the ability of human intruder pilots to mitigate near-collision-course and on-collision-course encounters, the pilot visual acquisition model was coupled with the pilot response model to provide the intruder response given an encounter, as shown in Figure H-14.

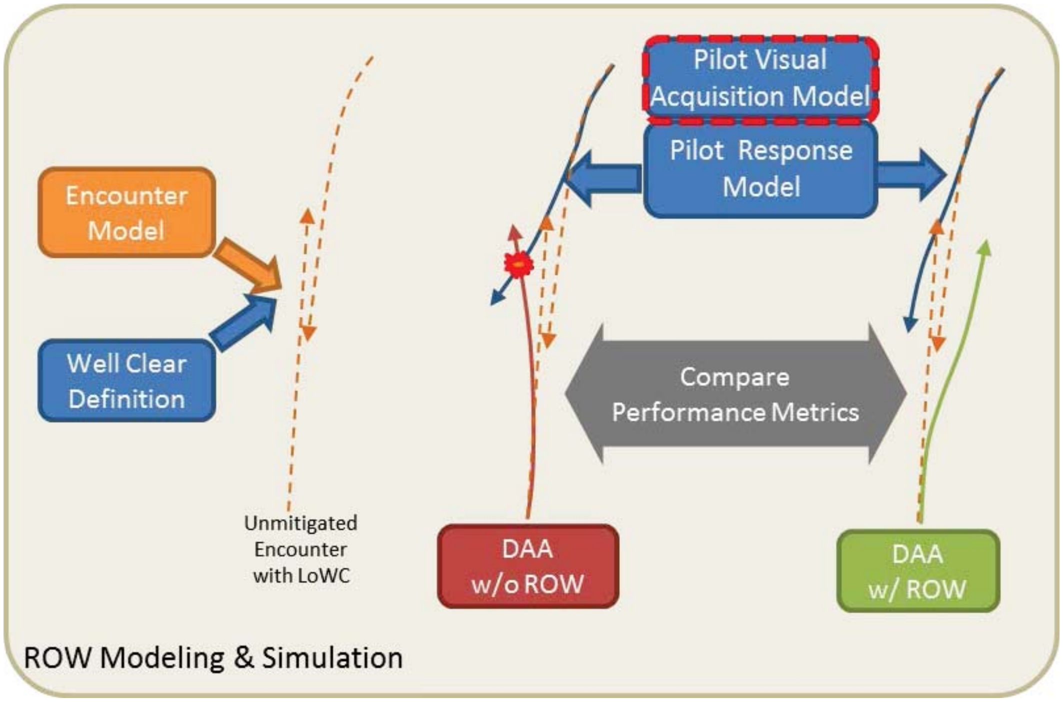


Figure H-14 **Human Visual Acquisition Model in the M&S Framework**

To model the response of manned non-cooperative intruder aircraft, a system for identifying when a human would have likely seen the UA was incorporated into the simulation, based on Reference 4. The model provides the probability of a human pilot's ability to visually identify a UA on a collision course given relative positions/speeds, the size of the intruder, atmospheric conditions and the pilot's search vigilance. This model was experimentally validated with flight tests involving twenty-four pilots with varying levels of experience, all with at least a private pilot's license (Reference 5).

The human pilot visual acquisition model was originally written in Pascal with a simplifying assumption that the aircraft were on a collision course. To incorporate this model into the modern simulation environment, the ROW subgroup re-implemented the functional components in MATLAB. After reimplementation, all check cases in reference documents were run, and all passed. The visual acquisition model included a number of variables that can affect a pilot's visual search effectiveness. To help constrain the scope, the ROW subgroup selected representative fixed values for each as enumerated in Table H-2.

Table H-2 **Human Visual Acquisition Model Parameters Used for ROW M&S**

Field of View	
Elevation	±12 degrees
Bearing	120 degrees counter-clockwise from forward
	90 degrees clockwise from forward
Atmospheric Conditions	10 NM visibility

Human Search Effectiveness Factor	
	17,000 per steradian-second (The nominal value for a single unalerted pilot used in M&S by researchers at Andrews Air Force Base)
UA Size	
MQ-9 Reaper	3-degree view areas, calculated from public sources. (The UA was not intended to represent an MQ-9 Reaper but this was used as the standard sized UA being observed by human pilots at the time these MOPS were published.)

An example of the resultant time history of visual detection probabilities is shown in Figure H-15 against a Piper Cherokee and against a larger Cessna 421 for an overtaking geometry at different horizontal offset distances. In this co-altitude example, the effect of the intruder aircraft size, range and bearing angle can be seen, and all contributed to the increased overall detectability of the slower intruder.

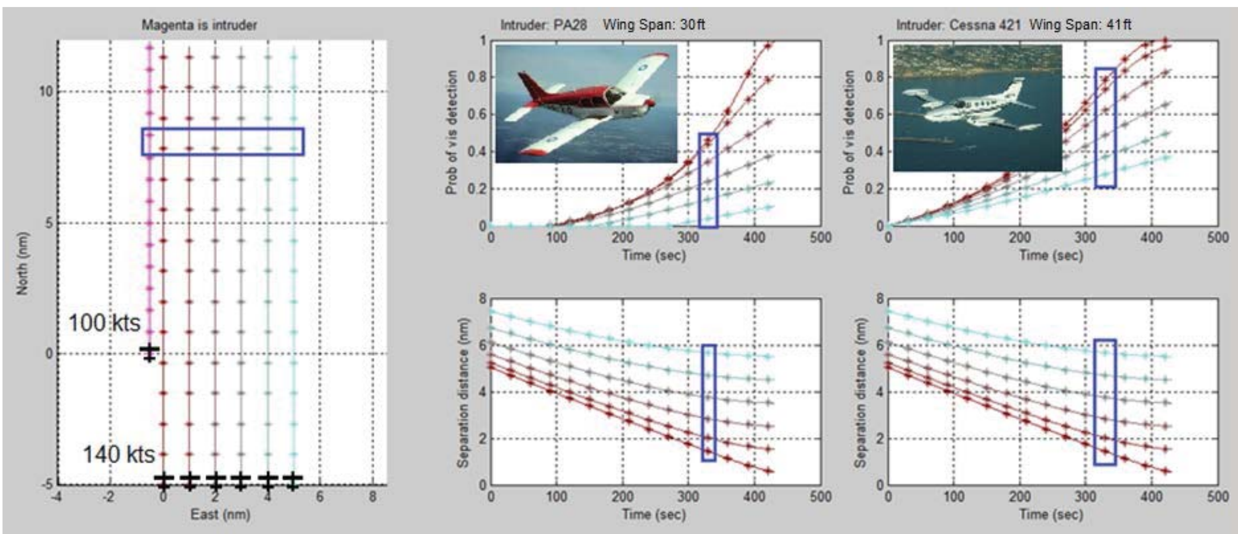


Figure H-15 **P(Visual Detection of Small & Large Aircraft in Overtaking Scenarios**

H.4.1.3.1 Explanation of Probability Threshold

The visual acquisition model described in Subparagraph H.4.1.3 outputs a numerical probability of acquisition between 0 and 100% corresponding to very low and very high probability of having visually acquired the UA at a particular stage of the encounter. It was desired that the simulation be fully deterministic, ruling out probabilistic methods. A probability threshold was determined based on mean and median ranges of observation such that Andrews flight test data and the LL encounter set coincided for the same aircraft being observed (Cessna 421). Figure H-16 shows flight test ranges of observation. Ultimately a visual acquisition probability threshold of 40% was selected to achieve similar mean and median observation ranges as seen for converging and head-on geometries in the LL data set as the Andrews flight test (see Figure H-17 and Figure H-18).

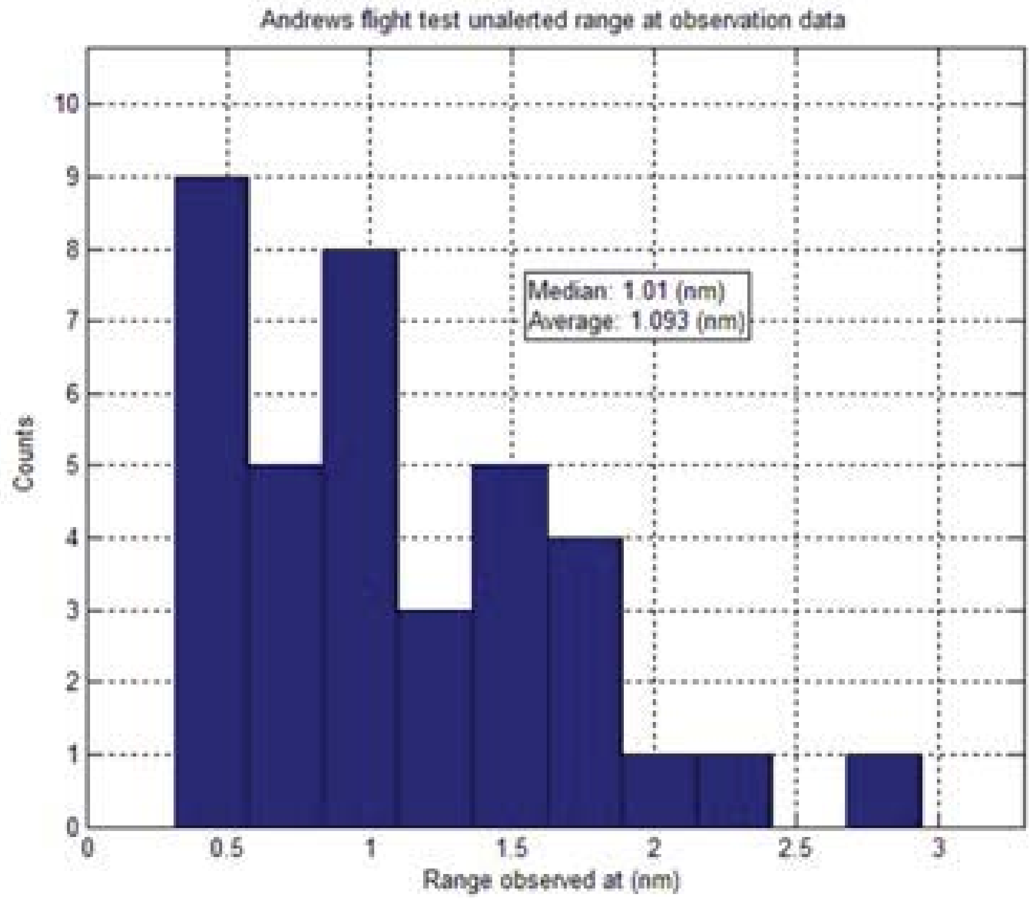


Figure H-16 Observation Flight Test Ranges

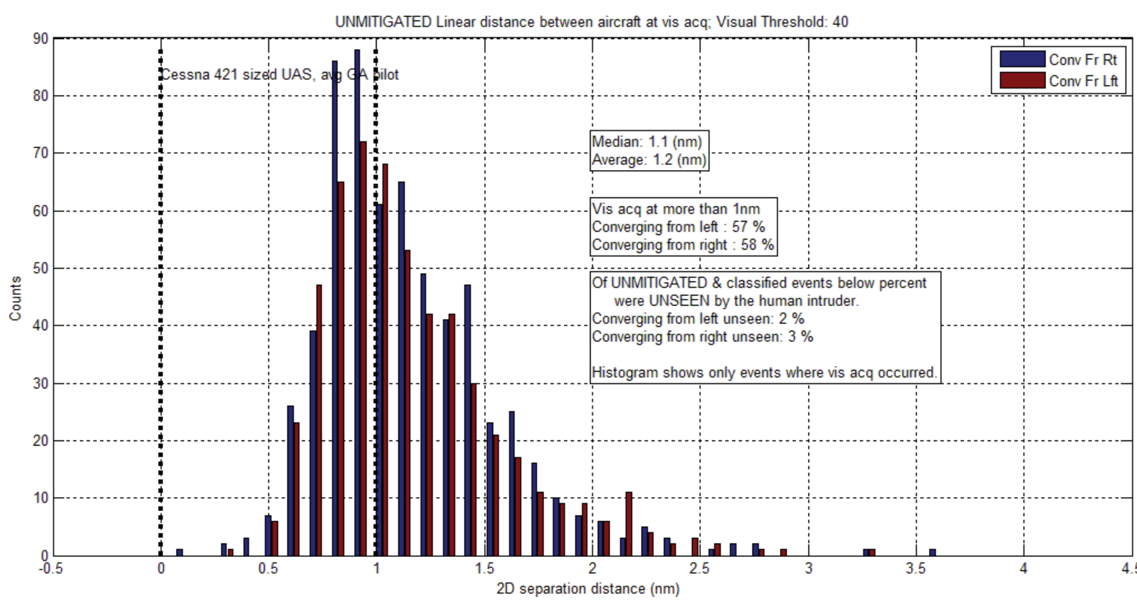


Figure H-17 LL Observation Ranges, Converging from Left/Right

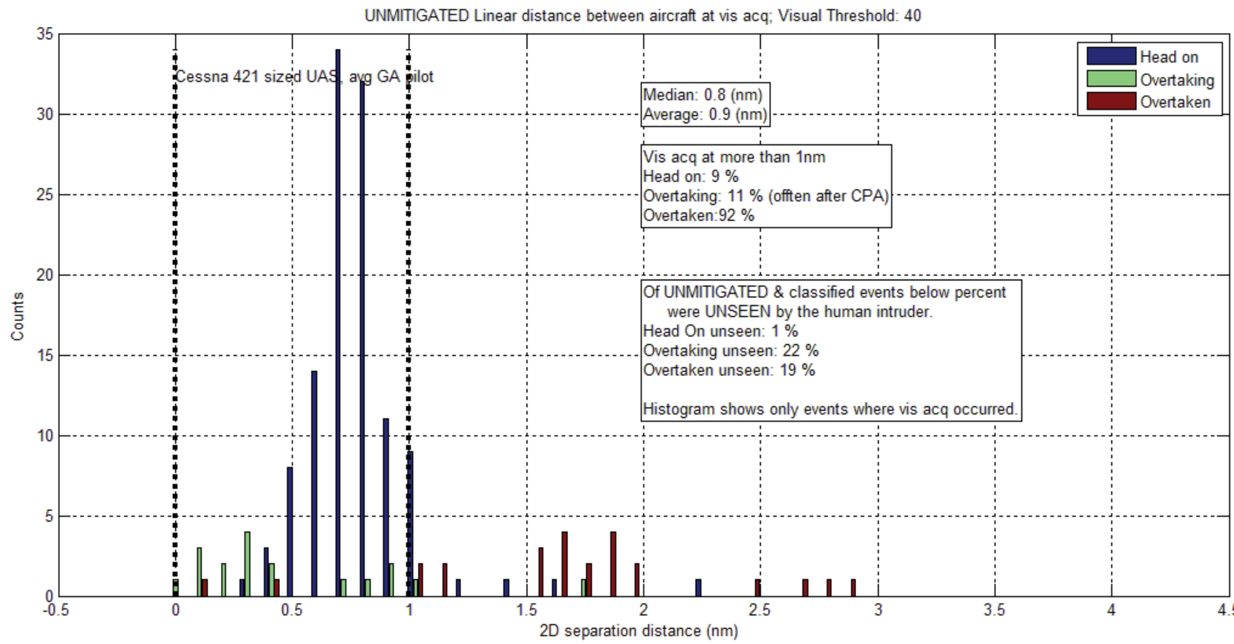


Figure H-18 LL Observation Ranges, Head-On, Overtaking and Overtaken

H.4.1.4 Pilot Model (LL Dynamic Protection Zone)

The second major component of the non-cooperative manned intruder aircraft is the pilot response model, which was used to determine if and how the manned aircraft will react after having visually acquired the opposing UA, as shown in Figure H-19.

Reference 8 provided the basis for the model of how a human pilot reacts after having observed an intruder aircraft. This pilot response model partitions bearing zones around each aircraft (Figure H-20), and applies a maneuver logic table to determine the human response, if any. Negative zone letters are defined as the reciprocal of the positive zone about the longitudinal axis.

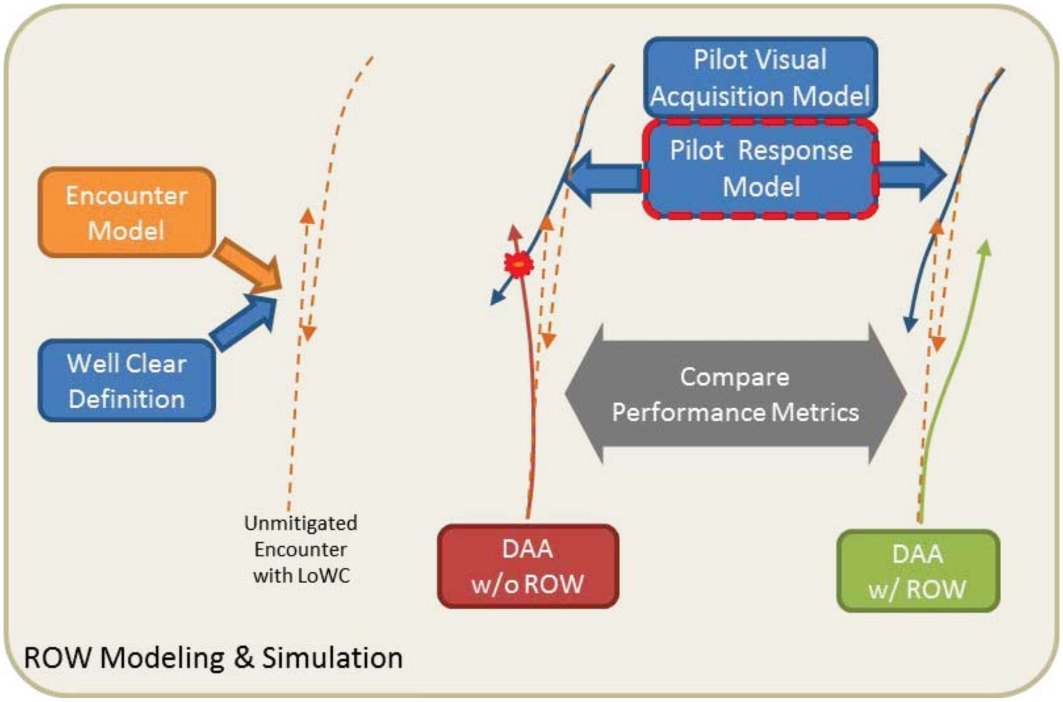


Figure H-19 **Manned Aircraft Pilot Response Model after Visual Acquisition of the UA**

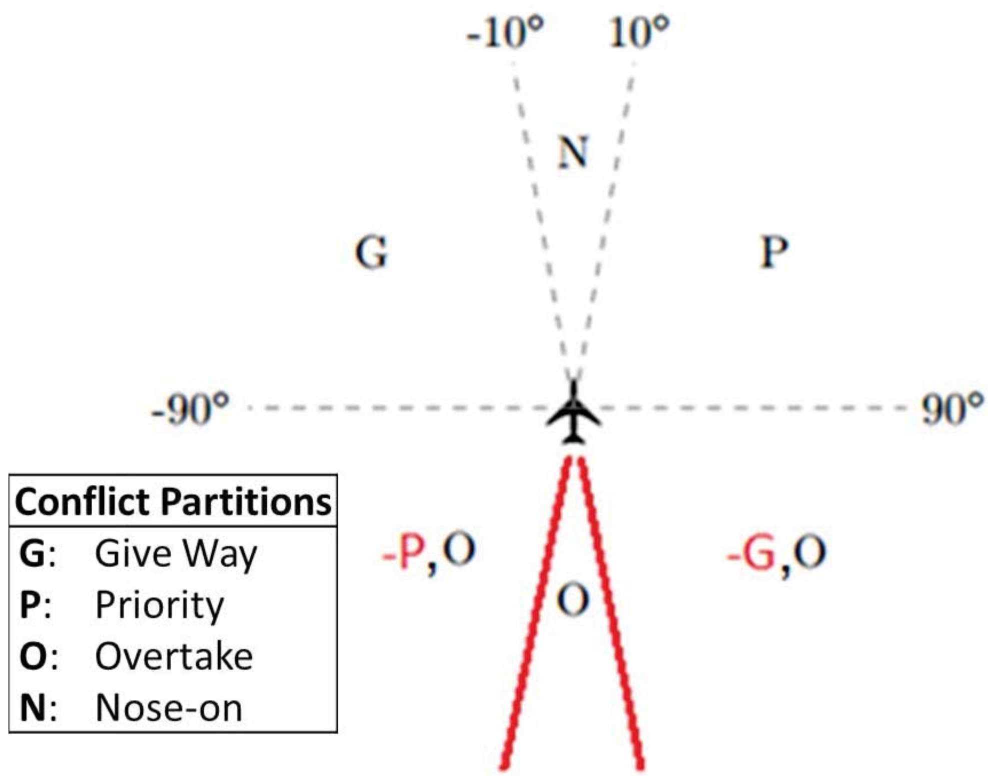


Figure H-20 **Bearing Partition Zones**

It should be noted that certain bearing partition zone combinations were not identified in the reference document. The ROW M&S team extracted representative encounter plots for these cases and leveraged pilot and controller Subject Matter Experts (SMEs) to determine the maneuvering direction, if any, for the missing partition zone combinations. The comprehensive list of partition pairs and their corresponding maneuver behavior is shown in Table H-3.

Table H-3 Comprehensive Maneuver Directions Based on Partition Zone Pairs

Human	UAS	Turn Command	Source		Human	UAS	Turn Command	Source
O	P	None	LL		N	-P	Right	LL
O	N	None	LL		N	N	Right	SME
O	G	None	LL		N	O	Right	SME
O	O	None	SME		N	G	Right	SME
O	-G	None	SME		G	-P	Right	LL
O	-P	None	SME		G	G	Right	SME
P	-G	None	LL		G	N	Right	SME
G	P	None	LL					
P	P	Left	SME		N	P	Left	LL
P	N	Left	SME		N	-G	Left	SME
P	O	Left	SME		G	-G	Left	SME
P	G	Bearing Rate Rule	LL		G	O	Special Rule #2	SME
P	-P	Special Rule #1	SME					

Special Rule #1: Right if 4000' bubble not violated, else left.

Special Rule #2: Maintain course if 4000' bubble not violated, else right.

Bearing Rate Rule: Maneuver to increase bearing rate.

Example use of Table H-3:

The relative bearing from human to UA falls in the "O" range, and the relative bearing from UA to human falls in the "G" range (as shown in Figure H-21).

Referring to Table H-3 (third line down on the left), this represents the human not maneuvering.

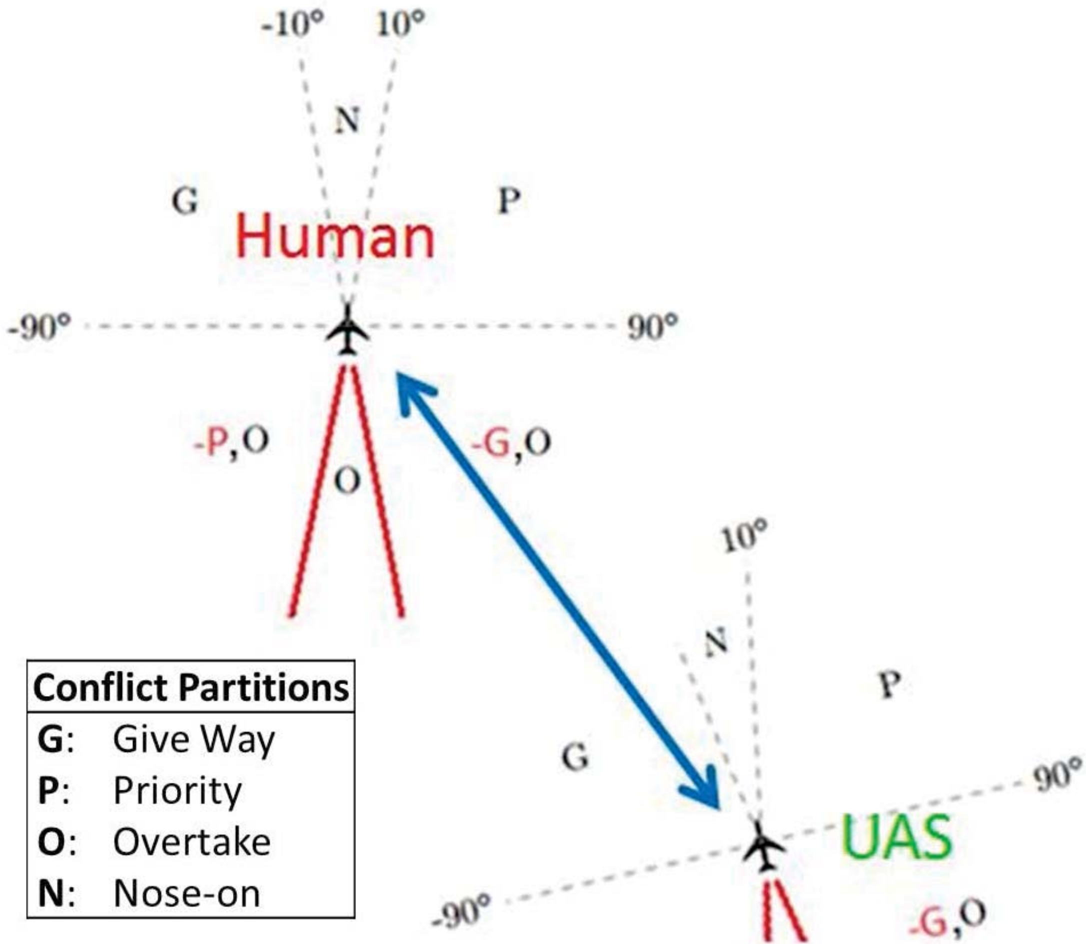


Figure H-21 **Example of Human Partition Zones**

Additionally, the ROW subgroup made additional assumptions for the intruder response model, as listed in Table H-4:

Table H-4 **Intruder Pilot Response Assumptions**

Parameter	Pilot Response Assumption
4000’	The projected Horizontal Miss Distance below which a human intruder pilot will apply maneuver logic until the HMD is larger than this tolerance. This was chosen with subgroup consensus to be the same as the SC-228 DWC threshold.
±700’	The altitude tolerance within which a human will apply the maneuver logic, based on SME judgment. The reference document considered only co-altitude encounters.

Parameter	Pilot Response Assumption
8 seconds	The delay time between visual acquisition and maneuver initiation per delay represents the time required for human to assess the situation and determine the correct maneuver before the collision avoidance domain.
90 degrees	The maximum heading change allowed.

H.4.1.5 Performance Metrics

To validate QROW thresholds identified in Subsection H.3 and demonstrate the efficacy of applying QROW to the UA's mitigating maneuver, a closed-loop performance metric was needed to compare DAA results with and without QROW, as illustrated in Figure H-22.

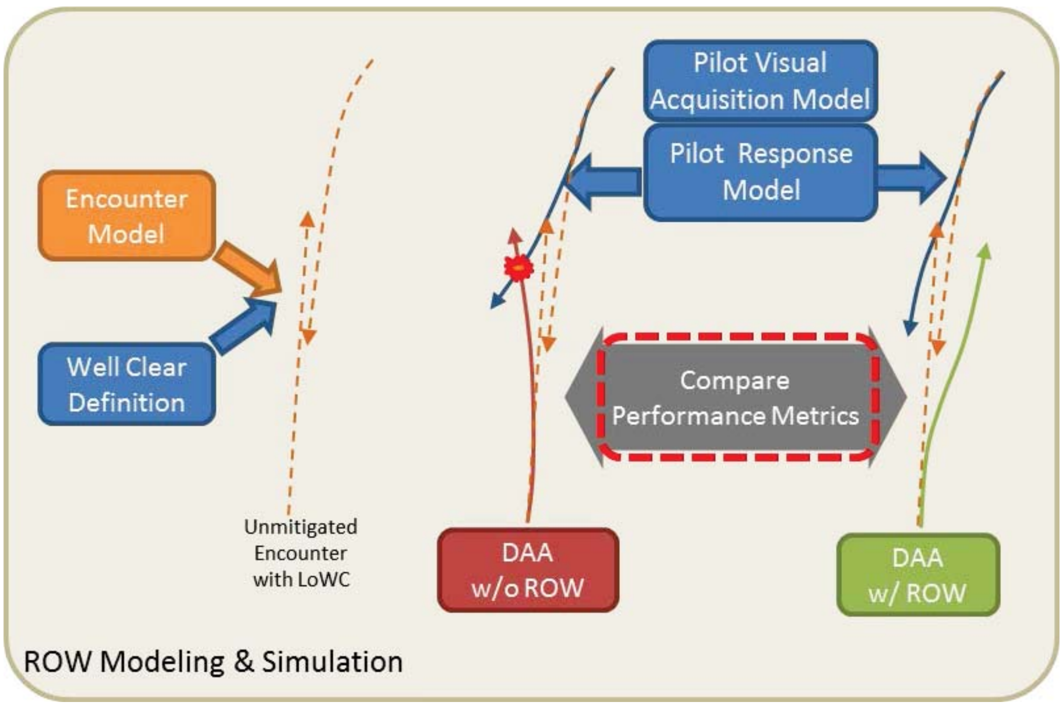


Figure H-22 Performance Metrics to Demonstrate Efficacy of QROW

Initially several metrics for Well Clear and Near Mid-Air Collision (NMAC) were considered:

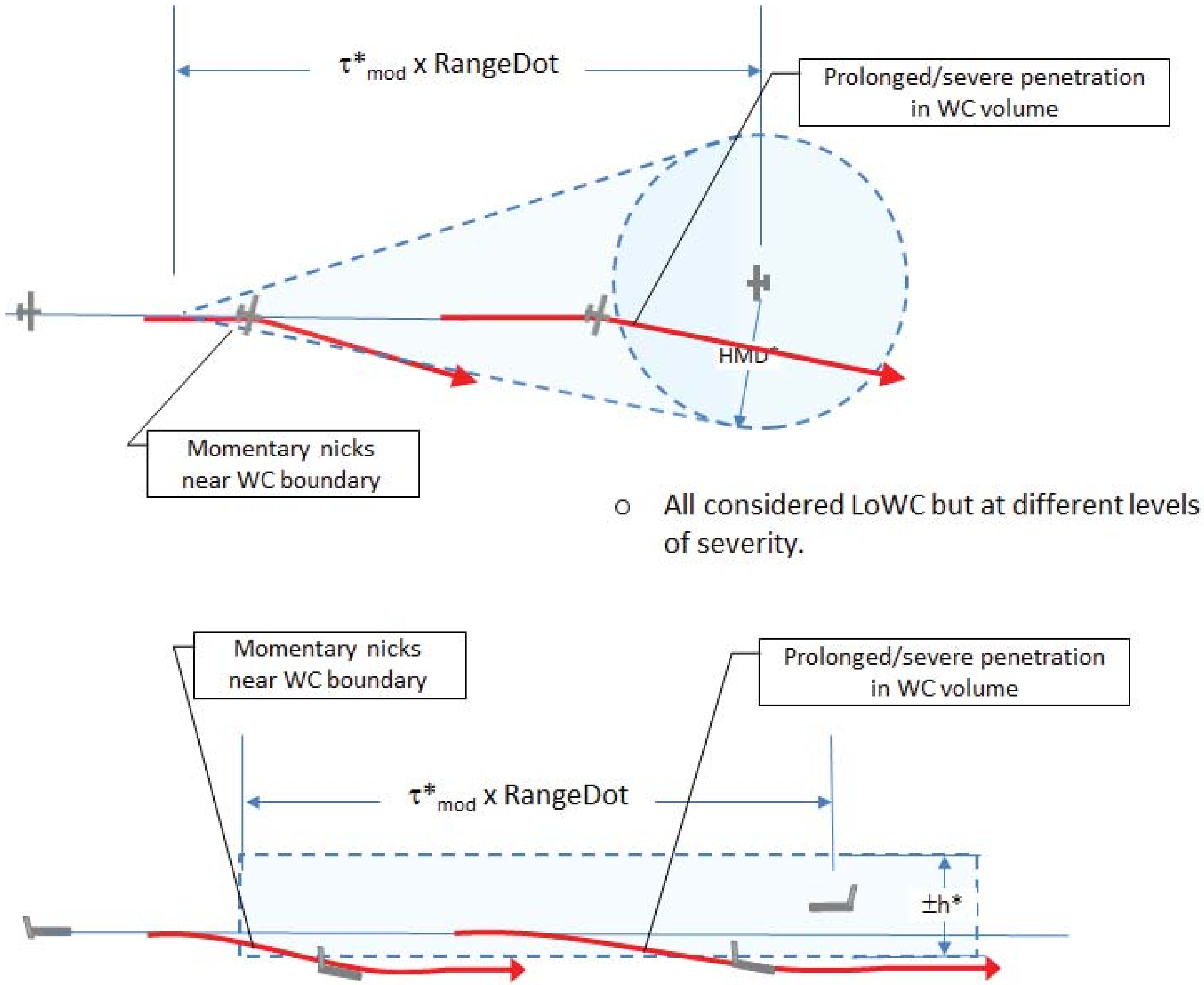
- NMAC Rate. Due to the rare occurrence of an NMAC after mitigation by the UA and/or intruder pilot, the NMAC rate was statistically insignificant to compare the effects of QROW given the size of the encounter set.
- LoWC Rate. The LoWC rate measures the percent of encounters with at least one instance of LoWC. All LoWCs are counted equally regardless of severity and duration, which is a major drawback of this metric.
- Well Clear Penetration Integral (PI). This metric provides a means of quantifying the severity of each LoWC encounter. Detailed definition for PI and encounter examples assessed using PI can be found in Subparagraph H.4.1.5.1.

As the ROW M&S activities progressed, it became evident both NMAC-rate and LoWC-rate metrics were inadequate to capture the performance details needed for QROW validation while the PI was able to characterize subtle variations suitable for this effort. Therefore the ROW M&S results presented in subsequent subparagraphs are based on comparisons of PI histograms.

It should be noted that a new closed-loop performance metric, Severity of LoWC (SLoWC), has been proposed and formalized after the ROW M&S activities were underway (see Appendix L). If schedule and resources allow, the subgroup may consider additional QROW validation analysis using SLoWC.

H.4.1.5.1 Well Clear Penetration Integral

The Well Clear Penetration Integral (PI) provides a means of quantifying the severity of each LoWC in terms of severity and duration. PI is a scalar measure that distinguishes between prolonged/severe LoWC and momentary LoWCs. Larger PI values indicate longer, more severe LoWC while PI values nearer zero represent less severe LoWC. Figure H-23 illustrates a comparison of momentary, benign LoWC at the DWC boundary (near-zero PI) and prolonged, severe LoWC (large PI value).



<u>Figure H-23</u> Benign Momentary Nick at the LoWC Boundary Vs. Prolonged, Severe LoWC

The proposed PI formulation for DWC is shown in <u>Figure H-24</u> along with the stated rationale to integrate, merge and scale horizontal and vertical penetrations based on τ_{mod}.

$$PI = \int \text{MIN}\left(\frac{(4000 - HMD)}{4000}, \frac{(450 - DH)}{450}\right) \frac{35-\tau_{\text{mod}}}{35}\, dt$$

$$PI = \sum_{i=1}^{n} \overbrace{\overbrace{\text{MIN}\left(\underbrace{\frac{(4000 - HMD_i)}{4000}}_{\substack{\text{Normalized}\\ \text{Horizontal}\\ \text{Penetration}}}, \underbrace{\frac{(450 - DH_i)}{450}}_{\substack{\text{Normalized}\\ \text{Vertical}\\ \text{Penetration}}}\right)}^{\substack{\text{Well Clear can be achieved vertically OR horizontally.}\\ \text{MIN() captures the one with least penetration}}} \underbrace{\frac{(35-\tau_{\text{mod}\,i})}{35}}_{\substack{\text{Scales back}\\ \text{significance at early}\\ \text{stage of encounter}\\ (\text{large } \tau_{\text{mod}})}} \Delta t}^{\substack{\text{Integrated over period of LoWC producing unit of Time}\\ \text{Captures sense of duration and exposure}}}$$

i = local instance of LoWC

Figure H-24 **Well Clear Penetration Integral Formulation**

Constants within equations from Figure H-24 are taken from SC-228's DWC definition and are used to normalize penetration. The equations in Figure H-24 assume a proper safeguard against division by zero and other singularities for HMD and τ_{mod}.

Examples of PI values for co-altitude, head-on encounters with varying horizontal offsets are shown in Figure H-25 along with the local incremental PI contribution to each encounter's overall PI Value. Similar plots are shown for co-altitude converging from right encounters in Figure H-26, and for co-altitude overtaking encounters in Figure H-27. Encounters with PI value of zero indicate well clear was maintained, while increasing PI values represent encounters with greater collision risk. Notice that the encounters with 4000' HMD and 0' HMD both trigger LoWC, but have vastly different PI values. In comparison, LoWC is strictly pass/fail, while PI provides more insights with a measure of the severity and duration of a LoWC. Generally speaking, LoWC encounters with PI values less than 2 are considered benign, momentary nicks while PI values greater than 10 are considered significant LoWC. PI can be used as a supplement to LoWC to provide more insights to the pathology of encounter geometries and DAA system performance.

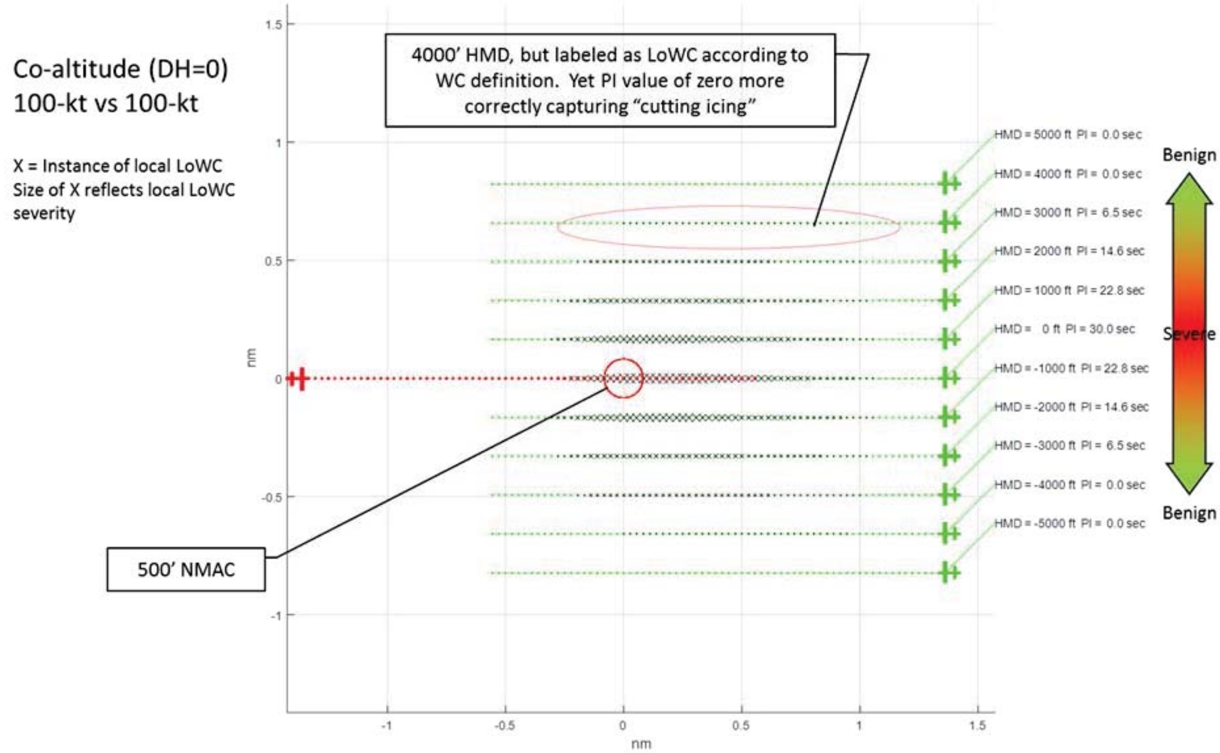


Figure H-25 **Well Clear Penetration Integral: Head-On**

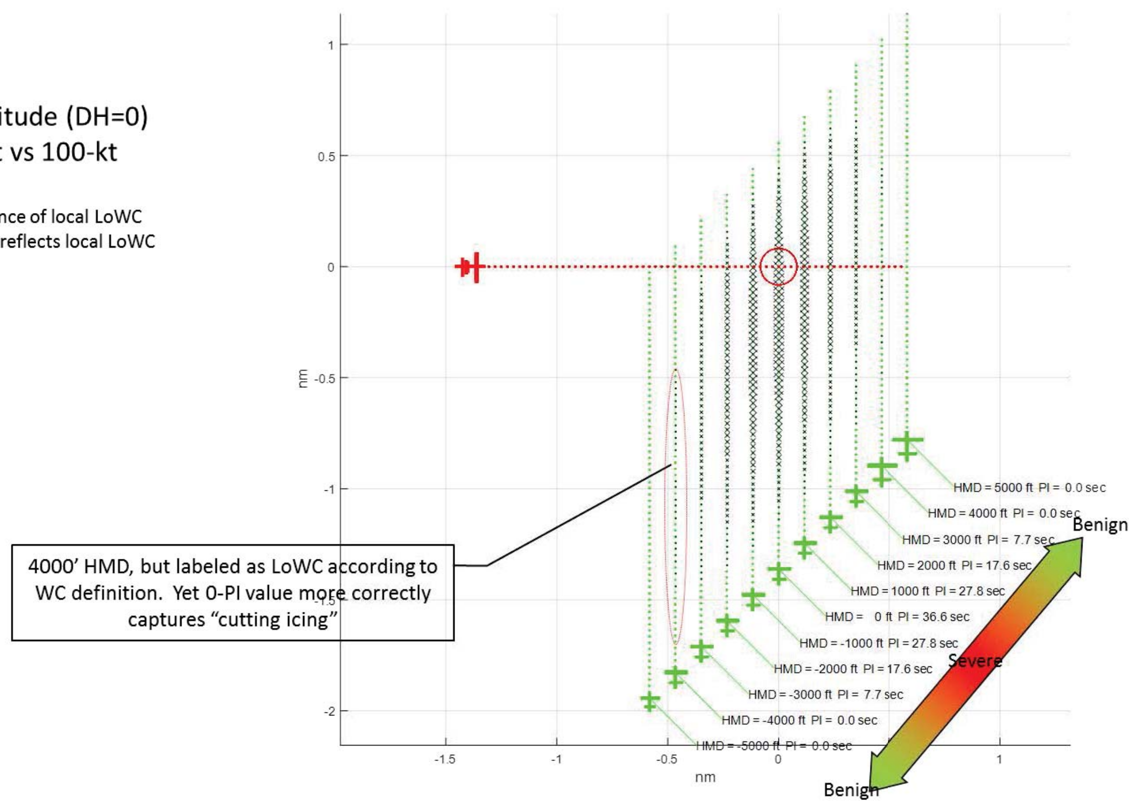


Figure H-26 **Well Clear Penetration Integral: Converging from Right**

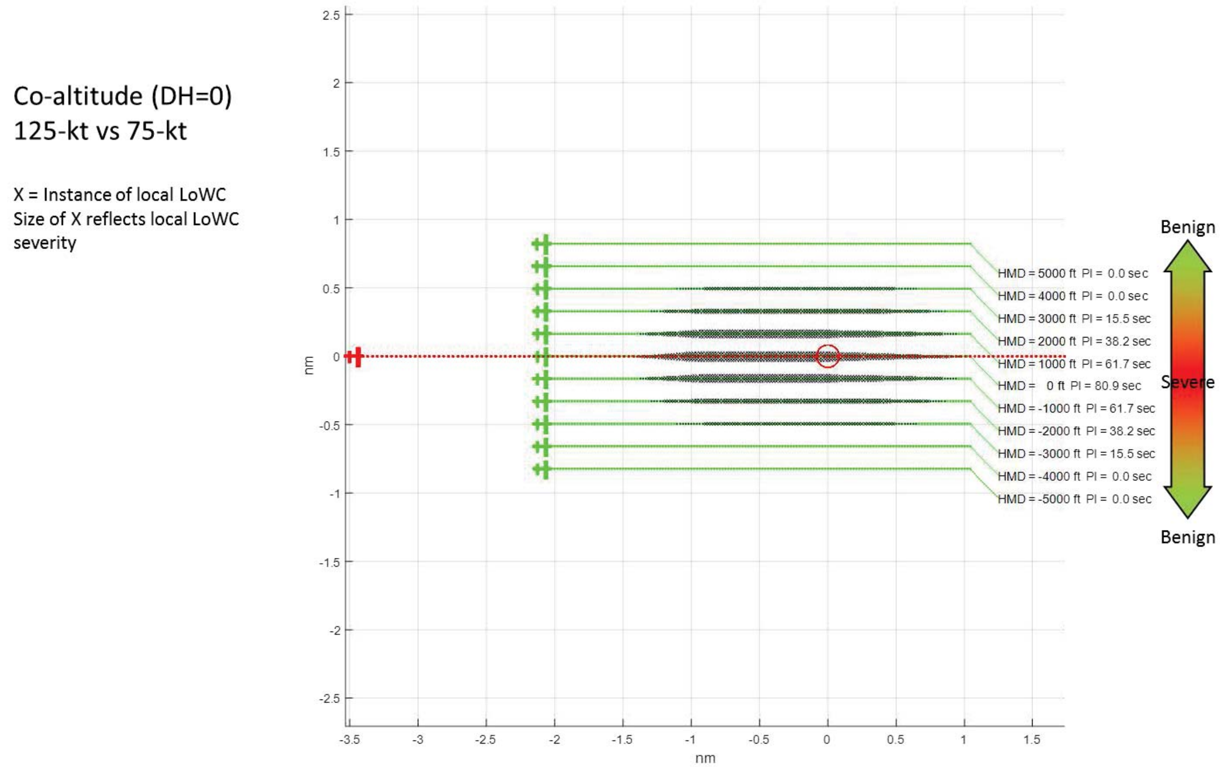


Figure H-27 **Well Clear Penetration Integral: Overtaking**

H.4.2 Description of Simulation Environment

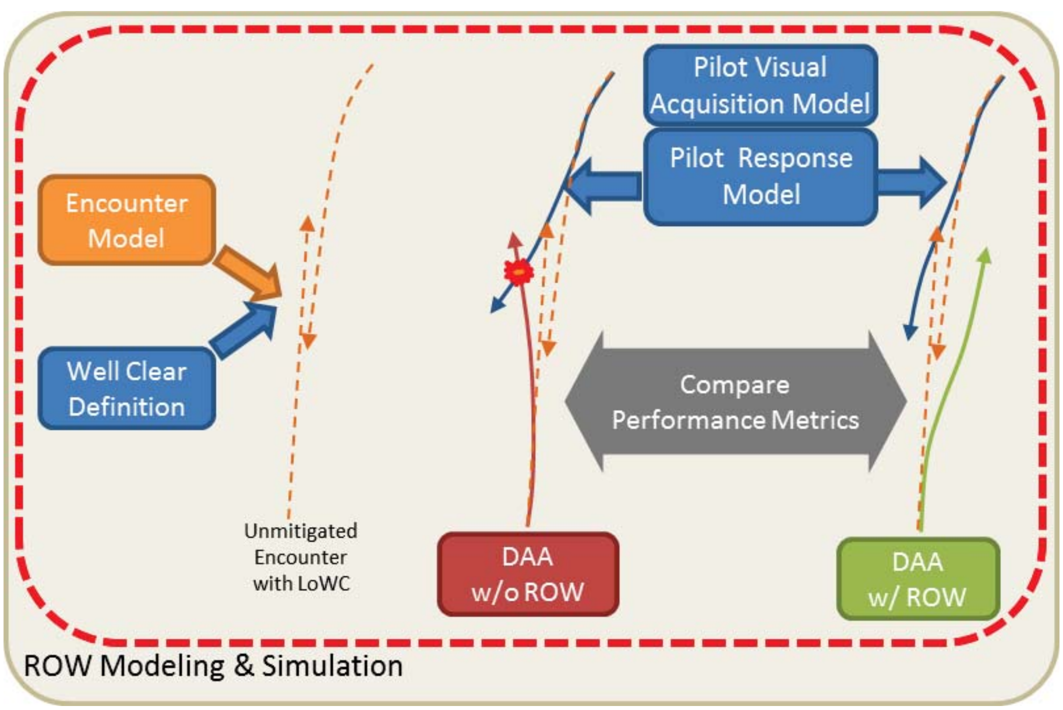


Figure H-28 **Description of Simulation Environment**

In order to validate the QROW deliberations quantitatively a simulation environment was constructed that allowed fast-time simulation of proposed rule sets. This environment was constructed in the MATLAB programming language and incorporated the LL unmitigated encounter trajectories, the DWC definition, pilot visual acquisition and response models, and DAA/QROW deliberations. As depicted in Figure H-29, the simulation ran each encounter individually with the two aircraft dynamically interacting according to predefined rules. At the start of the simulation both aircraft followed the unmitigated trajectory; during this time each continually tested its maneuver triggering condition. Once a maneuver trigger condition is met, the UAS or manned maneuver rules were applied.

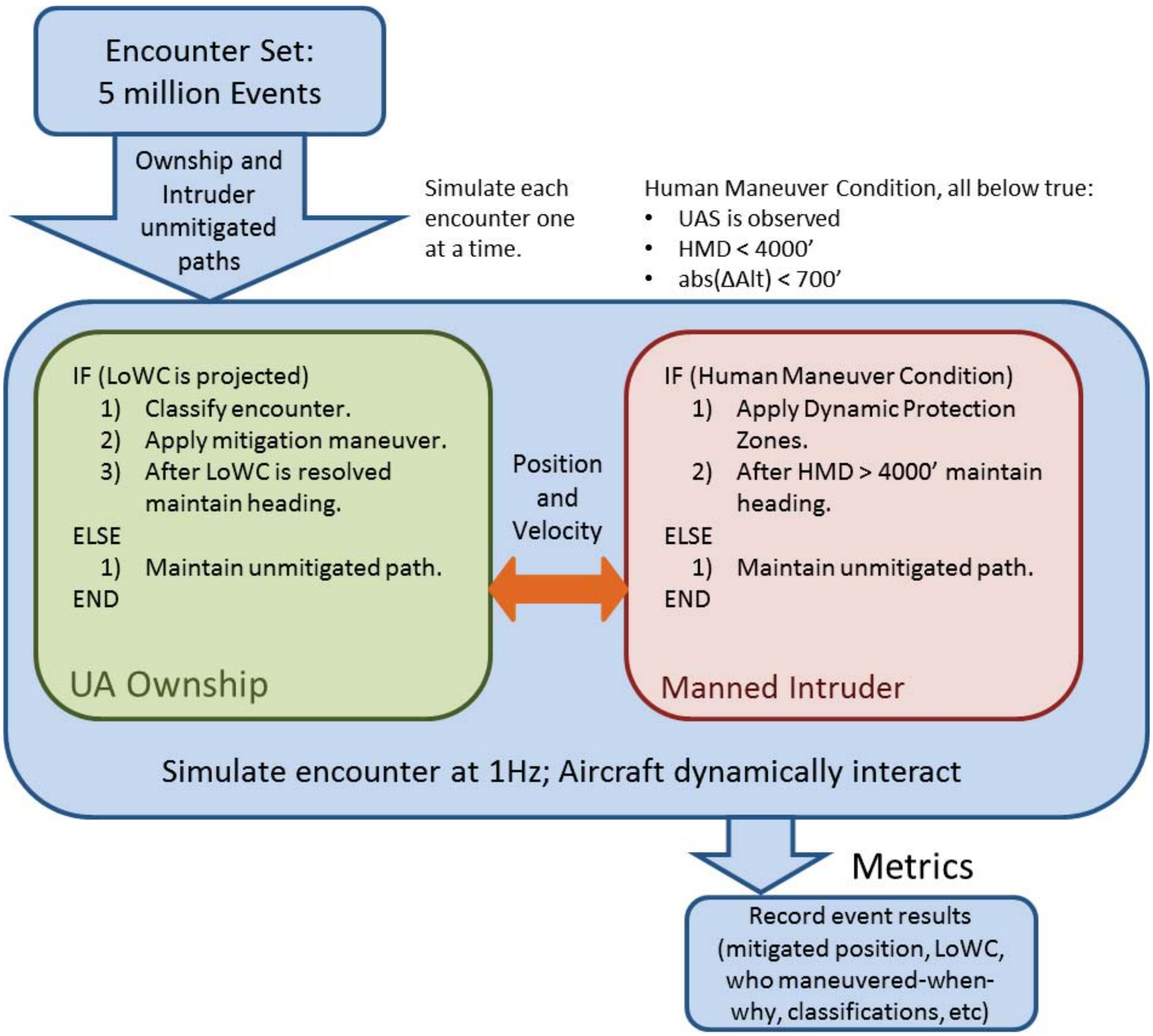


Figure H-29 **LoWC Maneuver Logic**

After the end of the encounter simulation, results were cataloged and saved for later analysis.

In order to limit the scope of the simulation effort to focus on the effects of QROW, the following assumptions were made after vetting them through the SC-228 ROW subgroup.

- Many encounters' initial positions and headings were such that LoWC occurred in the first few seconds of the encounter. To ensure DAA had sufficient time to be applied, these encounters were linearly back-propagated to allow a minimum of 30 seconds before the first instance of LoWC.
- Error-free sensors were assumed at this juncture. Both the intruder and UA had perfect knowledge of each other (the intruder only after it has made visual acquisition).
- The UA and manned aircraft were assumed to be capable of instantaneous bank angle changes. Each vehicle's roll dynamics were assumed to be negligible
- A 40-percent probability threshold (above which the human pilot was considered to have visually acquired the UA) was selected based on a calibration effort to replicate the statistical likelihood of visually detecting an intruder from similar approach angles against reference flight test results. See Subparagraph H.4.1.3.1 for more details.
- Mitigation maneuvers were limited to 90 degrees of heading change.

The following assumptions relate only to the manned intruder:

- Mitigation maneuvers were performed at a standard turn rate of three degrees per second.
- The intruder maintained airspeed and climb rate during and after the mitigation.
- If the UA left the intruder's field of view, the integrated probability of detection maintained its value.

The following assumptions relate only to the UA.

- Mitigation maneuvers were performed at half the standard turn rate (1.5 degrees per second) when UAS airspeed was greater than 60 knots. When UAS airspeed was between 40 and 60 knots, the UAS mitigation turns were performed at full standard rate, per Appendix D.
- In addition, turn rate was further restricted by a maximum bank angle limit of ±20 degrees.
- Unmanned aircraft with initial speeds less than 40 Knots were not considered, per Appendix D.
- Vertical mitigation maneuvers were limited to a ±5-degree flight path angle, and the rate of change for flight path angle was limited to ±½ degree per second. Heading was maintained during vertical mitigation maneuvers.
- Vertical mitigation maneuvers targeted a 700' vertical offset, followed by leveling off to a constant altitude.
- Speed and climb rate were held constant during lateral mitigation maneuvers.
- Lateral mitigation maneuvers were terminated when 6000' of projected HMD was reached, after which a constant heading was maintained.

H.4.3 Results

Quantitative results are presented in this paragraph, demonstrating the efficacy of the DAA system using the QROW rule set for each ambiguous encounter classification. Throughout the on-going M&S effort experience was gained with difficult encounter geometries. Lessons learned and possible mitigation options are presented in Paragraph H.4.3.2.

H.4.3.1 Comparison of Performance Metrics for DAA with and without QROW

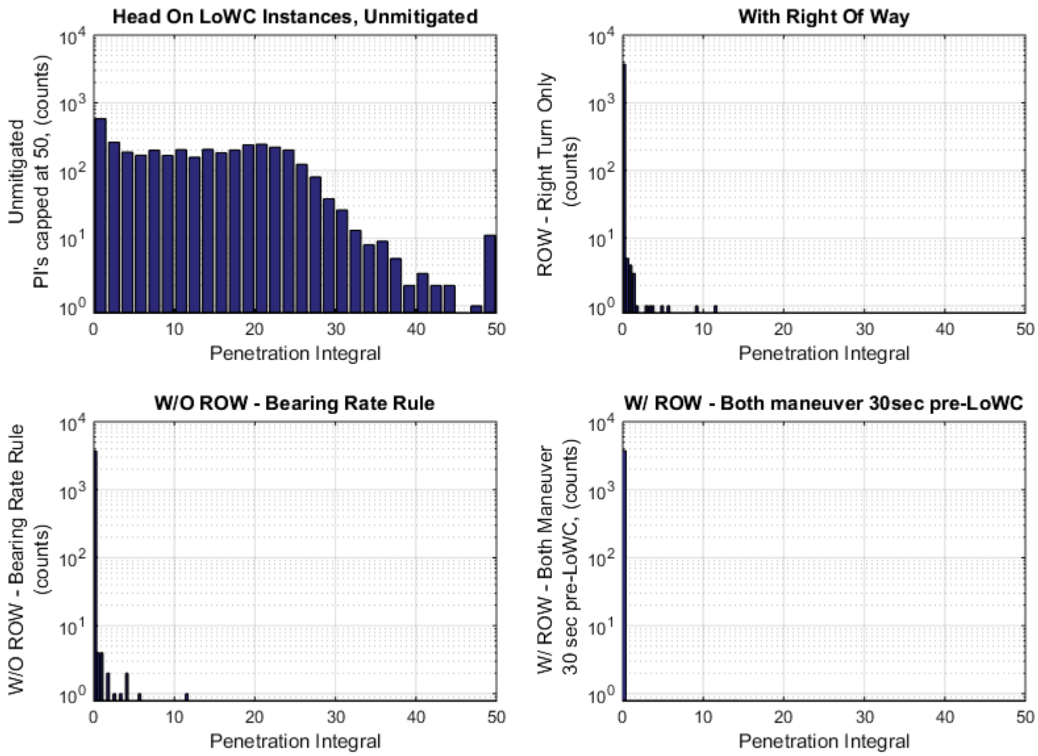
This paragraph compares the performance metrics for DAA with and without QROW for the different horizontally ambiguous geometries identified in Paragraph H.3.3.

H.4.3.1.1 Comparison: Head-On

As shown in Figure H-25, the effect of QROW is compared based on several simulation configurations. For the 3736 head-on encounters that resulted in various levels of well clear penetration, the resultant Well Clear PI distributions are plotted and compared for:

- Unmitigated.
- The UAS ownship commences maneuvering at 30 seconds before LoWC without QROW. The ownship was configured to select maneuvering direction based on the encounter bearing rate at the time of maneuver.
- The UAS ownship commences maneuvering at 30 seconds before LoWC with QROW (right-turn only).
- The UAS ownship commences maneuvering at 30 seconds before LoWC with QROW AND intruder maneuvering at 30 seconds before LoWC based on the LL Dynamic Protection Zone.

Even without QROW, the ownship maneuvering alone is very effective to maintain DWC, and applying QROW does not appear to provide an additional safety benefit. Further investigation revealed that in most cases, the human intruder does not visually acquire the UAS until most of the conflicts had already resolved with or without QROW. If the intruder is unaware of the approaching UA, the benefit of implicit coordination by turning right cannot be fully realized. This dependency on intruder awareness of an approaching head-on UA before maneuvering can be observed if the human intruder is not limited to his or her visual acuity in the simulation where each aircraft turning right is able to maintain well clear for all 3736 cases and produce incremental safety benefits.



<u>Figure H-30</u> **DAA Performance Metrics with and without QROW: Head-On**

H.4.3.1.2 Comparison: Overtaken

Since the UA has the right of way in this geometry, the UA model was configured to initiate its DAA maneuver at 15 seconds prior to LoWC in the simulation if the threat of LoWC persisted according to the QROW specification in Subparagraph H.3.3.2. For such conditions, four maneuver directions – left, right, climb and descend – were separately simulated with corresponding intruder behavior within the simulation, and their resultant PIs were recorded and analyzed.

For the 4724 overtaken encounters examined, relying solely on the approaching intruder to resolve the conflict did appear to provide measurable improvement in the overall separation in terms of PI (Unmitigated vs. UAS does not maneuver). Furthermore, allowing the UA ownship to maneuver provided additional improvements in performance to maintain DWC. Assuming the UA ownship maneuvered at 15 seconds before LoWC, over 12% of the encounters had only one viable maneuver direction remaining to maintain DWC. The direction breakdown for these encounters confirmed that QROW as defined in Subparagraph H.3.3.2 should not over-specify which direction the UA should maneuver for the overtaken geometry.

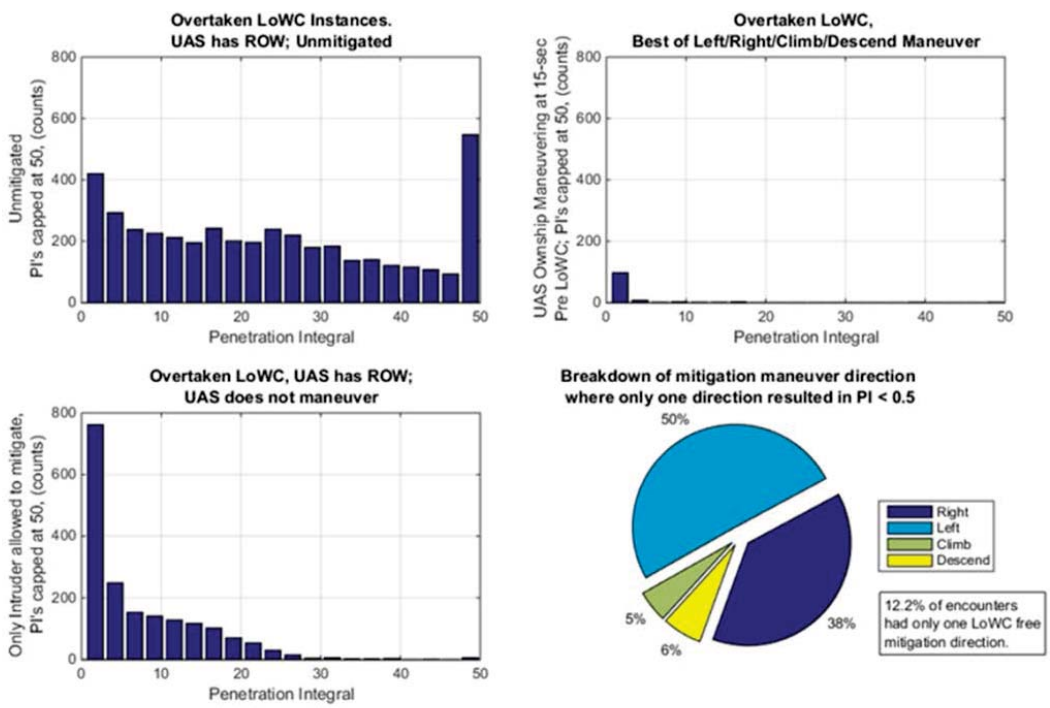


Figure H-31 **DAA Performance Metrics with QROW: Overtaken**

H.4.3.1.3 Comparison: Overtaking

For this geometry, the overtaking UA, approaching from astern, does not have the right of way. Following the QROW prescription in Subparagraph H.3.3.3, the simulation was configured to initiate the avoidance maneuver at 30 seconds prior to LoWC and maneuver the overtaking UA to the right to maintain DWC. A total of 860 encounters fell under this geometric classification. The comparison of PI for unmitigated and mitigated (according to QROW) is shown in Figure H-32, demonstrating the overall effectiveness of the avoidance maneuver to maintain DWC.

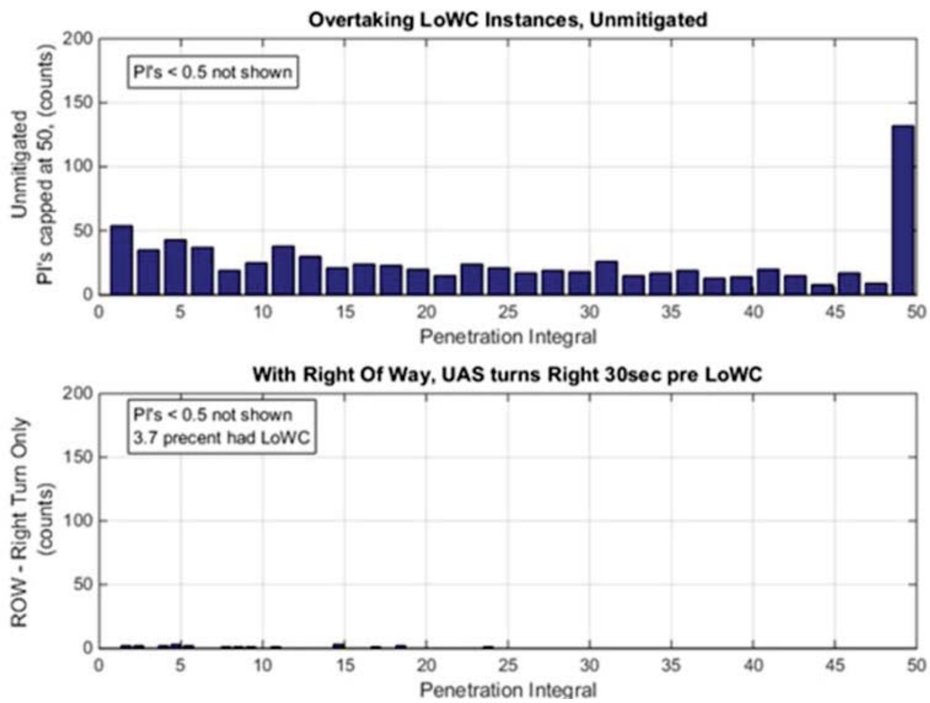


Figure H-32 **DAA Performance Metrics with QROW: Overtaking**

H.4.3.1.4 Comparison: Left Oblique Overtaking

For this oblique overtaking geometry, the UA is required to maneuver to maintain DWC. Since QROW in Subparagraph H.3.3.4 does not explicitly prescribe the direction of the required maneuver, the simulation was configured to choose a left or a right turn based on the projected horizontal geometry at the closest point of approach. If the projected HMD vector was on the overtaking UA's left (intruder's right), then the overtaking UA was configured to turn to the right to maintain DWC, taking advantage of the encounter's horizontal offset. Conversely, the UA was configured to turn to the left if the projected HMD vector was on the overtaking UA's right. This HMD Rule is a simplistic scheme employed in place of a more sophisticated DAA maneuvering algorithm.

The PI distribution was compared for the 2779 unmitigated and mitigated left oblique overtaking encounters, demonstrating the overall effectiveness of initiating a maneuver at 30 seconds before LoWC. Additionally, the success of both left and right turn mitigations using the HMD Rule confirmed that QROW in Subparagraph H.3.3.4 should not over-specify maneuvering direction for this geometry.

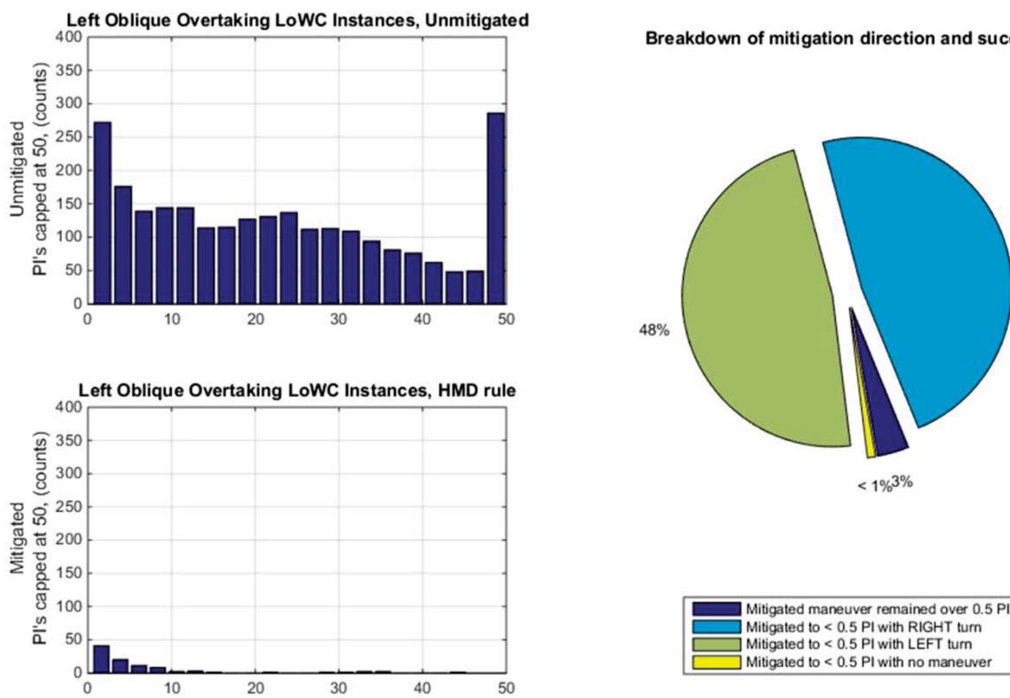


Figure H-33 **DAA Performance Metrics with QROW: Left Oblique Overtaking**

H.4.3.1.5 Comparison: Right Oblique Overtaking

For this oblique overtaking geometry, the UA was required to maneuver to maintain DWC. Since QROW in Subparagraph H.3.3.5 does not explicitly prescribe the direction of the required maneuver, the simulation was again configured to choose the maneuver direction based on the HMD Rule described earlier.

The PI distribution was compared for the 2819 unmitigated and mitigated right-oblique-overtaking encounters, demonstrating the overall effectiveness of initiating the avoidance maneuver at 30 seconds before LoWC. Again, the success of both left and right turns generated by the HMD Rule confirmed that QROW in Subparagraph H.3.3.5 should not over-specify maneuvering direction for this geometry.

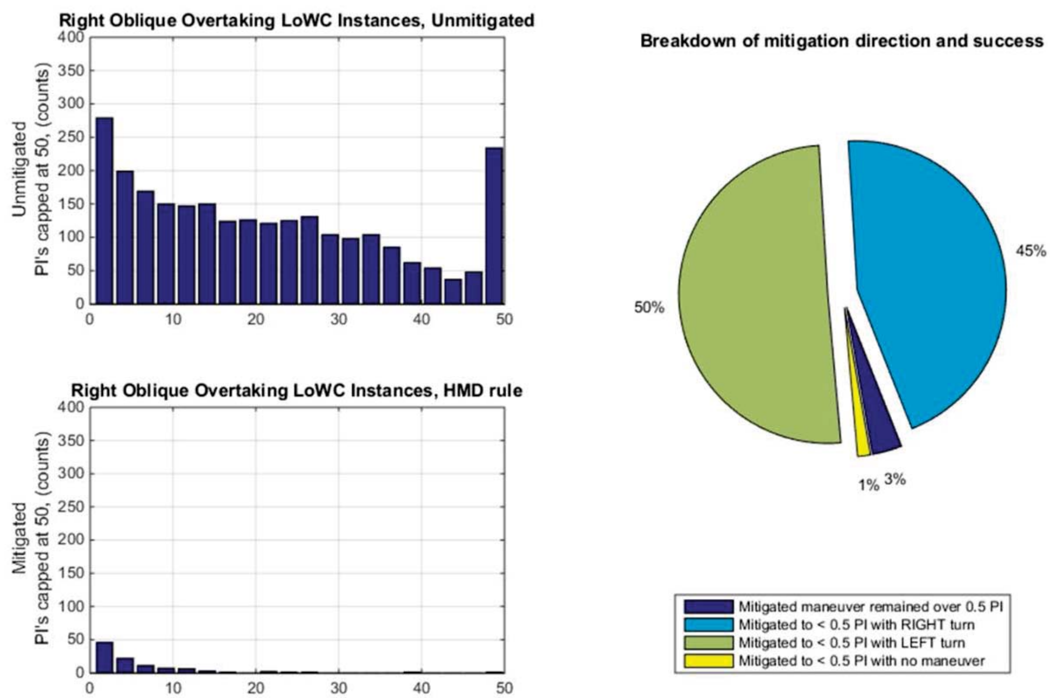


Figure H-34 DAA Performance Metrics with QROW: Right Oblique Overtaking

H.4.3.1.6 Comparison: Converging from Left

Since the UA has the ROW in this geometry, the UA model was configured to wait an additional 15 seconds to allow the intruder an opportunity to resolve the conflict. The UA model was configured to initiate its DAA maneuver at 15 seconds prior to LoWC in the simulation if the risk of a LoWC persisted. Since no specific maneuvering direction was prescribed for this geometry in the QROW in Subparagraph H.3.3.6 the UA model was configured to maneuver in four different directions – left, right, climb and descend – with the resultant PI values for all four options recorded for analysis.

As shown in Figure H-35 with 25601 encounters, asserting QROW and relying completely on the left-converging intruder to maintain well clear is utterly ineffective. This is a result of the DWC 35-second Modified Tau boundary extending well beyond the limitation of human visual acuity. Conversely, in most cases even with the UA delaying its maneuver, DWC can still be maintained with more than one maneuver direction option. Additionally, nearly 10% of the encounters required one specific maneuvering direction to maintain well clear. This confirms the QROW in Subparagraph H.3.3.6 should not over-specify maneuver direction for this geometry.

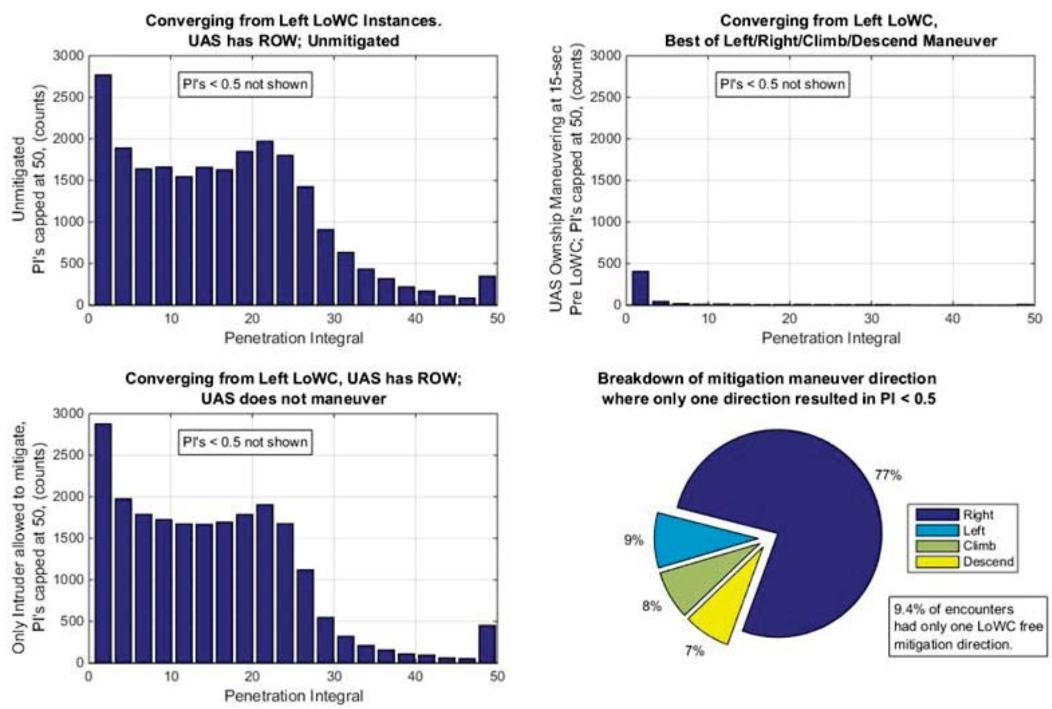


Figure H-35 **DAA Performance Metrics with QROW: Converging from Left**

QROW does not explicitly specify the maneuver direction for converging from left. M&S has revealed that viable maneuvering directions can vary significantly even within this converging geometry. Figure H-36 compares the number of viable maneuvers remaining 15 seconds prior to LoWC for converging geometries with intruders positioned between 0° and 60° bearing versus encounters with intruders positioned between 60° and 90° bearing. These statistics are further aggregated by the percentages of the direction of viable maneuvers. For this converging geometry, as the intruder's bearing angle increases, the number of viable maneuvers becomes more limited. Furthermore, having the UA turn left to maneuver behind the intruder becomes significantly less effective if the intruder is approaching from a bearing angle between 60° and 90°. This variation in the viable maneuver directions within this converging-from-left geometric classification confirms that QROW should not over-specify a maneuver direction for this geometry.

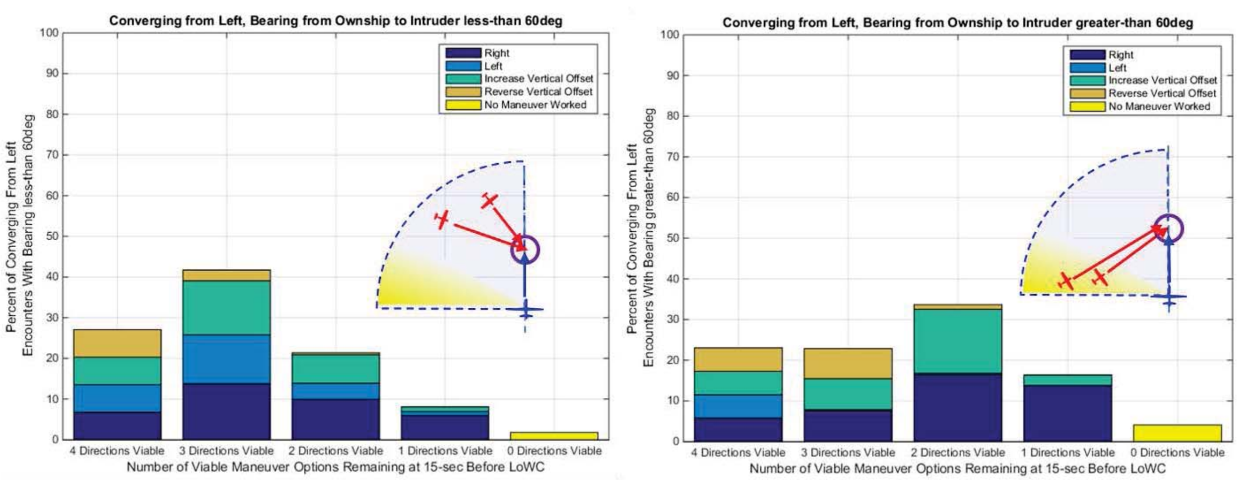


Figure H-36 **Number of Viable DAA Maneuvers for Converging from Left**

H.4.3.1.7 Comparison: Converging from Right

For encounters with an intruder converging from right, the UA does not have the right of way and must maneuver to maintain DWC. In the batch simulation, the UA was configured to initiate maneuvering at 30 seconds before LoWC. In place of a smart DAA maneuver algorithm, all four maneuvers – left, right, climb and descend – were evaluated in the simulation and their resultant PI values were individually recorded and compared. The best maneuver (lowest PI value) of the four possible directions was recorded as the mitigated performance for each of the 23,531 converging-from-right encounters tested.

As shown in Figure H-37, by comparing the unmitigated PI histogram against the PI histogram for the UA initiating its avoidance maneuver at 30 seconds before LoWC, the overall effectiveness in reducing DWC penetration is demonstrated for this geometry. Furthermore, the simulation results also indicate that multiple maneuver direction options are available to maintain DWC at 30 seconds before LoWC.

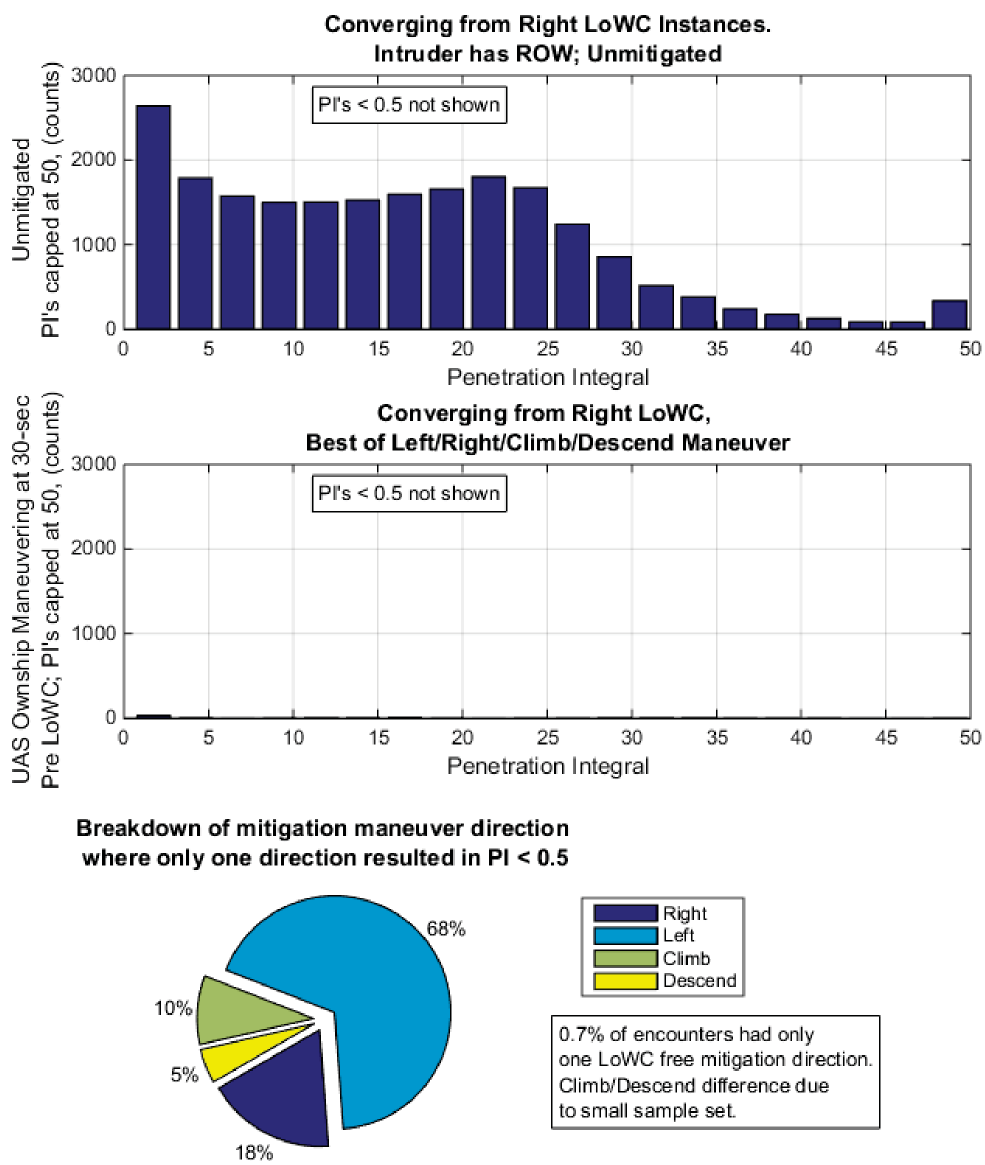


Figure H-37 **DAA Performance Metrics with QROW: Converging from Right**

Similar to some other geometric classifications, QROW does not explicitly specify the maneuver direction for converging from right. M&S has revealed viable maneuvering directions can vary significantly even within this converging geometry. Figure H-38 compares the number of viable maneuvers remaining 30 seconds prior to LoWC for converging geometries with intruders positioned at a less than 60° bearing versus encounters with intruders positioned between 60° to 90° bearing. These statistics are further aggregated by the percentages of the direction of viable maneuvers. For the converging geometry, as the intruder's bearing angle increases, the number of viable maneuvers becomes more limited. Furthermore, having the UA ownship turn right becomes significantly less feasible if the intruder is approaching from a bearing angle greater than 60°. This variability in the viable maneuver directions within this converging-from-right geometric classification validates that QROW should not over-specify maneuver direction for this geometry.

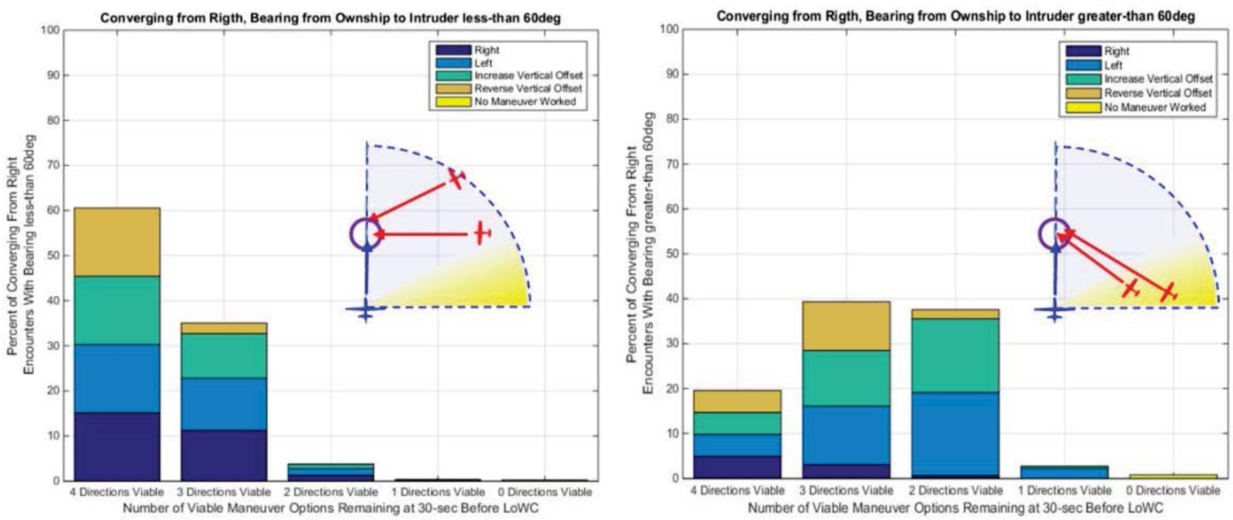


Figure H-38 **Number of Viable DAA Maneuvers for Converging from Right**

H.4.3.2 Lessons Learned

In this subparagraph, issues encountered during the ROW M&S validation activities are discussed.

H.4.3.2.1 Stressing Geometry for Converging from Right

M&S activities revealed certain conditions, such as a fast and maneuvering intruder or limited UA maneuverability, can reduce the UA's effectiveness to maintain DWC. More specifically, converging geometries with intruders approaching from bearing angles of 60° to 90° relative to the UA present a particular challenge. These conditions can render a horizontal DAA maneuver by the UA ineffective, as illustrated in Figure H-39. In this QROW classification in which the intruder is converging from the right, the UA does not have the ROW and must maneuver to maintain DWC.

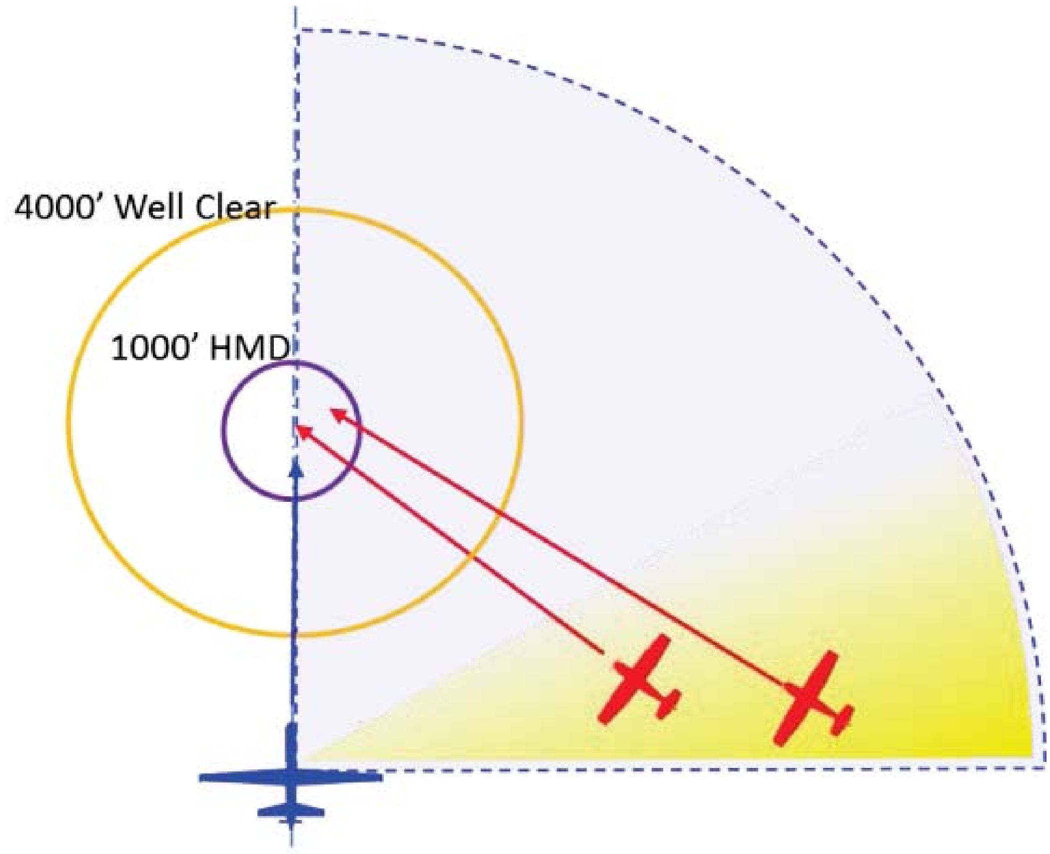


Figure H-39 **Stressing Geometry – Converging from Right**

Considering the two horizontal turning options, having the UA ownship turn right becomes increasingly ineffective in maintaining DWC if the intruder is converging from the 60° to 90° bearing range, as indicated by the elevated average PI value shown in Figure H-40. Conversely, having the UA ownship turn left in these geometries may initially appear to maintain DWC, but the resultant trajectories can become protracted if the intruder and the UA ownship are flying at comparable speeds. The SC-228 ROW subgroup recommends that alternate maneuvers such as speed change and/or vertical profile adjustments be considered to maintain DWC for such stressing geometries.

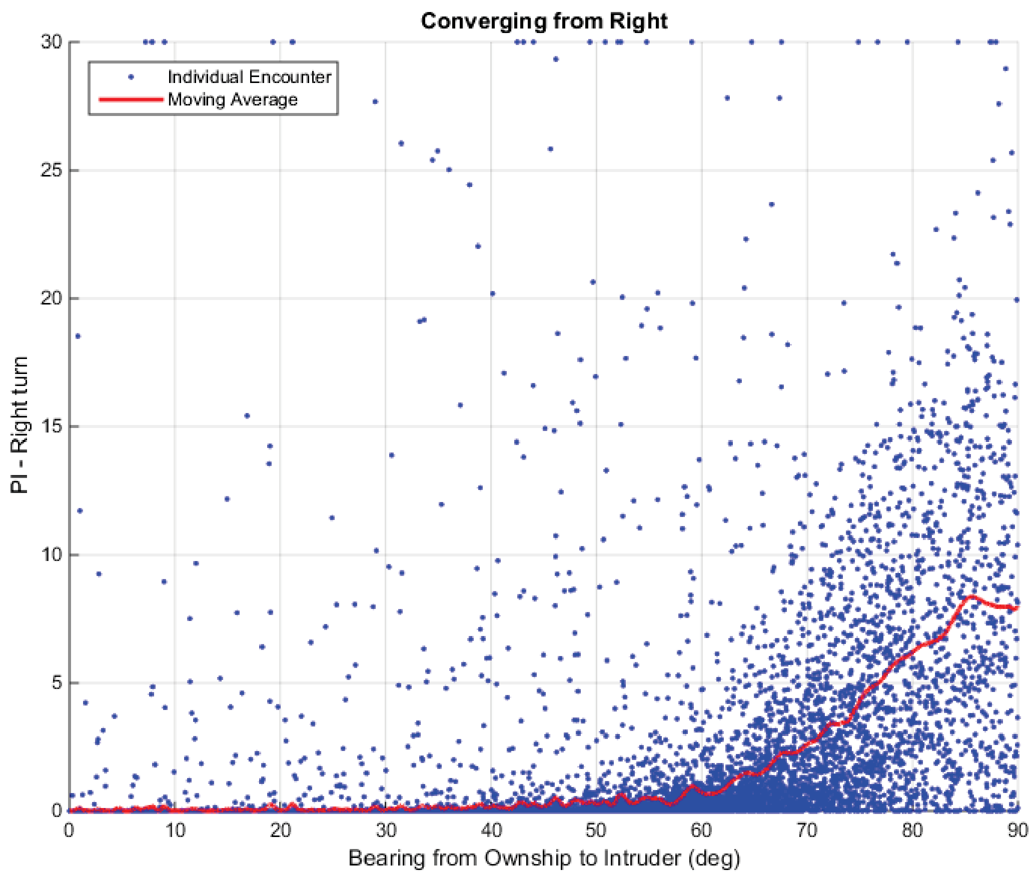


Figure H-40 **PI for Right Turn Maneuver vs. Intruder Location**

H.4.3.2.2 Delaying Ownship Maneuvering for Converging from Left

For the converging-from-left geometry, QROW asserts the UA as ROW-consistent with Code of Federal Regulations Title 14, §91.113, Part 91. The intent was for the UA to remain "stable and predictable," so that the intruder can more effectively maneuver to maintain well clear. QROW further allows the UA to maneuver if the risk of LoWC persists by the DAA Warning Alert.

M&S activities for encounters within this converging-from-left category revealed that the likelihood of the VFR intruder starting its maneuver by 15 seconds before LoWC is not very high depending on the intruder's approach angle. If the intruder is located in a 60° to 90° bearing range, there is a greater probability that it will have started its maneuvering, as indicated by the elevated average Delta-HMD in Figure H-41. Conversely, the probability of intruders converging from the 0° to 50° bearing range to have generated any significant maneuvering to reduce the projected HMD is effectively nil. These observations are a direct consequence of the timeline for the VFR intruder pilots to visually acquire the UA ownship. Intruders converging from the 60° to 90° bearing range will likely have slower closure rates than intruders converging from the 0° to 50° bearing range. Consequently intruders converging from the high-bearing region will likely be closer to the UA ownship and have a greater probability to have initiated their maneuvering to maintain separation.

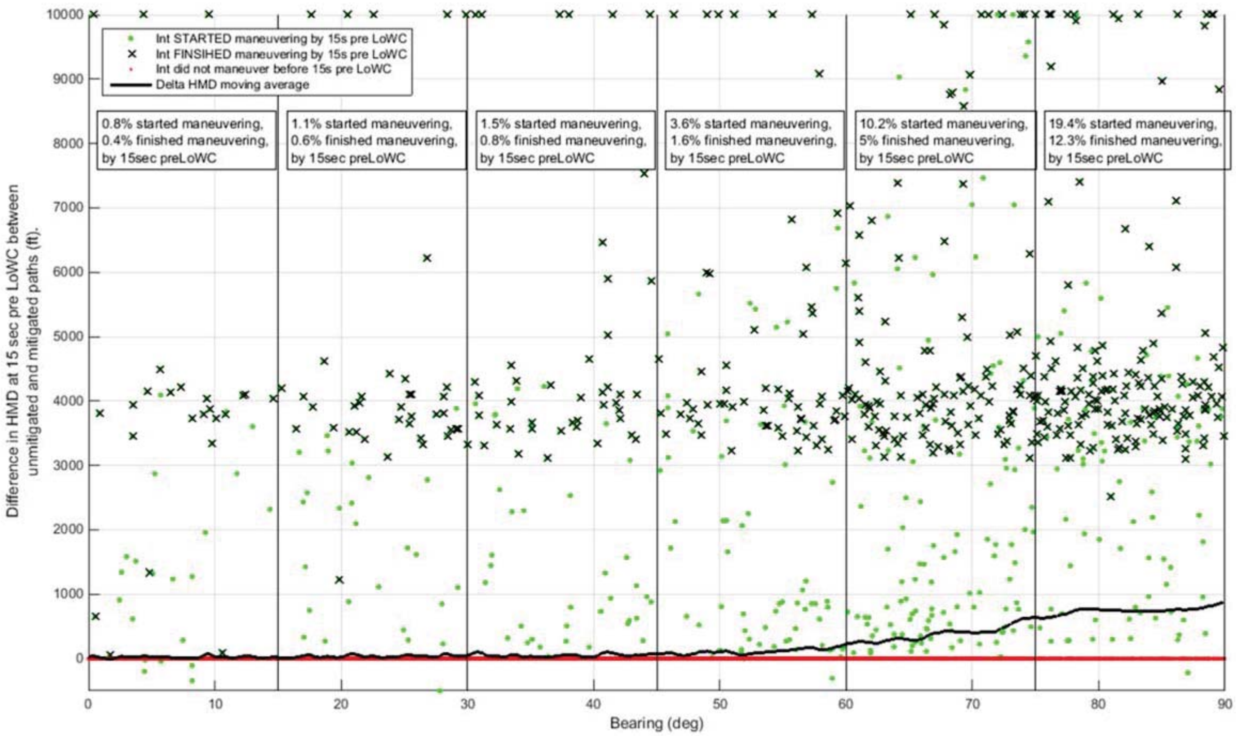


Figure H-41 **HMD and Maneuver Likelihood at 15 seconds before LoWC**

More importantly, for encounters where the VFR intruder is converging from the 0° to 50° bearing range, requiring the UA to "remain stable and predictable" is statistically ineffective in maintaining DWC due to the limitation of the intruder's visual acuity. If safety statistics require greater overall DAA system performance to maintain DWC, perhaps modification of QROW should be considered to allow the UA to maneuver at an earlier timeline for VFR intruders converging from a left 0° to 50° bearing range even if the ownship has ROW.

H.5 Check Cases

In order to assist the reader, numerical snapshot check cases are presented for each horizontally ambiguous classification at 30 seconds prior to LoWC. Cases presented are in the heart of the classification region; future releases may include additional check cases near classification boundaries as well as unambiguous cases.

H.5.1 Check Case: Head-On

Table H-5 **Check Case: Head-on**

Parameter	Ownship	Intruder
Heading (degrees)	0	180
Speed (knots)	150	150
East Position (feet)	0	0
North Position (feet)	-16962	16963
Altitude (feet)	2000	2000
Vertical Velocity (feet per second (fps))	0	0

H.5.2 Check Case: Overtaken

Table H-6 Check Case: Overtaken

Parameter	Ownship	Intruder
Heading (degrees)	0	0
Speed (knots)	150	200
East Position (feet)	0	0
North Position (feet)	-21265	-28355
Altitude (feet)	2000	2000
Vertical Velocity (fps)	0	0

H.5.3 Check Case: Overtaking

Table H-7 Check Case: Overtaking

Parameter	Ownship	Intruder
Heading (degrees)	0	0
Speed (knots)	200	150
East Position (feet)	0	0
North Position (feet)	-25062	-33418
Altitude (feet)	2000	2000
Vertical Velocity (fps)	0	0

H.5.4 Check Case: Left Oblique Overtaking

Table H-8 Check Case: Left Oblique Overtaking

Parameter	Ownship	Intruder
Heading (degrees)	0	45
Speed (knots)	200	150
East Position (feet)	0	-12888
North Position (feet)	-24304	-12888
Altitude (feet)	2000	2000
Vertical Velocity (fps)	0	0

H.5.5 Check Case: Right Oblique Overtaking

Table H-9 **Check Case: Right Oblique Overtaking**

Parameter	Ownship	Intruder
Heading (degrees)	0	315
Speed (knots)	200	150
East Position (feet)	0	12888
North Position (feet)	-24304	-12888
Altitude (feet)	2000	2000
Vertical Velocity (fps)	0	0

H.5.6 Check Case: Converging from Left

Table H-10 **Check Case: Converging from Left**

Parameter	Ownship	Intruder
Heading (degrees)	0	135
Speed (knots)	150	150
East Position (feet)	0	-11994
North Position (feet)	-16962	11994
Altitude (feet)	2000	2000
Vertical Velocity (fps)	0	0

H.5.7 Check Case: Converging from Right

Table H-11 **Check Case: Converging from Right**

Parameter	Ownship	Intruder
Heading (degrees)	0	225
Speed (knots)	150	150
East Position (feet)	0	11994
North Position (feet)	-16962	11994
Altitude (feet)	2000	2000
Vertical Velocity (fps)	0	0

I APPENDIX I TCAS GUIDANCE MATERIAL

I.1 Introduction

This appendix contains guidance material related to Traffic Alert and Collision Avoidance Systems (TCAS) on Unmanned Aircraft Systems (UAS) platforms. Information is provided for TCAS antenna installation and performance criteria as well as for the effect of the Interference Limiting (IL) response on the detection range of active surveillance.

I.2 Antenna Installation Guidance

A complete analysis of the parameters affecting installed antenna performance must consider the effects of reduced ground plane size, variations in fuselage radii of curvature, reflections and obstructions due to aircraft features, as well as effects of the conductivity of various composite fuselage materials. In addition it must be generic enough to apply to all antenna design architectures (i.e., phase monopulse, amplitude monopulse, sum and difference, etc.).

Consistent with Section 1 of this document, the Phase 1 Minimum Operational Performance Standards (MOPS) necessarily limits the application of a Phase 1 Detect and Avoid (DAA) system to large UAS due to the weight of the expected payload. It is acknowledged that even on larger UAS there may be unique challenges with TCAS installations due to the factors listed above. However, these challenges are not unlike those faced in typical TCAS installations already, so it is appropriate to apply the installed antenna performance criteria that already exist in the TCAS MOPS, RTCA Document 185B (DO-185B) and associated advisory circulars, which are incorporated by reference.

A note in RTCA DO-185B Subparagraph 3.4.3.1 provides guidance for TCAS antenna mounting locations to optimize the likelihood of installed performance success.

RTCA DO-260B Subsection 3.3 provides guidance for the Automatic Dependent Surveillance-Broadcast (ADS-B) antenna installation and performance of installed antenna testing. Paragraph 3.3.3 instructs the installer to mount the antennas near the center line of the fuselage and near the forward part of the fuselage to minimize reflections from the vertical stabilizer and engine nacelles. Subparagraph 3.3.3.1 describes requirements for minimum spacing between antennas.

Additional TCAS and transponder antenna installation guidance is provided in Advisory Circular (AC) 20-151B §2-8a. This AC describes how to obtain airworthiness approval of TCAS and transponder systems.

A full discussion of TCAS antenna installation guidance on small UAS is planned in this appendix concurrent with the Phase 2 DAA MOPS. For the Phase 2 DAA MOPS, it will be necessary to perform studies considering the tradeoffs and limitations for all of the variables identified. This is necessary to address the issues peculiar to smaller UAS that would not have the capability to host a Phase 1 system supporting a four-sector antenna.

I.3 Antenna Installed Performance

For the TCAS function, Paragraph 3.4.3 of RTCA DO-185B addresses the installed antenna gain performance. It emphasizes maintaining adequate performance quality in the forward ±45-degree (deg) sector. Acceptable performance is defined in Subparagraph 3.4.3.1 where the success criteria for the antenna gain in the forward

±45-degree sector is defined to be less than a 1-Decibel (dB) reduction in antenna gain as compared to the performance on the four-foot ground plane. In the remaining 270 degrees of coverage, a gain degradation of up to 3 dB is considered acceptable.

Similarly, Paragraph 3.4.5 of RTCA DO-185B provides test methods for bearing estimation of installed systems. In this section, the objective is to identify all azimuthal locations where the bearing error persistently exceeds 30 degrees. Thus the success criterion is a bearing error less than 30 degrees.

For the ADS-B function, Paragraph 3.3.4 of RTCA DO-260B defines acceptable installed antenna gain to be less than a 1 dB reduction from the gain when measured on the four-foot ground plane in the forward ±45-degree sector and no more than 3 dB reduction in the remaining 270 degrees of coverage. These specifications match exactly with the installed antenna specifications in the TCAS MOPS. Since traditional ADS-B receivers generally use omnidirectional antennas, there is no requirement for bearing testing.

I.4 Interference Limiting

Surveillance of transponder equipped aircraft contained in the DAA MOPS is derived from the TCAS active surveillance requirements in RTCA DO-185B. Interrogation power and rates are consistent with TCAS active surveillance and include any reduction from operation of the IL function. Interference Limiting is a method used by TCAS interrogators to control electromagnetic interference to Air Traffic Control (ATC) by limiting interrogation rates and powers. High interrogation rates act to increase transponder occupancy thereby reducing its ability to respond to interrogations from ground-based ATC interrogators. The limits on interrogation rate and power are functions of such variables as the Number of TCAS II Airborne interrogators (NTA) in the vicinity and their respective ranges, the use of hybrid surveillance, and the distribution of Air Traffic Control Radar Beacon System (ATCRBS) and Mode S traffic. RTCA DO-185B Subparagraph 2.2.3.6 contains a detailed explanation of the Interference Limiting function.

In general, TCAS operation is unaffected by interference limiting until the NTA count exceeds approximately 30 aircraft. As the NTA count continues to increase, the interrogation power is reduced in 1-dB steps until it reaches the maximum attenuation (10 dB for Mode S interrogations and 7 dB for Mode C interrogations). The effect of this increase in attenuation is a reduction in interrogation range. Figure I-1 shows how interrogation range is reduced as attenuation is increased.

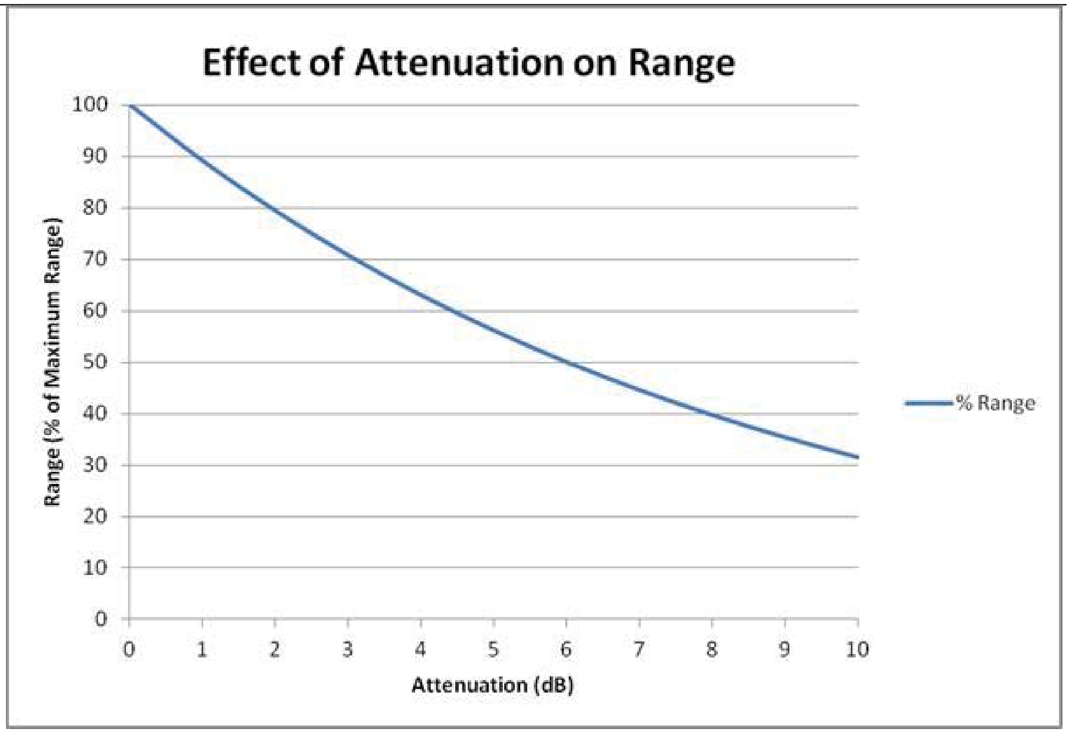


Figure I-1 Interrogation Range Reduction as a Function of Attenuation

Not only is the maximum attenuation due to IL different for ATCRBS and Mode S traffic, the power levels transmitted during the standard TCAS interrogations are also different depending on the type of traffic. For ATCRBS interrogations using Whisper-Shout techniques, the transmitted power level is also dependent on the quadrant into which the interrogation is directed. Table I-1 shows a typical interrogation range reduction for ATCRBS and Mode S traffic with various levels of Interference Limiting applied. The range depicted in the first row with no Interference Limiting represents the 90% detection range from RTCA DO-185B based on the surveillance performance achieved by meeting MOPS requirements under the traffic densities, 1090 Megahertz (MHz) interference environment, interrogation technique, antenna and Radio Frequency (RF) link budget assumptions. The ranges for Moderate, High and Maximum (Max) Interference Limiting are derived from applying the applicable reduction of interrogation power and receiver sensitivity from the baseline.

Table I-1 90% Detection Range as a Function of Interference Limiting

Interference Limiting Level	Range (NM) Mode S	Range (NM) ATCRBS Front (0 ±45 deg)	Range (NM) ATCRBS Sides (-135 to -45 deg, +45 to +135 deg)	Range (NM) ATCRBS Rear (180 ±45 deg)
No IL	30	15	9.5	5.3
Moderate IL	18.9	13.4	8.5	4.7
High IL	13.4	9.5	6	3.3
Max IL	9.5	6.7	4.2	2.4

The surveillance ranges based on RTCA DO-185B assumptions have shown to be conservative as actual operation of TCAS surveillance achieves much greater ranges. An analysis was performed to derive a realistic estimate of the surveillance range, both for Mode S and Mode C. The analysis assumed worst case Mode S and ATCRBS transponder receiver sensitivities according to the applicable standards, a 1090 MHz interference environment based on operation in high density, realistic application of Mode C Interference Limiting reduction by quadrant and conservative reply decoding assumptions. The model took into account the multiple opportunities available each update interval to receive a reply. The Whisper-Shout interrogation sequence used for Mode C tracking provides 2.5 replies per update interval. Since Mode S operates with discrete interrogations to individual aircraft, it was assumed that there are 5 opportunities per update interval. The model was validated using empirical data and compared to a separate ADS-B model for consistency. Using the model to compute the single message probability of decode, the probability of update versus range was determined. The resulting 90% detection range is shown in Table I-2.

Table I-2 Adjusted 90% Detection Range as a Function of Interference Limiting

Interference Limiting Level	Range (NM) Mode S	Range (NM) ATCRBS Front (0 ±45 deg)	Range (NM) ATCRBS Sides (-135 to -45 deg, +45 to +135 deg)	Range (NM) ATCRBS Rear (180 ±45 deg)
No IL	30	25.7	22.3	14.6
Moderate IL	24.9	23.4	19.3	11.3
High IL	20.4	20.6	14.3	8.0
Max IL	15.1	14.6	9.3	5.3

Based on the adjusted surveillance range per Table I-2, an analysis was performed to determine if the ranges provided by TCAS active surveillance provided sufficient performance for DAA alerting. Active surveillance serves two primary purposes in DAA. It is used to validate ADS-B data and is also the sole surveillance data source of aircraft equipped with a transponder but not ADS-B Out and additionally are outside of radar coverage.

A set of scenarios were considered to determine the ability of the DAA system to have surveillance data to support alerting in sufficient time to meet the minimum alert time requirements in the MOPS. The altitude range of interest where IL may have an impact is 10,000-18,000', in which higher closure rates need to be examined. First, Mode S surveillance range was examined. Maximum IL provides a surveillance range of 15 Nautical Miles (NM), so if a head-on encounter is considered at 800 knots (kts) closure with the ownship at 200 kts and the intruder at 600 kts, modified tau is roughly 68 seconds. This shows that the average alert time for a warning alert is supported. Average alert time for preventive/corrective alerting is not supported.

Mode C surveillance range needs to be considered in the forward, side and rear directions. Mode C was considered at slower closure rates since aircraft equipped with ATCRBS transponders are typically less capable in maximum altitude and airspeed. A 450-kt closure rate with the ownship at 200 kts head-on and the intruder at 250 kts was examined. Ownship speed was set to 40 kts to adjust closure rate for the rear to capture worst case in that direction. From Table I-2, the forward direction surveillance range when at maximum IL is 14.6 NM. A modified tau of 118 seconds is supported at that range. Similarly, the surveillance range in the sides at the maximum IL range of 9.3 NM from Table I-2 provides a modified tau of 98 seconds. The rear direction supports a modified tau of 88 seconds. For this closure rate case, the front, sides and rear directions all provide adequate surveillance range for preventive, corrective and warning alerts.

Additionally, a higher closure rate of 650 kts was examined for Mode C to consider the older Citation aircraft which may be equipped with an ATCRBS transponder and are capable of airspeeds to 450 kts. The results when under maximum IL are depicted in Table I-3.

Table I-3 Supported Alert Times at Maximum IL

Head-On Closure Rate (kts)	Alert Time (seconds) Mode S	Alert Time (seconds) ATCRBS Front (0 ±45 deg)	Alert Time (seconds) ATCRBS Sides (-135 to -45 deg, +45 to +135 deg)	Alert Time (seconds) ATCRBS Rear (180 ±45 deg)
800	68	-	-	-
450	121	118	98	88
650	84	80	59	45

Since maximum IL only occurs in limited high density areas within the busiest and densest terminal airspace environments, alert times when in high IL conditions is also provided as shown in Table I-4.

Table I-4 Supported Alert Times in High IL Conditions

Head-On Closure Rate (kts)	Alert Time (seconds) Mode S	Alert Time (seconds) ATCRBS Front (0 ±45 deg)	Alert Time (seconds) ATCRBS Sides (-135 to -45 deg, +45 to +135 deg)	Alert Time (seconds) ATCRBS Rear (180 ±45 deg)
800	92	-	-	-
450	163	165	148	131
650	113	114	90	69

This Page Intentionally Left Blank

J APPENDIX J GROUND ENVIRONMENT TEST CONDITIONS

This appendix addresses optional environmental ranges and can be used in lieu of the ranges specified in RTCA DO-160 and Military Standard (MIL STD) 810G. These test procedures set forth below are not complete and are only for those specified in Table 2-27. Use of these ranges is considered satisfactory for use in determining equipment performance under environmental conditions as described.

Although specific test procedures are cited, it is recognized that other methods may be preferred. These alternative procedures may be used if the manufacturer can show that they provide at least equivalent information. In such cases, the procedures cited herein should be used as one criterion in evaluating the acceptability of the alternative procedures. Unless otherwise specified, the pass/fail criteria are those specified in the test procedures in Subsection 2.4. When using special purpose test software, the applicant must establish pass/fail criteria consistent with Subsection 2.4.

J.1 Section 4 – Temperature (Temp.) and Altitude

The equipment must be tested to environmental categories appropriate to the location. Additional categories beyond RTCA DO-160 may be used. Those categories are defined in Table J-1. Column headings A1 through F4 refer to the environmental locations as specified in Table 2-29.

1. Ground Survival Low Temperature Test (RTCA DO-160G, Figure 4-1): The Short-Time Operating Low Temperature (T) is the same as the Operating Low Temperature and is set per Table J-1.
2. Ground Survival Low Temperature Test: Note 1 – T0 to T1: The cool-down temperature rate is chosen to prevent thermal shock damage.
3. Ground Survival Low Temperature Test (RTCA DO-160G, Figure 4-1): Note 5 – T4 to T5: The interval is set to a minimum of 16 hours.
4. Operating Low Temperature Test (RTCA DO-160G, Figure 4-2): Note 1 – T0 to T1: The cool-down temperature rate is chosen to prevent thermal shock damage.
5. Operating Low Temperature Test (RTCA DO-160G, Figure 4-2): Note 3 – T2 to T3: The interval is set to a minimum of 16 hours.
6. Operating Low Temperature Test (RTCA DO-160G, Figure 4-2): Not required if the Ground Survival Low Temperature Test (RTCA DO-160G, Figure 4-1) is performed.
7. Ground Survival High Temperature Test (RTCA DO-160G, Figure 4-3): The Short-Time Operating High Temperature is the same as the Operating High Temperature and is set to the lower of the test temperatures if the equipment is protected against solar and heat radiation or the equipment is ventilated (natural or forced) else it is set to higher value.
8. Ground Survival High Temperature Test (RTCA DO-160G, Figure 4-3): Note 1 – T0 to T1: The warm-up temperature rate is chosen to prevent thermal shock damage.
9. Ground Survival High Temperature Test (RTCA DO-160G, Figure 4-3): Note 5 – T4 to T5: The interval is set to a minimum of 16 hours.
10. Operating High Temperature Test (RTCA DO-160G, Figure 4-4): Note 1 – T0 to T1: The warm-up temperature rate is chosen to prevent thermal shock damage.

11. Operating High Temperature Test (RTCA DO-160G, Figure 4-4): Note 3 – T2 to T3: The interval is set to a minimum of 16 hours.
12. Operating High Temperature Test (RTCA DO-160G, Figure 4-4): Not required if the Ground Survival High Temperature Test (Figure 4-3) is performed.
13. In-Flight Loss of Cooling Test (RTCA DO-160G, Figure 4-5): Not Required
14. Altitude Test (RTCA DO-160G, Figure 4-6): This test is conducted at pressures of 70 Kilopascals (kPa) (8500 feet/2589 meters (m)) and 106 kPa (-1036 feet/-316 m).
15. Decompression Test (RTCA DO-160G, Figure 4-7): Not Required
16. Overpressure Test (RTCA DO-160G, Figure 4-8): Not Required

Table J-1 **Temperature Test Criteria**

Category	A1	A2	B1	B2	B3	C1	D1
Operating Low Temp. (°Celsius (C))	-5	+15	-55/-45 Note 1	-75/-65 Note 1	-30/-20 Note 1	-10	-25
Ground Survival Low Temp. (°C)	-40	0	-55	-75	-40	-40	-40
Operating High Temp. (°C)	+45/+55 Note 1	+30/+40 Note 1	+45/+60 Note 1	+35/+50 Note 1	+55/+70 Note 1	+40	+40/+55 Note 1, 2
Ground Survival High Temp. (°C)	+70	+70	+85	+70	+85	+70	+85 Note 2
Operating High Temp. (°C)							+70/+85 Note 1, 3
Ground Survival High Temp. (°C)							+100 Note 3

Category	D2	E1	E2	F1	F2	F3	F4
Operating Low Temp. (°C)	-40	+5	-40	+5	-5	-25	-40
Ground Survival Low Temp. (°C)	-55	0	-55	0	-40	-40	-55
Operating High Temp (°C)	+40/+55 Note 1, 2	+40	+70/+85 Note 1	+40/+50 Note 1	+45/+55 Note 1	+70/+85 Note 1	+70/+85 Note 1
Ground Survival High Temp. (°C)	+85 Note 2	+70	+100	+70	+70	+100	+100
Operating High Temp. (°C)	+70/+85 Note 1, 3						
Ground Survival High Temp. (°C)	+100 Note 3						

Note:

1. *The lower of the test temperatures applies if the equipment is protected against solar radiation.*
2. *Ventilated or not engine compartment*
3. *Unventilated or engine compartment*

J.2 Section 5 – Temperature Variation

Additional categories beyond RTCA DO-160 may be used. Those categories are defined in Table J-2. Column headings A1 through F4 refer to the environmental locations as specified in Table 2-29.

1. Temperature Variation Test (RTCA DO-160G, Figure 5-1): The High Operational Temperature is set per Table J-2.
2. Temperature Variation Test (RTCA DO-160G, Figure 5-1): The Low Operational Temperature is set per Table J-2.
3. High and Low Operational Temperature exposure durations are 3 hours each, minimum.

Table J-2 Temperature Variation Test Parameters

Category	A1	A2	B1	B2	B3	C1	D1
Operating Low Temp. (°C)	-5	+15	-55/-45 Note 1	-75/-65 Note 1	-30/-20 Note 1	-10	-25
Operating High Temp. (°C)	+45/+55 Note 1	+30/+40 Note 1	+45/+60 Note 1	+35/+50 Note 1	+55/+70 Note 1	+40	+40/+55 Note 1, 2
Change (°C/minute (min))	0.5	0.5	0.5	0.5	0.5	5	5 Note 2
Operating High Temp. (°C)							+70/+85 Note 1, 3
Change (°C/min)							5 Note 3
Duration	1 Cycle	1 Cycle	2 Cycles	2 Cycles	2 Cycles	2 Cycles	5 Cycles

Category	D2	E1	E2	F1	F2	F3	F4
Operating Low Temp. (°C)	-40	+5	-40	+5	-5	-25	-40
Operating High Temp. (°C)	+40/+55 Note 1, 2	+40	+70/+85 Note 1	+40/+50 Note 1	+45/+55 Note 1	+70/+85 Note 1	+70/+85 Note 1
Change (°C/min)	5 Note 2	N/A	3	0.5	0.5	0.5	0.5
Operating High Temp. (°C)	+70/+85 Note 1, 3						
Change (°C/min)	10 Note 3						
Duration	5 Cycles	N/A	5 Cycles	3 Cycles	3 Cycles	3 Cycles	3 Cycles

Note:

1. *The lower of the test temperatures applies if the equipment is protected against solar radiation.*
2. *Ventilated or not engine compartment*
3. *Unventilated or engine compartment*

J.3 Section 6 – Humidity

Additional categories beyond RTCA DO-160 may be used. Those categories are defined in Table J-3. Column headings A1 through F4 refer to the environmental locations as specified in Table 2-29.

RTCA DO-160G, Paragraph 6.3.1, Step 6: "Repeat these steps until the specified number of cycles (24 hours each) have been completed."

Table J-3 Humidity Test Parameters

Category	A1	A2	B1	B2	B3	C1	D1
Relative Humidity (%) (High) (°C)	93 +30	85 +30	93 +30	93 +30	93 +40	93 +30	93 +40
Duration (Cycles)	4	4	10	10	10	21	4
Relative Humidity (%) (Condensation) (°C)			90-100 +30	90-100 +30	90-100 +30	90-100 +40	
Duration (Cycles)			2	2	2	2	
Relative Humidity (%) (Rapid Temp. Change) (°C)							90-100 +40 Note 1
Relative Humidity (%) (Rapid Temp. Change) (°C)							90-100 +55 Note 2
Duration (Cycles)							2

Category	D2	E1	E2	F1	F2	F3	F4
Relative Humidity (%) (°C)	93 +40	93 +30	93 +40	93 +30	93 +30	93 +40	93 +40
Duration (Cycles)	4	4	21	4	4	4	21
Relative Humidity (%) (Condensation) (°C)				90-100 +30	90-100 +30	90-100 +40	90-100 +40
Duration (Cycles)				2	2	2	6
Relative Humidity (%) (Rapid Temp. Change) (°C)	90-100 +40 Note 1						
Relative Humidity (%) (Rapid Temp. Change) (°C)	90-100 +55 Note 2						
Duration (Cycles)	2						
Absolute Humidity (High)(%) (Rapid Temp. Change) (°C)			90-100 +55				
Duration (Cycles)			6				

Note:

1. *Not near refrigerated air conditioning*
2. *Near refrigerated air conditioning*

J.4 Section 7 – Operational and Crash-Safety Shocks

Additional categories beyond RTCA DO-160 may be used. Those categories are defined in Table J-4. Column headings A1 through F4 refer to the environmental locations as specified in Table 2-29.

1. Test Procedure (RTCA DO-160G, Paragraph 7.2.1/7.2.2): The acceleration peak value in meters per second squared (m/s^2) is per Table 7 of RTCA DO-160G in each orientation/direction.
2. Crash safety testing (RTCA DO-160G, Paragraph 7.3(.x)): Not Required
3. Drop and Topple and Free Fall tests may be performed per MIL-STD-810.

Table J-4 Operational Shocks Test Parameters

Category		A1	A2	B1	B2	B3	C1	D1
Spectrum		Half Sine	Half Sine	Half Sine	Half Sine	Half Sine	Half Sine	Half Sine
Mass	Kilograms (kg)							
Acceleration (Shocks)	(m/s^2) The acceleration of gravity (g).	30 3	30 3	30 3	30 3	30 3	30 3	1000 100
Duration	(ms)	11	11	11	11	11	11	6
Number of Shocks (Each Direction)		3	3	3	3	3	3	3
Direction of Shocks		6	6	6	6	6	6	6
Mass	(kg)							
Acceleration (Bump)	(m/s^2) (g)							100 10
Duration	(ms)							11
Number of Bumps (Each Direction)								100
Direction of Bumps								6

Category		D2	E1	E2	F1	F2	F3	F4
Spectrum		Half Sine	Half Sine	Half Sine	Half Sine			
Mass	(kg)		≥100	≥100				
Acceleration (Shocks)	(m/s^2) (g)	1000 100	300 30	300 30	1000 100			
Duration	(ms)	6	6	6	6			
Number of Shocks (Each Direction)		3	3	3	3			
Direction of Shocks		6	6	6	6			
Mass	(kg)		< 100	< 100				
Acceleration (Bump)	(m/s^2) (g)	100 10	300 30	400 40	250 25			
Duration	(ms)	11	6	6	6			

Category	D2	E1	E2	F1	F2	F3	F4
Number of Bumps (each direction)	100	100	100	100			
Direction of Bumps	6	6	6	6			
Free Fall							
Height (m)				1.0	0.5		0.25
Mass (kg)				≤ 1	≤ 10		≤ 50
Number of Falls/Direction				2			
Number of Directions				6			
Drop and Topple							
Height (m)				0.1			
Number of Drops/Direction				1			
Number of Drop Directions (Bottom Edges and Corners)				4 Edges + 4 Corners			

J.5 Section 8 – Vibration

Additional categories beyond RTCA DO-160 may be used. Those categories are defined in Table J-5. Column headings A1 through F4 refer to the environmental locations as specified in Table 2-29.

Table J-5 Vibration Test Parameters

Category	A1	A2	B1	B2	B3	C1	D1
Spectrum			Sinusoidal				
Displacement Millimeters(mm)			1.2				
Acceleration (m/s^2) (g)			4 0.4				
Frequency Range Hertz (Hz).			5-9			9-200	
Axes of Vibration			3				
Duration (Sweep Cycles)			3 x 5				
Spectrum			Random				
Acceleration Spectral Density (ASD) (m^2/s^3) (Decibels per/ Octave (dB/Oct)			0.04 +12			-12	2 -3
Frequency Range (Hz)			5-10	10-50		50-100	5-20 20-500
Axes of Vibration			3				3
Duration (Minutes)			3 x 30				3 x 30

Category	D2	E1	E2	F1	F2	F3	F4
Spectrum		Sinusoidal					
Displacement (mm)		1.5					
Acceleration (m/s^2) (g)		19.6 2	49 4.9				
Frequency Range (Hz)		5-18 18-20	5-28 28-150				
Axes of Vibration		3	3				
Duration (Sweep Cycles)		3 x 10	3 x 10				
Spectrum	Random		Random	Random			
ASD (m^2/s^3) (dB/Octave)	2 -3		19.2 -3	2 -3			
Frequency Range (Hz)	5-20 20-500		5-28 28-150	10-12 12-150			
Axes of Vibration	3		3	3			
Duration (Minutes)	3 x 30		3 x 30	3 x 30			

If earthquake conditions are specified, then compliance with the vibration requirement can be verified using MIL-STD-810G, Method 514.6. Alternatively, the RTCA DO-160G §8 Category U2 random vibration test procedure can be used with the following considerations:

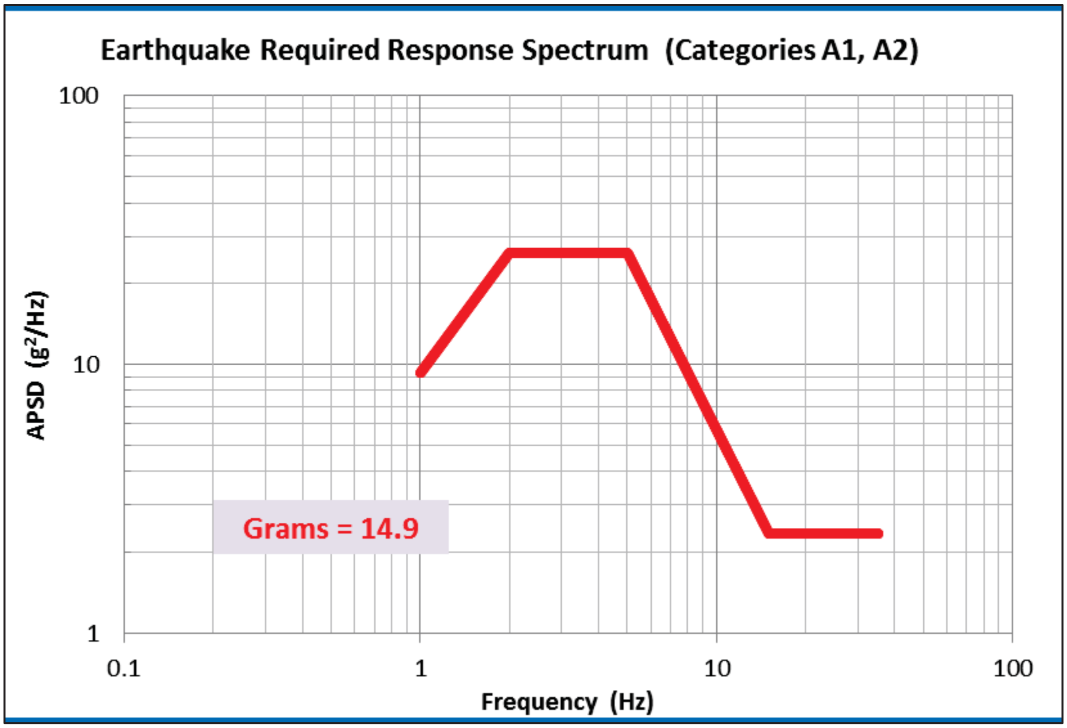
1. The analyzer characteristics are adjusted to accommodate the lower frequency range and higher amplitudes of the Required Response Spectrum (RRS) defined in Table J-6 and Figure J-1.
2. Table J-6 and Figure J-1 amplitudes may be reduced if the article under test is designed for regions expecting less than Richter scale 7 ground accelerations.
3. Perform the Random Test Procedure for Category U2 (RTCA DO-160G, Paragraph 8.8.3) modified as:
4. In each of the equipment's three orthogonal axes, perform the following tests using the test curve and test level of Table J-6 and Figure J-1.
    a. With the equipment operating, apply the test Acceleration Power Spectral Density (APSD) for the duration necessary (minimum of 5 minutes) to determine compliance with applicable equipment performance standards during vibration.

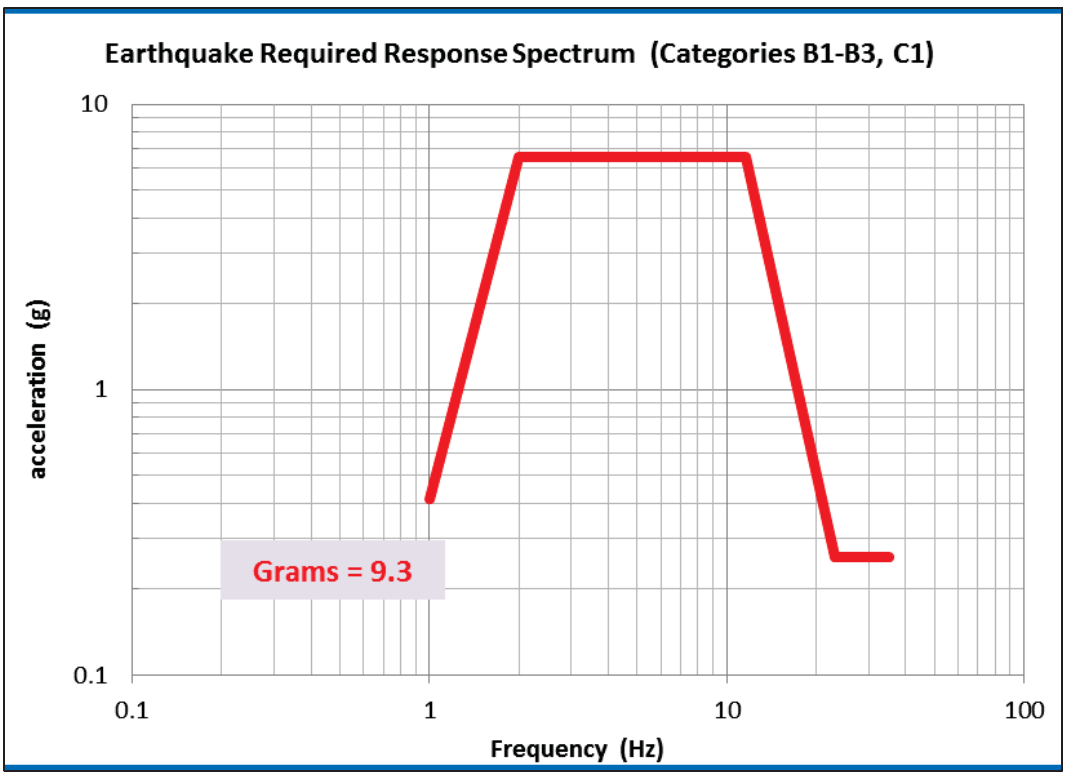
       During this time period, also perform an APSD analysis of the vibration acceleration response at selected positions on the equipment.

    b. At the completion of the test, the equipment shall be inspected and there shall be no evidence of structural failure of any internal or external component.

Table J-6 **Earthquake RRS Parameters**

Category & Grams	Point	Frequency (Hz)	Acceleration (m/s^2)	APSD (g^2/Hz)	Slope (dB/Oct)
A1 – A2 14.89	1	1.0	30	9.36	*
	2	2.0	50	26.00	4.44
	3	5.0	50	26.00	0.00
	4	15.0	15	2.34	-6.60
	5	35.0	15	2.34	0.00
B1 – B3 C1 9.32	1	1.0	6.3	0.41	*
	2	2.0	25.0	6.50	11.97
	3	11.6	25.0	6.50	0.00
	4	23.0	5.0	0.26	-14.16
	5	35.0	5.0	0.26	0.00
D1 – D2 E1 – E2 F1 – F4					





<u>Figure J-1</u> **Earthquake Required Response Spectrum**

J.6 Section 11 – Fluids Susceptibility

Additional categories beyond RTCA DO-160 may be used. Those categories are defined in Table J-7. Column headings A1 through F4 refer to the environmental locations as specified in Table 2-29.

Table J-7 Fluids Susceptibility Test Parameters

Category	A1	A2	B1	B2	B3	C1	D1
Fuels	-	-	-	-	-	-	-
Hydraulic Fluids	-	-	-	-	-	-	-
Lubricating Oils	-	-	-	-	-	X	-
Solvents and Cleaning Fluids	-	-	-	-	-	X	X
De-Icing Fluid	-	-	-	X	-	-	-
Insecticides	-	-	X	-	X	X	-
Sullage (see Note)	-	-	TBD	TBD	TBD	X	TBD
Disinfectant (Heavy-duty Phenolics)	-	-	-	-	X	X	X
Coolant Dielectric Fluid	-	-	-	-	X	-	X
Fire Extinguishants	-	-	-	-	-	-	-

Category	D2	E1	E2	F1	F2	F3	F4
Fuels	X	-	-	-	-	-	-
Hydraulic Fluids	X	-	-	-	-	-	-
Lubricating Oils	X	-	-	-	-	-	-
Solvents and Cleaning Fluids	X	X	X	X	X	X	X
De-Icing Fluid	-	-	-	-	-	-	-
Insecticides	-	-	X	-	X	X	X
Sullage (see Note)	TBD	TBD	TBD	TBD	TBD	TBD	TBD
Disinfectant (Heavy-duty Phenolics)	X	-	-	-	X	X	X
Coolant Dielectric Fluid	X	-	X	-	-	-	-
Fire Extinguishants	-	-	-	-	-	-	-

Note: ***TBD*** *= To be determined by the equipment manufacturer*

J.7 Section 12 – Sand and Dust

Additional categories beyond RTCA DO-160 may be used. Those categories are defined in Table J-8. Column headings A1 through F4 refer to the environmental locations as specified in Table 2-29.

Table J-8 Sand and Dust Test Parameters

Category	A1	A2	B1	B2	B3	C1	D1
Dust							
Sedimentation (1) ($mg/(m^2h)$)			20	20	20	15	-
Other than Cabin ($mg/(m^2h)$)			-	-	-	-	3.0
Cabin Only ($mg/(m^2h)$)			-	-	-	-	1.0
Suspension (mg/m^3)			5	5	5	0.4	-
Sand (mg/m^3)			300	300	300	300	0.1

Category	D2	E1	E2	F1	F2	F3	F4
Dust							
Sedimentation ($mg/(m^2h)$)	-			1.5	20	20	20
Other than Cabin ($mg/(m^2h)$)	3.0			-	-	-	-
Cabin Only ($mg/(m^2h)$)	1.0			-	-	-	-
Suspension (mg/m^3)	-			0.2	5.0	5.0	5.0
Sand (mg/m^3)	-			30	300	300	300
Other than Cabin (mg/m^3)	0.1			-	-	-	-
Cabin Only (mg/m^3)	No (2)			-	-	-	-

Note:

1. *$mg/(m^2h)$=milligrams per meter squared per hour.*
2. *No: This condition does not occur in this category.*

This Page Intentionally Left Blank

K APPENDIX K UAS COMMAND AND NON-PAYLOAD CONTROL (CNPC) LINK PERFORMANCE

K.1 Introduction

This appendix addresses the Required Link Performance (RLP) of the Control and Non-Payload Communications (CNPC)[62] link system when used to support the Unmanned Aircraft Systems (UAS) Detect and Avoid (DAA) functions. The CNPC RLP is an essential segment of the DAA Required Communication Performance (RCP) mainly because it is the interface between the Pilot in Command (PIC) and the Unmanned Aircraft (UA). The PIC is situated at a Control Station (CS). The elements of a UAS are defined in Appendix B. The format of this appendix is consistent with Appendix K of the Command and Control (C2) Data Link MOPS – Terrestrial, RTCA Document 362 (DO-362), a counterpart of this DAA MOPS for UAS. The detailed Modeling and Simulation (M&S) procedures used to derive the CNPC RLP will reference the appropriate subdivision of that appendix wherever applicable.

The CNPC RLP specified for safety-critical services depends on the levels of automation of UAS. This appendix discusses CNPC RLP transaction expiration time, availability, continuity, and integrity requirements for the minimum level of automation for the DAA System, also known as a Pilot In The Loop (PITL) system. In this approach the PIC performs subfunctions to maintain DAA Well Clear (DWC) using an informational display, and the UA has no automated maneuver guidance algorithm. In addition, the appendix recommends various mitigations to improve RLP parameters and characteristics, and establishes the relationships between RLP parameters and the levels of automation of the DAA system.

K.2 RLP Definitions

(RLP definitions are specific to this appendix.)

Required Link Performance (RLP): RLP is a specification of the of the performance of the CNPC link system in terms of the availability, transaction time, transaction expiration time, continuity, and integrity necessary for operation within in a defined airspace.

RLP Availability (A): The probability that an operational transaction supported by the CNPC link system can be initiated when needed.

RLP Transaction Time: The nominal time for the completion of the operational transaction supported by the CNPC Link System.

RLP Transaction Expiration Time (TET): The maximum time for the completion of the operational transaction supported by the CNPC link system, after which the initiator is required to revert to an alternative procedure.

RLP Continuity (C): The probability that an operational transaction supported by the CNPC link system can be completed within the transaction expiration time, given that the CNPC link system was available at the start of the transaction.

[62] The CNPC downlink refers to the combination of the telemetry link and pilot/ATC voice or data communication link from the UA to the CS.

RLP Integrity (I): The probability that an operational transaction supported by the CNPC link system is completed with undetected errors.

Note:

1. *While RLP integrity is defined in terms of the "goodness" of the CNPC capability, it is specified in terms of the likelihood of occurrence of malfunction on a per-flight-hour basis.*
2. *From a safety perspective the undetected errors associated with integrity are much more important than detected errors.*

K.3 Approach

The technical approaches for joint DAA and CNPC link system analysis are shown below.

1. Timelines are developed to determine how long the CNPC link system can be interrupted before the UAS becomes unsafe. The timelines effectively derive the RLP Transaction Expiration Times.
2. Safety analyses are developed to determine how often messages can be missed (availability and continuity) or erroneous (integrity) before the UAS becomes degraded. The safety analysis also provides guidance on how frequently a loss of function, i.e., Lost CNPC Link, can occur.
3. The link analysis (from Subsection K.4 of the C2 Data Link MOPS – Terrestrial) determines the frequency and length of the CNPC link system interruptions.
4. Using the information obtained from the above three steps, the frequency of interruptions (from Step 3 above) of a length longer than the Transaction Expiration Time (from Step 1 above) can be compared to the safety target (from Step 2 above) to assess if the safety target in the example analysis has been met. Additionally a similar analysis can be used to determine if the frequency of lost CNPC Links is also acceptable based on the Lost CNPC Link Decision Time developed from Step 1 (see Subsection F.5 of the C2 Data Link MOPS – Terrestrial).

M&S along with safety analysis activities were conducted to assess the CNPC link system RLP to safely support C2, DAA, Air Traffic Control (ATC) data relay, weather radar and video services, as well as evaluate the relationships between RLP and the levels of automation of UAS operations.

Several propagation M&S approaches were used to estimate CNPC link performance. Possibly the most accurate approach is actual flight testing in a variety of scenarios that vary aircraft altitude, slant range, maneuvering, terrain type, among other encounter parameters. Propagation modeling tools are ways to check the validity of flight testing and provide advanced design inputs while still in the engineering tradeoff phase. Additionally, site surveys are an important tool for insuring that antennas are pointed clear of nearby obstructions.

K.3.1 Propagation Modeling

Air-Ground (AG) channel M&S using the Spherical-Earth-Model (SEM) and Terrain Integrated Rough Earth Model (TIREM) as well as the airframe shadow M&S were conducted to determine the CNPC link system Radio Frequency (RF) propagation loss.

TIREM was used to predict RF propagation loss over variable terrain and sea water for ground-based and airborne transmitters and receivers using Digital Terrain Elevation Data (DTED). In SEM, the terrain profile is represented as the arc of a circle, valid for propagation over a smooth sea or fresh water. TIREM takes into account the effects of irregular terrain along the propagation path, requiring information regarding terrain elevations of the region of interest. TIREM and SEM can be used as independent propagation models for rough-earth or smooth applications, respectively. If a clear Line-of-Sight (LOS) exists between two antennas, both models consider the effects of surface-wave propagation (refraction), diffraction, tropospheric-scatter propagation (not useful for CNPC), and atmospheric absorption, as appropriate. TIREM evaluates the effects of irregular terrain along the great circle path in the calculation of diffraction loss. If the terrain elevation profile supplied to TIREM has been adjusted by adding the height of known man-made obstacles or trees, their effect on diffraction will be included in the predicted path loss. In the majority of cases, the required terrain information was taken from Level 1 DTED generated by the National Geospatial – Intelligence Agency (NGA). The DTED Level 1 format is a uniform matrix of terrain-elevation values spaced at 3-arc-seconds (approximately 100-meter (m)) intervals to approximate the vertical resolution of 1:250,000 scale elevation contour maps. It should be noted that many of the equations internal to TIREM are themselves statistical estimates.

K.3.2 Control Station Site Survey

The site survey approach to propagation modeling uses terrain and local building information to assess the Radio LOS (RLOS) path obstruction at various azimuths of interest to determine the lowest altitude that the UA can fly before the RLOS path clearance becomes less than acceptable in accordance with the link budget. Terrain-based propagation models will miss man-made obstructions like buildings. A 360-degree (deg) site survey shown in Figure K-1 describes the local horizon elevation angle versus azimuth seen by an antenna.

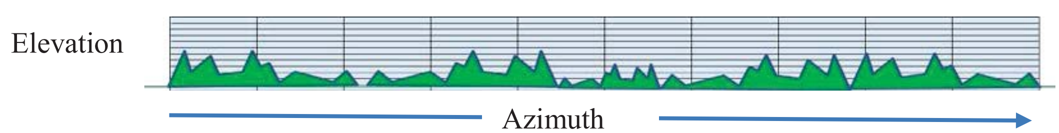


Figure K-1 **Site Survey of a Local Horizon Elevation Angle versus Azimuth**

K.3.3 Message Traffic Modeling

The industry-standard OPNET toolset was used to develop the communications networks for both sending and receiving nodes and to calculate the CNPC link system transaction time. The simulation model used to analyze CNPC transaction performance is based on two commercial-off-the-shelf software packages: OPNET Modeler and OPNET AppTransaction Xpert.

OPNET Modeler provides a comprehensive development environment supporting the modeling of communication networks and distributed systems. Both behavior and performance of modeled systems can be analyzed by performing discrete event simulations. The OPNET Modeler environment incorporates tools for all phases of a study, including model design, simulation, data collection, and data analysis. A CNPC Link was developed in OPNET Modeler that captures the connectivity of the Control Station and UAS.

OPNET AppTransaction Xpert provides capabilities to design applications with its Transaction Whiteboard features. Transaction Whiteboard includes an Application Programming Interface (API) of Python functions for modeling application behavior based on network, application, and user-specified inputs.

K.3.4 Flight Test Data Analysis

The availability for L-band and C-band CNPC Link Systems were derived from the AG channel M&S statistical outputs (e.g., received signal strength statistics) of the TIREM/SEM addressing channel shadowing due to terrain-based obstructions combined with the M&S of channel shadowing due to the airframe itself.

One can take advantage of Flight Test (FT) data to estimate likely durations of link interruptions (Fade Durations) and the time between consecutive interruptions (Interfade Durations) among other important link quality measures, as follows:

- Single Link Interruption
    - Maximum time period of link interruption (Maximum Fade Duration)
    - Minimum time period of link interruption (Minimum Fade Duration)
    - Aggregate link interruption time
    - Average time period of link interruptions
- Two Consecutive Interruptions
    - Maximum duration between two consecutive interruptions (Maximum Interfade Duration)
    - Minimum time between two consecutive interruptions (Minimum Interfade Duration)
    - Aggregate duration between two consecutive link interruptions
    - Average duration between two consecutive link interruptions

Of the above, the two most important parameters are the maximum time period of the link interruption (Maximum Fade Duration) and the minimum time period between two consecutive interruptions (Minimum Interfade Duration).

Note: *More detailed technical approach descriptions (including safety analysis approach) can be found in Subsection K.3 of RTCA DO-362.*

K.4 Results of Modeling, Simulation, and Flight Test Data Analyses

The AG channel modeling and OPNET simulation analyses of achievable values for the CNPC link system RLP parameters for a minimum level of DAA automation at the time these MOPS were published are based on the following assumptions:

- A link budget as reported in Appendix L of the C2 Data Link MOPS – Terrestrial, unless otherwise stated.
- Antenna nulls and shadowing by the airframe were not addressed by AG channel M&S. Antenna nulls and shadowing effects were assessed separately.
- A UA with a single CNPC link system antenna located on the bottom of the fuselage.

- Propagation due to ducting conditions was not considered.
- Pilot response time was not considered.

Note:

1. *The L- and C-band link budgets accounting for the CNPC M&S efforts and flight tests can be found in Appendix L of the C2 Data Link MOPS – Terrestrial.*
2. *In the ensuing flight test data related discussions, Figure K-2 and Figure K-5 through Figure K-9in this appendix are mirrored to Figures K-16, K-26, K-28, K-31, K-35, K-37 in the C2 Data Link MOPS – Terrestrial, respectively. Figure K-3 and Figure K-4 are mirrored to its Tables K-3 and K-4, respectively.*

The AG channel M&S using TIREM and DTED and SEM were first validated by comparing the outputs with the flight test data. The SC-228 Working Group 2 (WG-2) worked with National Aeronautics and Space Administration (NASA) Glenn as NASA conducted numerous flight tests and collected CNPC data. Figure K-2 illustrates that the M&S results (blue) and the flight test data (green) are in close agreement in several multipath fading events occurring in this flight path. Much more additional flight test data have consistently validated the AG channel M&S using TIREM and DTED, as well as the underlying assumptions used.

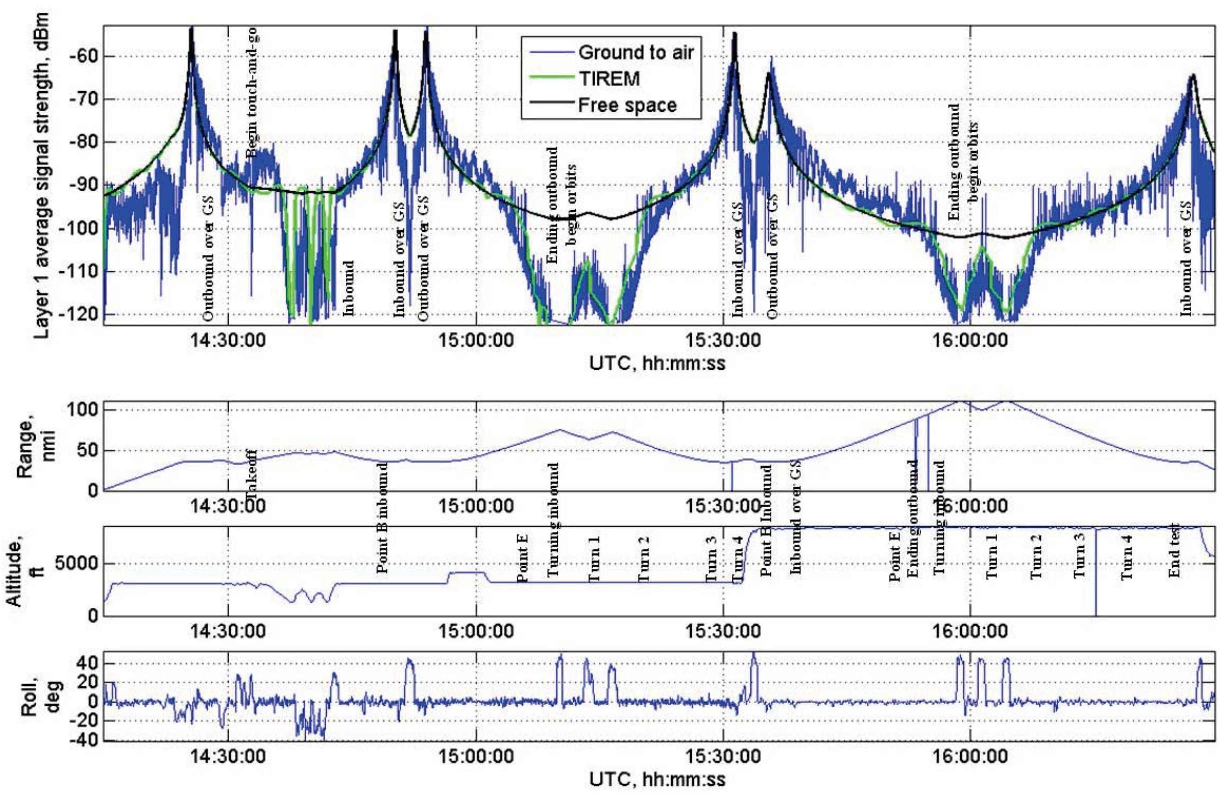


Figure K-2 **Flight Test 5 – May 29, 2013 – Sandusky, Ohio**

Once validation was completed showing good comparisons to flight test results, M&S was conducted with AG channel TIREM, DTED, and SEM to determine the L-band and C-band RLP parameters and characteristics of availability and continuity due to multipath propagation.

K.4.1 Availability

Target availability of 99.8% was used in the simulations to close the link. Figure K-3 and Figure K-4 show maximum UA ranges in Nautical Miles (NM) at various altitudes in feet (ft) for 99.8% availability for L-band and C-band in different terrain conditions like mountainous, flat, and hilly terrains, and sea water as obtained from simulations considering a ground antenna height of 100' above terrain.

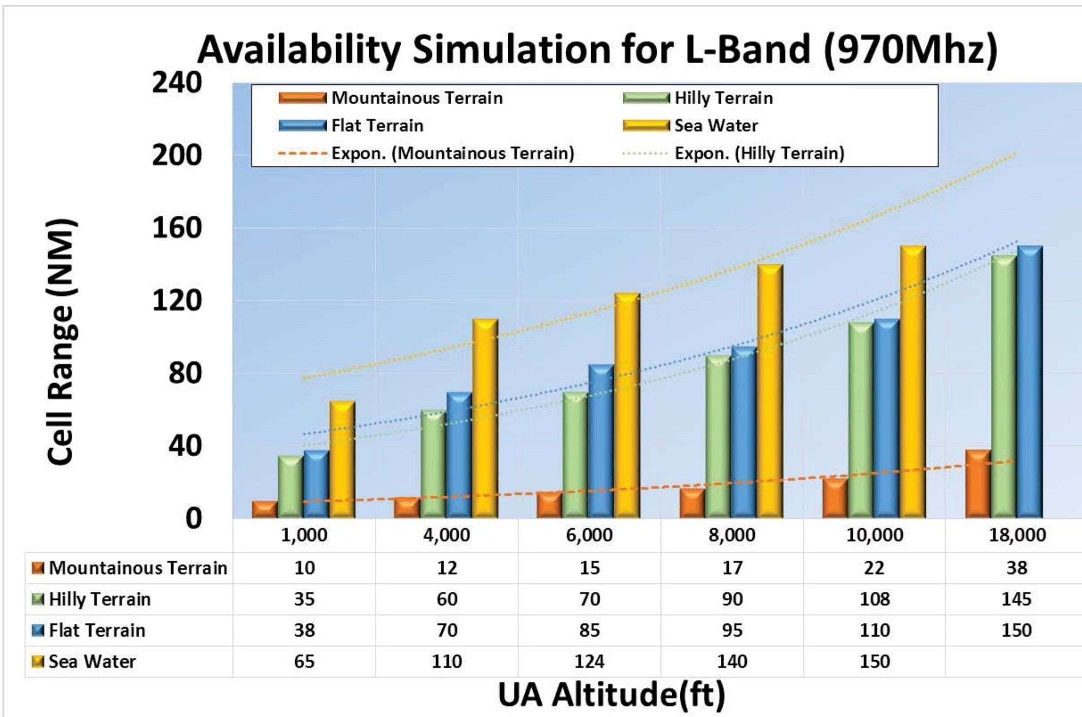


Figure K-3 **99.8% Availability Ranges and Altitudes for L-Band**

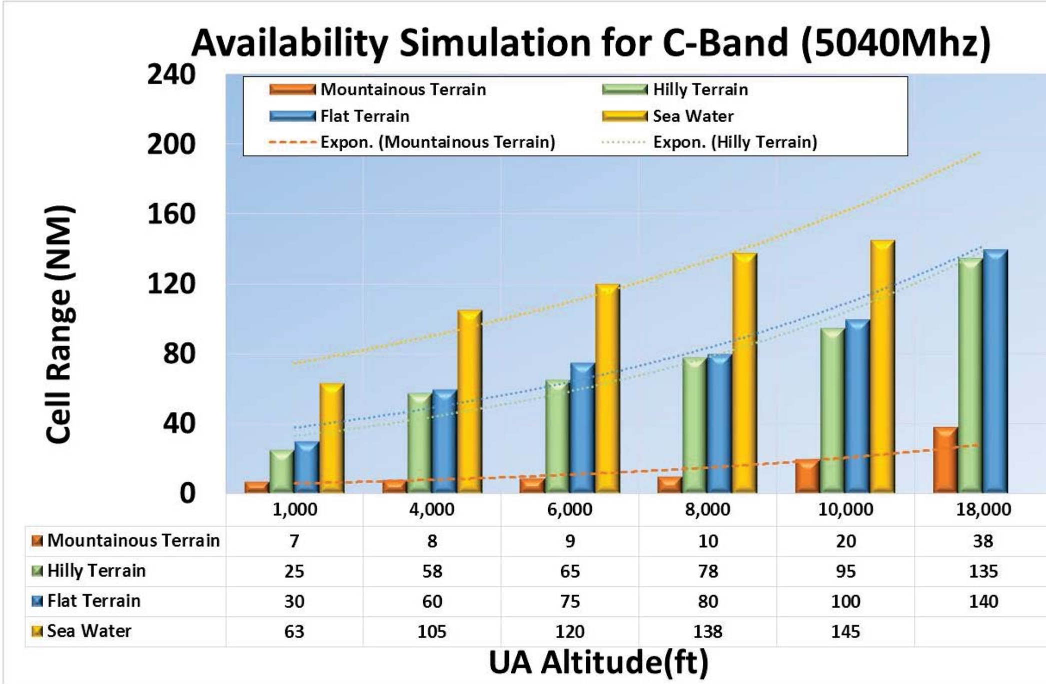


Figure K-4 **99.8% Availability Ranges and Altitudes for C-Band**

K.4.2 Continuity

The performance of the CNPC link system fluctuates with time. These fluctuations are caused by a number of environmental factors and are not associated with variation of the performance of the equipment itself but the attenuation of the signal on the propagation path between the antennas of the CNPC Link System.

Figure K-5 below depicts a notional variation of the signal level in dB at a CNPC link system receiver showing a Rayleigh Fading Envelope on the Y-axis. As the figure shows, the signal level may occasionally dip below the minimum required by the receiver to correctly receive the information from the CNPC link system transmitter, at which time a temporary (self-repairing) interruption occurs. The duration of these interruptions can vary from tens of milliseconds (ms) to many tens of seconds (secs). These interruptions are not necessarily associated with operating the CNPC link system at its maximum range and can occur for example when the UA is close to the runway or has maneuvered to place its wing in the propagation path of the CNPC link system signal. The statistics of the CNPC link system performance associated with these fluctuations in propagation path attenuation can be accurately modelled and their temporal characteristics can be calculated. A realization of this notional plot is Figure K-2, which is plotted from the real measured flight test data and M&S outcome.

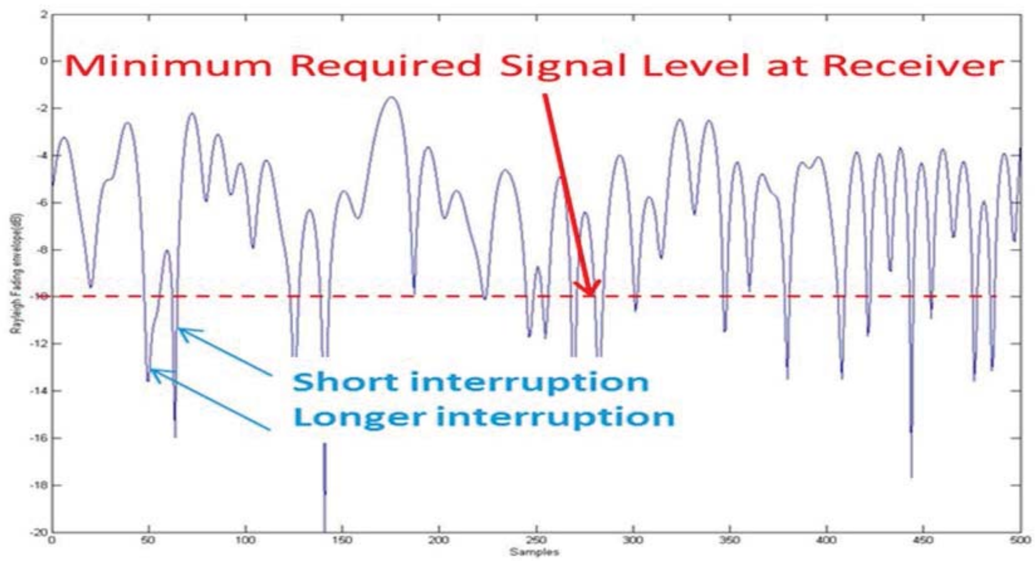


Figure K-5 **Notional Concept of Received Signal Level versus Time in a Fading Channel**

RLP Continuity can be further illustrated in the link outage times in Subparagraph K.4.3.1

K.4.3 Results of Flight Test Data Analyses

Flight tests using a manned aircraft equipped with L-band and C-band omnidirectional antennas were performed at various altitudes and ranges. This data supported the analysis in this appendix, the link budgets in Appendix L of the C2 Data Link MOPS – Terrestrial, the Undesired-to-Desired signal level ratios in Appendix R of the C2 Data Link MOPS – Terrestrial. The flight tests also provided UAS and CNPC link system designers and NAS system architects with data on which to base their system's performance without the need to perform their own flight tests. These tests were flown over the two most likely terrain types (hilly and water) at ranges of 35 NM to 100 NM and altitudes of 3,000' to 21,000', representative of the anticipated flight use cases that these MOPS will support (see Appendix O of the C2 Data Link MOPS – Terrestrial). Higher altitudes were not covered because they are almost completely immune from ground reflection multipath and diffraction effects, which allowed for easy calculation of path attenuation. Additionally, weather and foliage do not impact propagation at the frequencies under consideration.

Although some data and propagation models already exist (e.g., International Telecommunication Union – Radiocommunication Sector, P.528, Propagation curves for aeronautical mobile and radionavigation services using the Very High Frequency (VHF), Ultra High Frequency (UHF), Super High Frequency (SHF) bands and Intermediate Frequency (IF) 77) they do not provide the temporal characteristics of the fading required for the analysis needed to assess the safety of the UAS when the CNPC link system is experiencing fading.

Consequently, the flight tests focused on capturing data such as the maximum time period of a single link interruption (Maximum Fade Duration), which relates to the transaction expiration time, and the average duration between two consecutive link interruptions (Average Interfade Duration), which indicates how often fades typically occur.

Although the MOPS baseline CNPC link system equipment was used to capture the flight test data, post-flight analysis extracted just the (equipment- and data rate-independent) path attenuation between the two antennas (the Measured Path Loss (MPL)). This was then subtracted from the Free Space Path Loss (FSPL) (calculated using the slant range from the ground antenna to the aircraft antenna) to derive the Excess Path Loss (EPL) (EPL = FSPL – MPL). The EPL is attributed to the multipath loss and diffraction caused by the terrain below the LOS path. The aircraft's roll angle and bearing were held constant during the five-minute (min) data capture segments of the flight test to eliminate antenna gain variations as much as possible.

As can be seen in Figure K-6, which plots EPL against aircraft bearing from the ground antenna for three altitudes, the EPL varies much more at lower than higher altitudes. The variation characteristics are different depending on the terrain. Additional comparisons, such as over hills vs. over water, can be seen in Figures K-28, K-29, and K-30 in the C2 Data Link MOPS – Terrestrial.

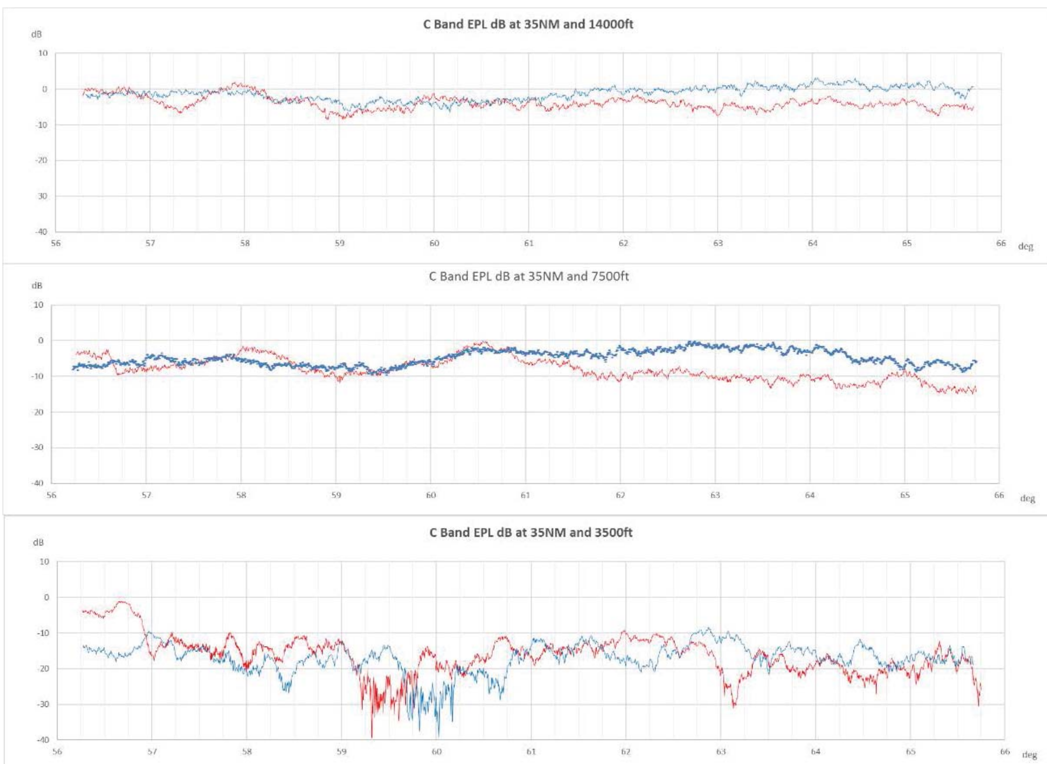


Figure K-6 **Example Flight Test (over Hills) Excessive Path Loss**

K.4.3.1 Temporal Fading Analysis

The temporal fading analysis may provide good info for assessing RLP continuity. To evaluate the temporal characteristics of the EPL, data was captured at 50-Millisecond (ms) intervals and the resulting EPL assessed at each time point to see if it was less than or greater than a selected value ranging from 6 Decibels (dB) to -42 dB. Analysis was then performed to measure how long the signal level was above or below the selected EPL and how long the gaps were to derive fade duration and interfade duration times. The number of fades and interfades were then binned into a variety of time slices to present the data in an easy to view histogram. The counts were extrapolated to one-hour durations.

Figure K-7 is an example (L-band over hilly terrain at 35 NM range and 3,500' altitude) of the results of this analysis showing the measured EPL in the upper part of the figure, the fade duration counts per hour versus bin time in the middle of the figure and the interfade durations counts per hour versus bin time in the lower part of the figure.

In this example the EPL does not vary much over the segment but it is in the order of 15 to 30 dB. Consequently, the fade durations are very long, greater than 50 seconds until the EPL is close to 15 dB, and they rapidly reduce to less than 100 ms at an EPL of 18 to 24 dB. With an EPL of 27 dB no fades occurred during the segment. From an interfade duration perspective the fades are only separated by less than 1 second at an EPL of 15 dB but the interfade duration rapidly increases to 20 seconds or greater as the EPL drops from 18 dB to 24 dB. With an EPL greater than 27 dB the interfade durations are longer than 100 seconds.

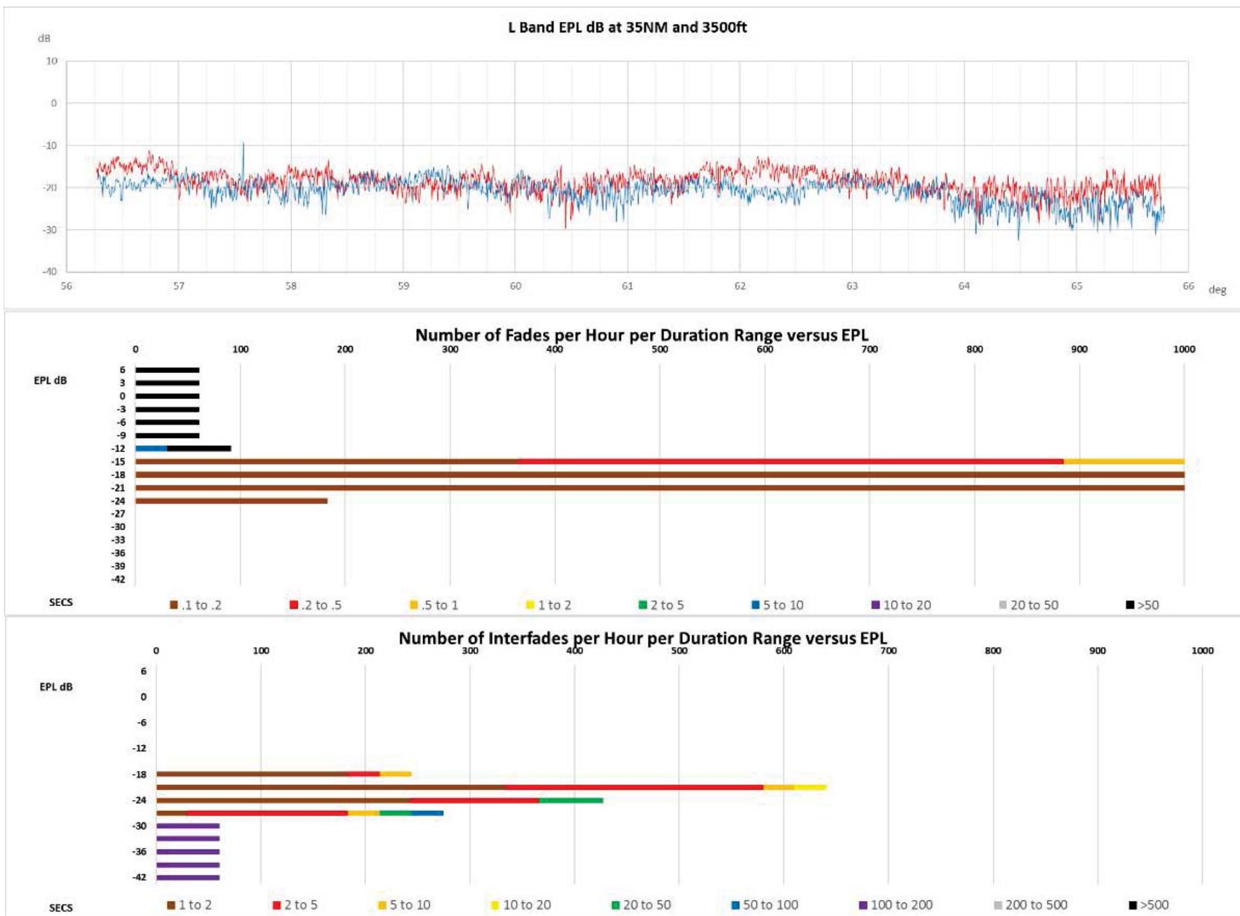


Figure K-7 **Example Flight Test Temporal Fading Analysis Results (L-band)**

For L-band at the same range and over the same hilly terrain but with the aircraft at 7,500' altitude (higher) only 3 dB is required to assure no fades longer than 2 seconds occur, with corresponding interfade durations of 10 seconds.

For C-band over hilly terrain at a 35 NM range and 3500' altitude, EPLs of greater than 24 dB are required to achieve fade durations of less than 2 seconds, with corresponding interfade durations of approximately 20 seconds. To achieve no fades, an EPL of close to 40 dB would be required. Additional flight test data analysis can be found in Figures K-32 and K-33 of the C2 Data Link MOPS – Terrestrial.

This information can be used to allocate a link margin (at the appropriate altitude and range for the desired operation) that can be added to the FSPL in the link budgets in Appendix L of the C2 Data Link MOPS – Terrestrial to compensate for the EPL, and the corresponding temporal fading characteristics can then be assumed.

It is desired to be able to achieve fade durations of less than 2 seconds to support the DAA function and the C2 function. Based on the analysis of all of the flight tests performed, this is achievable on the assumption that a link margin adequate to compensate for an EPL of approximately 17-20 dB is accommodated in the CNPC link system design. However, at this EPL the interfade durations are typically only 10-20 seconds, which would not be operationally acceptable as the fades would occur too frequently. Based on the flight test data, increasing the link margin by 3 dB reduces the fade durations to less than 100 ms and the corresponding interfade durations in excess of 50 seconds. Consequently, it is proposed that an EPL of 20 dB is included in the L and C-band link budgets in Appendix L of the C2 Data Link MOPS – Terrestrial and that these EPLs will be controlled by limiting the lowest altitude of operations based on path clearance over the intended terrain.

K.4.3.2 Minimizing The Duration of Unreliable Signal Predictions

Subparagraph K.4.3.1 above showed flight test data published by NASA [Reference 1] showing received signal strength versus time, along with information on altitude, aircraft roll and slant range for an L-band CNPC Link System. In what follows, the C2 Data Link Mops – Terrestrial went on to show how this type of flight test data can be used to develop a methodology for reliable link prediction.

It begins by defining a Prediction Quality Metric (PQM) as,

PQM = Actual Received Signal Strength (ARSS) – Predicted Received Signal Strength (PRSS)

PQM should be small in absolute value for purposes of accuracy, and positive so the PRSS errors on the side of caution. Stated differently, prediction techniques which have positive but small PQM for long time periods will be the most useful for not overdesigning a system. Periods of negative PQM imply the ARSS fell below the prediction, meaning it could be approaching or falling below the receiver sensitivity without the system designer knowing. The analysis went further to define two methods for deriving PRSS from Computed Signal Estimate (CSE) and Excess Signal Loss (ESL) as follows:

Method 1: $$\mathrm{PRSS(terrain)} = \mathrm{CSE}_{\mathrm{terrain}} - \mathrm{ESL}$$

Where $\mathrm{CSE}_{\mathrm{terrain}}$ is a terrain-based Computed Signal Estimate, and ESL is a sliding scale of dB by which PRSS can be optimized.

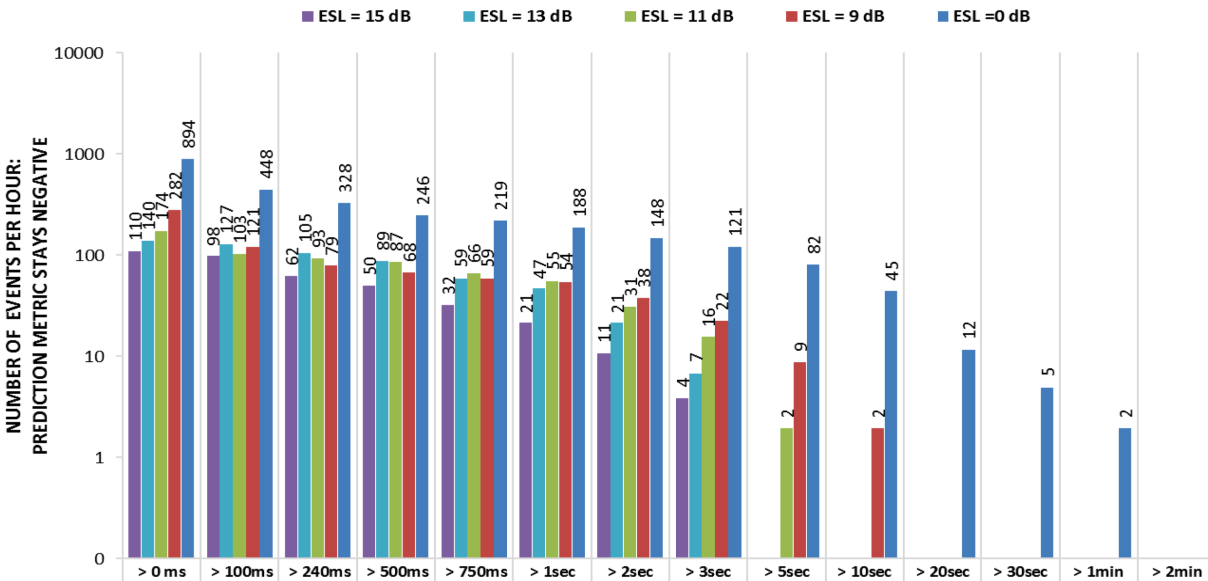
Method 2: $$\mathrm{PRSS(FSPL)} = \mathrm{CSE}_{\mathrm{FSPL}} - \mathrm{ESL}$$

Where $\mathrm{CSE}_{\mathrm{FSPL}}$ is a LOS-only (distance-squared) Computed Signal Estimate, and ESL is a sliding scale of dB by which PRSS can be optimized.

Note: *The term ESL for excess signal loss refers to a sliding scale correction term applied to an imperfect prediction of actual flight test data. It has the characteristic that the better the prediction, the smaller will be the loss. In Subparagraph K.4.3.1, the EPL refers to the difference between the actual path loss with all signal strength variables (high-power amplifier size, antenna gains, circuit losses, noise, temperatures, etc.) backed out and the Free Space Loss based on the distance between the airborne radio and ground radio antennas. One can recognize that ESL of Method 2 (FSPL) is equal to EPL when demand PQM = 0 (for best accuracy).*

Method 1 is generally used in the planning stage when no fight test data is available. Subparagraph K.4.4.1.6.3 of the C2 Data Link MOPS – Terrestrial provides in-depth discussion to show how well the TIREM model can predict the AG channel performance. Discussion continues on Method 2. Either discussion should not change the flight test performance. In general, flight test data reflect many subtle issues that cannot be easily modeled and simulated in computers. But a capable tool still needs to be developed (like Method 1) to characterize the performance prior to any real flights.

Figure K-8 displays the flight test data only with PRSS chosen using Method 2 (based on what the TIREM program calls free-space path losses). As noted earlier, ESL is equal to EPL in Method 2 when FSPL is considered. In turn, this ESL/EPL value is the link margin that the system integrator will design into the system to ensure the performance specified. (ESL (FSPL) = EPL)



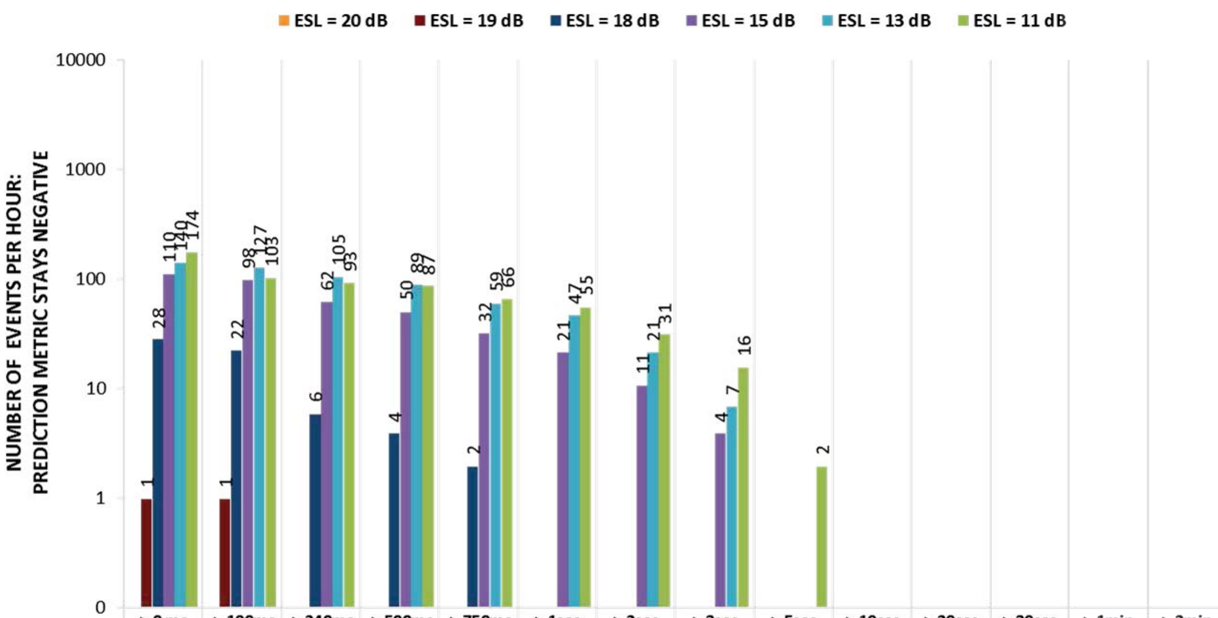
	> 0 ms	> 100ms	> 240ms	> 500ms	> 750ms	> 1sec	> 2sec	> 3sec	> 5sec	> 10sec	> 20sec	> 30sec	> 1min	> 2min
ESL = 15 dB	110	98	62	50	32	21	11	4	0	0	0	0	0	0
ESL = 13 dB	140	127	105	89	59	47	21	7	0	0	0	0	0	0
ESL = 11 dB	174	103	93	87	66	55	31	16	2	0	0	0	0	0
ESL = 9 dB	282	121	79	68	59	54	38	22	9	2	0	0	0	0
ESL =0 dB	894	448	328	246	219	188	148	121	82	45	12	5	2	0

DURATION OF EVENTS

Figure K-8 Negative PQM Events Using an FSPL PRSS Technique (Based on Analysis of Non-Maneuvering Flight Test Data – FT 2, Generation 1)

Examining the FSPL measurement criterion in Figure K-8, it can be seen that with 15 dB of ESL/EPL, there are 4 outages that could be as long as 5 seconds and 11 – 4 or 7 outages that can be as long as 3 seconds and 21 – 11=10 outages that could be as long as 2 seconds, for a one hour outage fraction of 4x5+7x3+10x2=61/3600=.01694.

Figure K-9shows that if larger ESLs are considered, namely, 18, 19, and 20 (i.e., smaller PQM), all outages greater than 1 second disappear. As a result, the link margin may need to be designed at 18 dB or more to result in a link outage duration within 1 second. These two figures provide informative data to assess the RLP continuity for the stable flight criterion. As shown, ESL/EPL (i.e., link margin) greater than 18 dB is recommended for good AG channel design.



	> 0 ms	> 100ms	> 240ms	> 500ms	> 750ms	> 1sec	> 2sec	> 3sec	> 5sec	> 10sec	> 20sec	> 30sec	> 1min	> 2min
ESL = 20 dB	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ESL = 19 dB	1	1	0	0	0	0	0	0	0	0	0	0	0	0
ESL = 18 dB	28	22	6	4	2	0	0	0	0	0	0	0	0	0
ESL = 15 dB	110	98	62	50	32	21	11	4	0	0	0	0	0	0
ESL = 13 dB	140	127	105	89	59	47	21	7	0	0	0	0	0	0
ESL = 11 dB	174	103	93	87	66	55	31	16	2	0	0	0	0	0

DURATION OF EVENTS

Figure K-9 Negative PQM Events Using an FSPL PRSS Technique and Larger ESL Margins (Based on Analysis of Non-Maneuvering (Flight Test 2) Data – FT 2, Generation 1)

Note: Extensive technical details of the M&S work and post-flight-test data analyses can be found in Subsection K.4 of the C2 Data Link MOPS – Terrestrial.

K.5 CNPC Link Performance Parameters and Characteristics for Minimum DAA Automation

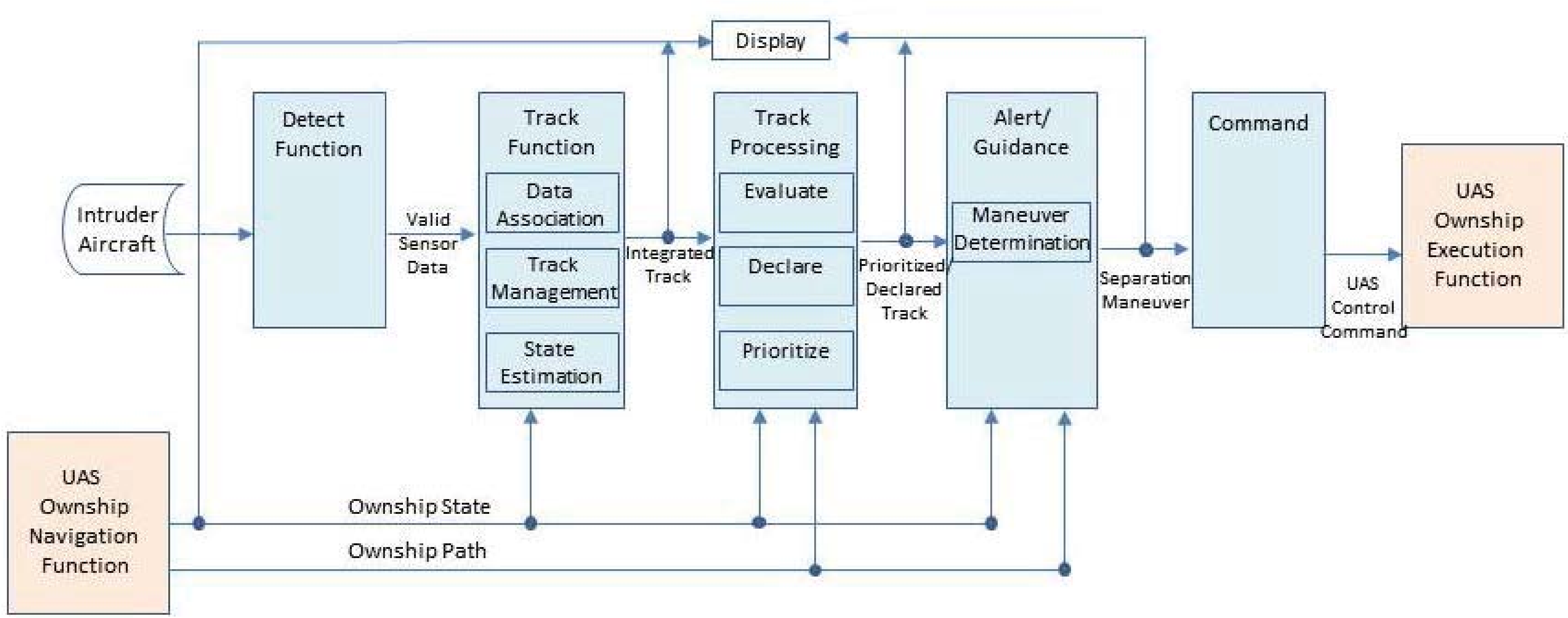
K.5.1 DAA Considerations

The objective of the DAA function is to maintain DAA well clear of other aircraft and facilitate the PIC to be a good user of the airspace. In this paragraph, a minimum level of automation for DAA means a PITL approach to performing DAA subfunctions using an informational display, precluding the need for an automated maneuver guidance algorithm. Since there are components of the DAA system both onboard the UA and hosted in the control station, the CNPC link system connecting the two becomes a safety-critical system.

Within the context of the DAA function, informational displays minimally refer to the display of ownship and traffic information, including positional icons and state information. DAA informational displays may also contain information about predicted conflict states of other traffic so as to aid pilot decision making. In the context of a DAA system, PITL generally refers to the PIC's direct, physical engagement of the CS-CNPC interface to perform DAA maneuvers based on information provided by the DAA system.

The PIC is responsible for determining what maneuver to command and for physically commanding that maneuver to the aircraft through the CS CNPC/navigation interface. That command could be in the form of a direct control input movement, or simple mouse click to select a new waypoint, or anything in between.

The following subparagraphs describe each of the DAA subfunctions shown in Figure K-10 and provide a notional description of how they interact with the CNPC Link. The baseline assumption is that the DAA function is controlled by a PITL with an informational display (i.e., no automated maneuver determination algorithm). Therefore the PIC is performing the Guidance (Subparagraph K.5.1.4) and Command (Subparagraph K.5.1.5) functions.



<u>Figure K-10</u> **DAA Functional Architecture**

K.5.1.1 Detect

The Detect function is responsible for monitoring the predetermined volume of airspace about the UA, determining the presence of potential airborne hazards (intruders), and providing sensor data (relative intruder state) for each hazard. This is done for each sensor type.

K.5.1.2 Track

The Track function performs data association, track management, and state estimation based on data received from all of the sensors. These integrated tracks are then sent both to the PIC and to the Track Evaluation function.

DAA should evaluate the track volume as a function of parameters such as the surveillance radius and traffic density. The tracks are automatically sent to CS display and the transmission does not need acknowledgment. This un-prioritized track data can be sent at the best opportunity and may be repeated at a specified interval. DAA should determine the total bandwidth and throughput required to process the un-prioritized tracks.

K.5.1.3 Track Processing

The Evaluate, Declare, and Prioritize subfunctions have been grouped into a function called Track Processing. The Track Processing function is responsible for processing the surveillance track data by assessing the risk of Mid-air collision (MAC) or Near-Mid-air Collision (NMAC), prioritizing hazards based on collision risk, and declaring action when needed to mitigate hazard risks.

The prioritized tracks sent to the CS radio must be acknowledged by the PIC. If no acknowledgement is received within a pre-determined interval, the data will be resent.

K.5.1.4 Alert/Guidance

The Alert/Guidance function is responsible for providing a recommended separation maneuver. In the PITL approach, this function is provided to the PIC. The primary advantage of a PITL with an informational display is that the PIC may be best positioned to handle the complex factors that must be taken into consideration at the long time horizon over which DAA operates. In addition to leveraging the potential PITL advantages, using an informational display has the additional benefit of not requiring an automated maneuver algorithm. This confers the responsibility for the safety of the aircraft clearly to the PIC and may greatly simplify the DAA system implementation.

It is important to note that this concept is most similar to today's ATC operations, which is accepted but requires a significant amount of training in order for the controllers to perform the functions given to them.

K.5.1.5 Command

The Command function is responsible for communicating avoidance or other instruction(s) to the Execute function (e.g., stay on course, return to mission, etc.).

When the PIC is commanding a maneuver from the CS, the CNPC link system will carry that command to the aircraft for execution. The commands sent by the PIC to perform DAA must be acknowledged by the CNPC radio on the UA. If no acknowledgement is received in a pre-determined interval, it will be resent.

K.5.1.6 Execute

This function is responsible for executing the commanded action and is the responsibility of control systems in the aircraft.

K.5.1.7 DAA Timeline and Data Flows

The DAA timeline considered in this appendix is illustrated in Figure K-11. Multiple RLPs (A/2, B, and B/2) for the CNPC link system are shown in this timeline. The RLPs shown here don't include the pilot response time. The pilot response time is addressed by the Guidance and Pilot Input functions shown in the DAA timeline in Figure K-11.

As shown in Figure K-11, the transaction Time (T) at the DAA level is comprised of RLP TETs, DAA system processing times, human response times (such as ATC time and pilot reaction time involving the Human-Machine Interface (HMI), and aircraft maneuver time, etc. However, the availability and continuity will be mainly determined by the times and probabilities provided in the RLPs because the CNPC link system operates in the RF environment that introduces physical phenomenon that humans cannot avoid, but can actively manage to minimize any adverse impact. As a result, the DAA system will continue using RCP to characterize the DAA performance. The RCP is defined in International Civil Aviation Organization (ICAO) Document 9869, First Edition 2006, Manual on Required Communication Performance (RCP).

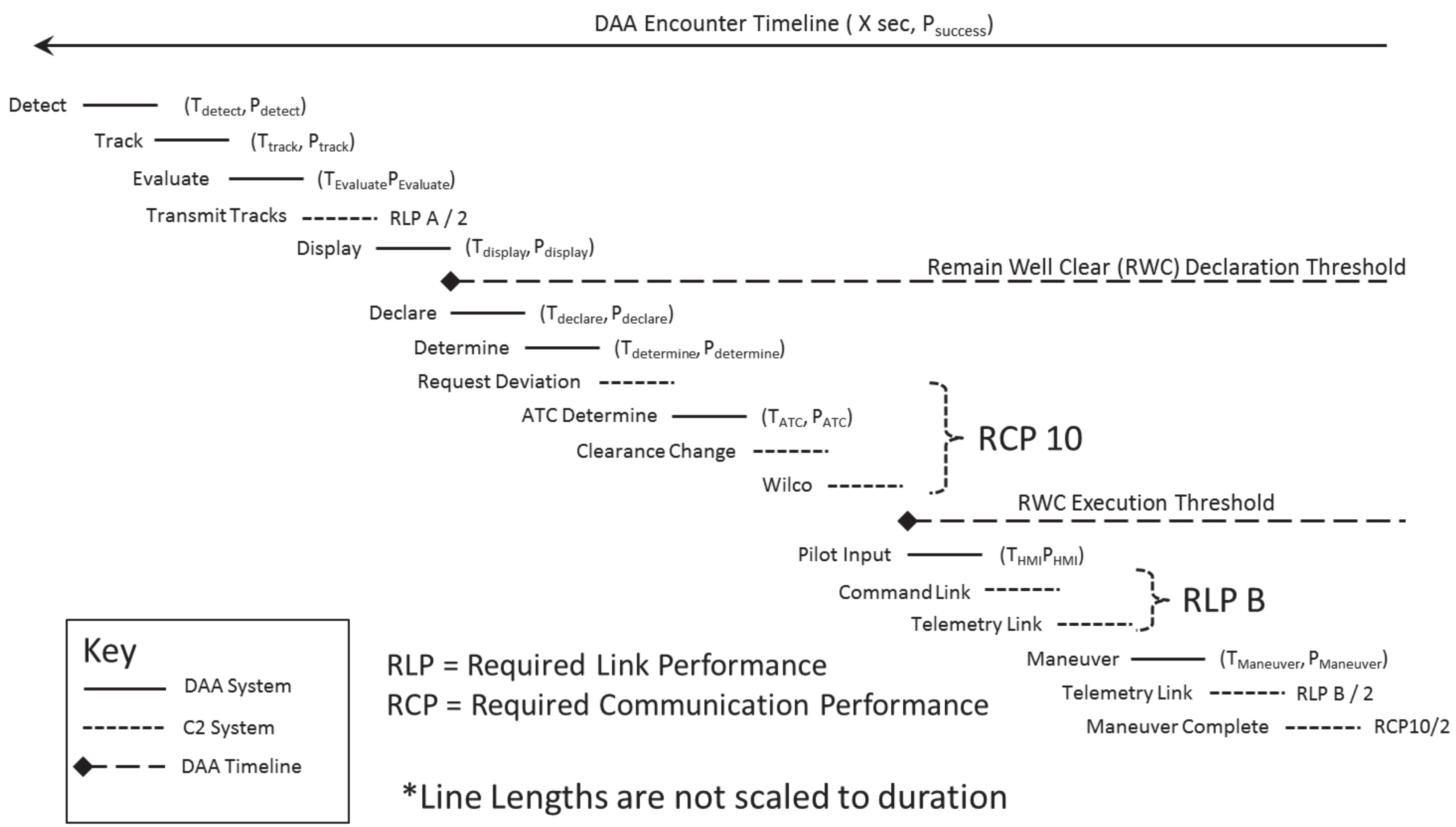


Figure K-11 **DAA Timeline Scenario**

The data flow for the PITL approach considered in this appendix is illustrated in Figure K-12. It presents a different look of the DAA timeline in Figure K-11.

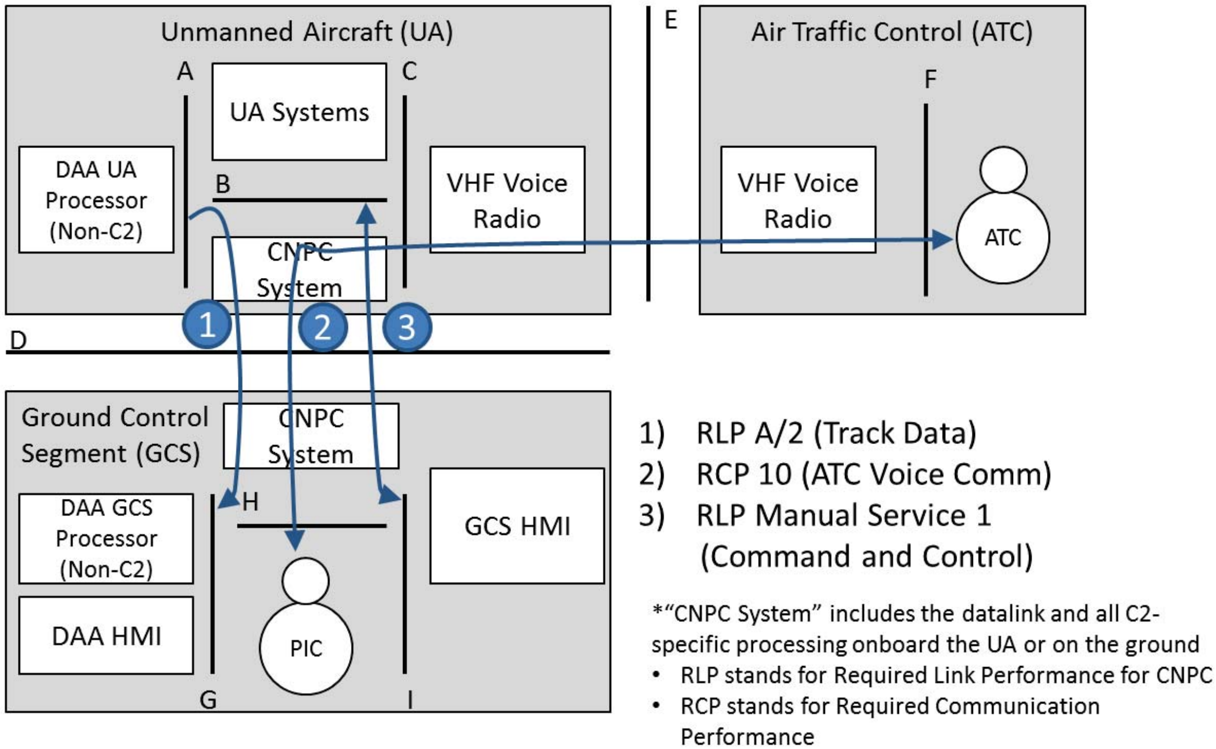


Figure K-12 **Data Flows for the PITL Approach**

K.5.1.8 Minimum Data Rate of Target Data for DAA

The minimum data rate of target data for DAA was first considered in [Reference 3] and the information has been incorporated in NASA flight tests [Reference 1] and CNPC link system M&S as part of the C2 Data Link MOPS – Terrestrial. The CNPC link system is required to provide sufficient traffic reports to support DAA functions, specifically for the use of a traffic display in the CS. The result is summarized in Table K-1. Detailed message contents can be found in Table K-2.

Table K-1 **Minimum Data Rate for DAA/CNPC Traffic Report/Display**

Parameter	Value
Number of Tracks	60
Number of Bits per Track	130
Number of Updates per Second	1
Total Downlink Data Rate (bits/second)	7800

Table K-2 **Minimum Data Rate for DAA/CNPC Traffic Report/Display Details**

Parameter (bits)	Bits	Unit	Notes
Unique Traffic Number (8)	1	N/A	
	2		
	4		
	8		
	16		
	32		
	64		
	128		
Display Matrix (3)	0	N/A	Non-threat
	1		Maintain DWC 1
	2		Maintain DWC 2
	3		CA Resolution Advisory
	4		
	5		
	6		
Source Data Type (8)	Automatic Dependent Surveillances-Broadcast (ADS-B) 1090ES (Air-Air)		
	Traffic Alert and Collision Avoidance System (TCAS)		
	Air-to-Air Radar		
	(Reserved) ADS-B UAT (Air-to-Air)		
	(Reserved) Automatic Dependent Surveillance-Rebroadcast (ADS-R)		
	(Reserved) TIS-B		
	(Reserved) Passive Non-Cooperative Sensor		
	Reserved		
Air/Ground Status (2)		N/A	
Latitude (23)	$1.0728836E^{-5}$	Degrees	Use Aeronautical Radio Incorporated (ARINC) 735B, Attachment 20K, Display Traffic Information File (DTIF) Type 2 as an example for bit structure
	$2.1457672E^{-5}$		
	$4.2915344E^{-5}$		
	$8.5830688E^{-5}$		
	$1.7166138E^{-4}$		
	$3.4332275E^{-4}$		
	$6.8664551E^{-4}$		
	0.00137329		
	0.00274658		
	0.00549316		
	0.0109863		
	0.0219726		
	0.0439453		
	0.0878906		
	0.175781		

Parameter (bits)	Bits	Unit	Notes
	0.351563		
	0.703125		
	1.40625		
	2.8125		
	5.625		
	11.25		
	22.5		
	45		
Latitude Sign (1)			
Longitude (24)	$1.0728836E^{-5}$	Degrees	Use ARINC 735B, Attachment 20K, DTIF Type 2 as an example for bit structure
	$2.1457672E^{-5}$		
	$4.2915344E^{-5}$		
	$8.5830688E^{-5}$		
	$1.7166138E^{-4}$		
	$3.4332275E^{-4}$		
	$6.8664551E^{-4}$		
	0.00137329		
	0.00274658		
	0.00549316		
	0.0109863		
	0.0219726		
	0.0439453		
	0.0878906		
	0.175781		
	0.351563		
	0.703125		
	1.40625		
	2.8125		
	5.625		
	11.25		
	22.5		
	45		
	90		
Longitude Sign (1)		N/A	
Horizontal Position Accuracy (4)	0	N/A	Estimated Position Uncertainty (EPU) ≥18.52 kilometers (km) (≥10 NM)
	1		EPU < 18.52 km (10 NM)
	2		EPU < 7.4 km (4 NM)
	3		EPU < 3.7 km (2 NM)
	4		EPU < 1852 m (1 NM)
	5		EPU < 926 m (0.5 NM)
	6		EPU < 555.6 m (0.3 NM)
	7		EPU < 185.2 m (0.1 NM)
	8		EPU < 92.6 m (0.05 NM)
	9		EPU < 30 m
	10		EPU < 10 m

Parameter (bits)	Bits	Unit	Notes
	11		EPU < 3 m
Relative Altitude (9)	25	Feet	Use ARINC 735B, Attachment 20I, DTIF Type 1 as an example for bit structure
	50		
	100		
	200		
	400		
	800		
	1600		
	3200		
	6400		
Relative Altitude Sign (1)			
Relative Altitude Accuracy (2)	0		> 100’
	1		< 100’
	2		< 25’
	3		< 5’
Vertical Velocity (9)	10	Feet/min	Use ARINC 735B, Attachment 20K, DTIF Type 2, Version 1 as an example for bit structure
	20		
	40		
	80		
	160		
	320		
	640		
	1280		
	2560		
Vertical Velocity Sign (1)			
Vertical Velocity Accuracy (2)	0	Feet/min	> 100
	1		< 100
	2		< 10
	3		< 1
Heading/Track (7)	1.40625	Degrees	Use ARINC 735B, Attachment 20L, DTIF Type 3, Version 1 as an example for bit structure
	2.8125		
	5.625		
	11.25		
	22.5		
	45.0		
	90		
Heading/Track Sign (1)			
Heading/Track Accuracy (2)	0	Degrees	> 10 or unavailable
	1		< 10
	2		< 5
	3		< 1
Ground/Air Speed (10)	1		Use ARINC 735B, Attachment 20L, DTIF Type 3, Version 1 as an example for bit structure
	2		
	4		
	8		

Parameter (bits)	Bits	Unit	Notes
	16		
	32		
	64		
	128		
	256		
	512		
Navigation Accuracy Category for Velocity (3)	0		Horizontal Velocity Error is Unknown or ≥ 10 m/s
	1		< 10 m/s
	2		< 3 m/s
	3		< 1 m/s
	4		< 0.3 m/s
Timestamp (10)	0.000976563	seconds	
	0.001953125		
	0.00390625		
	0.0078125		
	0.015625		
	0.03125		
	0.0625		
	0.125		
	0.25		
	0.5		
Total	**130 bits**		

This minimum data rate example along with other necessary message transfer for the CNPC link system has been incorporated in the OPNET simulation by SC-228 WG 2 and reported in Appendix K of the C2 Data Link MOPS – Terrestrial.

K.5.2 RLP Transaction Time

(Same as Paragraph K.5.4 of the C2 Data Link MOPS – Terrestrial)

Note: *As a note for convenience, the transaction time for one-way and two-way communications are determined to be 128 ms and 256 ms, respectively, in the OPNET simulation reported in the C2 Data Link MOPS – Terrestrial. The simulations account for the message structure and the data throughput. The DAA system will need to account for further delay such as software processing time. A two-second transaction expiration time is used in the summary presented in Table K-5*

K.5.3 CNPC Link Performance Parameters Supporting the PITL Approach

The CNPC link performances in the presence of multipath propagation and airframe shadowing have been extensively addressed in the WG-2 M&S effort. Specific discussions on RLP A/2 and RLP B that are used to support DAA PITL systems with informational display are included in Paragraph K.5.6 of the C2 Data Link MOPS – Terrestrial. The discussions include the link margins necessary to achieve the required link availability, e.g., 20 dB link margin for 99.8% availability – maximum range and UA altitude – due to multipath losses. They also include CNPC link system outages or interruption characteristics due to multipath losses.

The RLP A/2 shown in Table K-3 and Table K-4 below (corresponding to Tables K-9 and K-10 in the C2 Data Link MOPS – Terrestrial) are for sea water and hilly terrains and UAS minimum level of automation summarized from the flight test data.

Table K-3 RLP A/2 Supporting a DAA PITL System w/Informational Display – Water

Frequency Band	Max. UA Ranges and Altitudes	Transaction Exp. Time/Allowable Interfade Duration (seconds)	Link Interruption Time (seconds)	Transaction Time (ms)	Integrity (I) (per Flight-Hour (FH))
L-band	Note 1	2/10.7 – 107	Note 2 (1) < 2 @ 6 dB EPL (2) ~10 @ 21 dB EPL	Note 4 250	Note 5 (3) 10^{-5} (4) 10^{-6}
C-Band	Note 1	2/10.7 – 107	Note 2 (1) < 2 @ 9 dB EPL (2) ~ 10 @ 12 dB EPL	Note 4 250	Note 5 (3) 10^{-5} (4) 10^{-6}

Table K-4 RLP A/2 Supporting a DAA PITL System w/Informational Display – Hilly Terrain

Frequency Band	Max. UA Ranges and Altitudes	Transaction Exp. Time/Allowable Interfade Duration (seconds)	Link Interruption Time (seconds)	Transaction Time (ms)	Integrity (I) (per FH)
L-Band	Note 1	2/10.7 – 107	Note 2 (1) < 2 @ 3 dB EPL (2) ~10 @ 9 dB EPL	Note 4 250	Note 5 (3) 10^{-5} (4) 10^{-6}
C-Band	Note 1	2/10.7 – 107	Note 2 (1) < 2 @ 15 dB EPL (2) ~10 @ 15 dB EPL	Note 4 250	Note 5 (3) 10^{-5} (4) 10^{-6}

Note:

1. *The maximum UA ranges and altitudes for 99.8% link availability due to multipath losses.*
2. *Average fade duration and interfade duration for 35 NM range and 3500' altitude (Water), 7500' (Hilly).*
3. *N/A*

4. *OPNET was used to calculate the CNPC link system transaction time. The CNPC link system transaction times shown in the following tables include data link (antenna-to-antenna) transaction time and the ground/airborne processing time. The CNPC link system transaction time does not address pilot response time.*
5. *The probability of the loss of the CNPC link system providing the PITL DAA Maintain DWC service function.*
6. *The probability of an unannunciated failure of the CNPC link system providing the PITL DAA Maintain DWC service function.*

The summarized results provided by C2 Data Link MOPS – Terrestrial will be used to continue the RLP continuity discussion in the context of DAA in the following paragraph. See Paragraph K.5.6 of the C2 Data Link MOPS – Terrestrial for more technical details of CNPC link system RLP.

K.5.4 Continuity for the DAA Timeline in the CNPC Data Link

As shown in Subparagraph K.5.1.7 earlier, the transaction time for the DAA function with PITL involves the response time of the pilot and possibly ATC. As a result, the overall transaction expiration time for the DAA functions is much longer than that reported in the CNPC Only simulation. The 107-second DAA timeline allocations are summarized in the following table as a reference baseline. At the maintain DWC Execution Threshold the pilot has to take action to perform the guidance command. Once the command is initiated, the UA will start maneuvering until it is clear. If not, the pilot will take additional actions, such as reporting to ATC or trying to contact the intruder if possible, during the Well Clear (WC) boundary.

Table K-5 Timeline Allocation Summary

Step	Time (seconds)
Detect (Sensor)	5
Track (Sensor)	5
Evaluate (DAA Processor)	1
Transmit Tracks (CNPC)	2
Display	1
Declare	1
Determine (Pilot)	10 (NASA Human-in-the-Loop (HITL) Study)
Pilot-ATC Interaction	10 (NASA HITL)
Pilot Input (Pilot)	5 (NASA HITL)
RLP B (CNPC)	2
Maneuver (UA)	30 (Depends on speed)
WC Boundary	35
Total	**107**

K.6 Mitigations

This subsection describes mitigations for system design and procedures required in different scenarios, under different flight phases and environmental conditions based on assessment of the CNPC Link performance results discussed in Subsections K.4, K.5, and K.6 of the C2 Data Link MOPS – Terrestrial.

K.6.1 Mitigations to the CNPC Link System

(This paragraph is mirrored to Paragraph K.9.1 of the C2 Data Link MOPS – Terrestrial)

1. UAS radio systems should provide CNPC link system services to a level of RLP adequate to support the safety requirements of the class of UAS in which they are installed or connected, and in the environments in which the UA and CS operate.

   Note:

   1. *Compliance with this requirement is demonstrated by using data captured during the flight tests described in Subsection 3.3 of the C2 Data Link MOPS – Terrestrial, Test Procedures for Installed Equipment Performance, and the UAS applicant's safety case.*
   2. *The effects of CNPC Link availability, continuity, transaction expiration time, and integrity on the performance of the CNPC Link service function must be taken into account during normal, abnormal and emergency conditions.*

2. In the event of loss of all links with the CS the UA will autonomously squawk a pre-determined transponder code and execute the pre-programmed lost CNPC link function, and the PIC/operator will contact ATC and state the contingency trajectory.
3. There are various ways to improve CNPC Link performance. Some of them are listed below.
   - Excess Link Margin: Degradations in availability and continuity can be caused by undesirable propagation effects such as multipath cancellation. Such effects can cause the received power to be significantly less than the power expected in free space (with omnidirectional antennas). If the probability of these excess losses versus their magnitude were known, then enough extra power could be transmitted to lower the unavailability to an acceptable value.
   - Time Diversity: Transmitting extra power may not always be a practical solution. If the separate transmissions are degraded by statistically independent processes, sending messages multiple times (or repeating messages if no acknowledgement is received) can be a way to improve performance. Because such methods require extra bandwidth and more time, the benefits of these techniques need to be weighed against their disadvantages.
   - Spatial Diversity: To overcome blockages and multipath effects, spatial diversity in the form of multiple antennas can be used. For example, airframe blockage can be mitigated by placing antennas on the fuselage top and bottom or forward and aft (or on the wingtips of fixed-wing aircraft). In such cases it seems unlikely that both antennas would be blocked simultaneously. To address ground multipath issues, multiple well-separated ground antennas can be useful.

Note: *There is a downside to such methods in terms of cost (beyond just the cost of the antennas themselves). Typically, each antenna will have its own transceiver attached. Also, the receivers could be linked together and different receptions will have to be sorted out via some type of voting algorithm.*

- Frequency Diversity: Sending messages simultaneously in both L- and C-band can be a way to ensure that there are two paths with statistically independent fading mechanisms. This is similar to time diversity techniques, but it would not involve an increase in transaction time. On the other hand, two types of radios would be needed at the CS and onboard the UA. This could be a problem for small UA with size, weight and power constraints, especially because C-band communications can have path loss issues – requiring more power and/or directional antennas. Such small UA could be included in a category requiring less stringent RLP parameters.
- Improving link availability and continuity performance with the UA being able to hand-off its link connection to another CS, using higher link layer work-arounds, or using variable data rate control, etc.
- The use of circular polarization antenna(s) or other configurations such as dual linear polarization should be considered to mitigate fading.
- Integrity: Techniques to ensure a specified integrity level include Forward Error Correction codes (e.g., Reed-Solomon, Turbo Code), simple checksums, Fletcher checksums, Cyclic Redundancy Codes, context matching and possibly others. These methods involve adding extra bits to each message. The integrity level can be improved by increasing the number of extra bits. The numbers of extra bits required is generally not a significant driver of required throughput. Link redundancy (active diversity redundancy – separate hardware paths or elements carrying the same data or providing the same function, or standby – backup – path) can also be used to provide link integrity.

4. Conduct the CNPC Link operation within the maximum operating range and minimum operating altitude defined for the intended operational environment based on the CNPC Link performance assessment equivalent to the validated assessment described in this appendix.
5. Antenna nulling and shadowing is dictated by placement of antennas on the airframe and the resulting RLOS angles to the CS(s). Demonstrate that the installation of the UA antenna(s) operating in conjunction with the CS(s) provide(s) adequate coverage for minimum antenna gain to achieve 99.8% link availability with enough link margin for antenna shadowing/nulling.
6. The pilots have an ability to modify the link continuity performance by mapping out areas of terrain blockage as part of flight planning.
7. Information relating to site surveys from any given ground radio station can be stored in memory onboard the UA to delineate how a UA, in an emergency, can reestablish an LOS link with the ground radio system, and with minimum fuel or minimum time.
8. In the event of an unacceptable loss of link as indicated by maximum UA ranges and minimum safe altitudes for the required link availability, the PIC will notify ATC of the loss of link and the expected behavior of the UA until a link is reestablished or the UA lands or ends its mission.
9. The UAS tolerance to CNPC Link availability, continuity, transaction expiration time, transaction time, and integrity depends on the architecture of CNPC loops as shown in Figure K-13. Generally, the more automation on the UA itself, the less the dependency on the CNPC Link availability, continuity, transaction expiration time, integrity, and required mitigations.

K.6.2 Additional Mitigations to DAA

1. In the event of unacceptable link interruptions, the DAA-equipped UA should provide track coasting, message acknowledgement, PIC/DAA operator cautions, warnings or annunciations.
2. Operate the DAA PITL system with informational display and CNPC link system within the maximum operating range and minimum safe operating altitude defined for the intended operational environment, and within the UA operating envelope with adequate coverage for minimum antenna gain to achieve the required link availability (e.g., 99.8%) with link margin for antenna shadowing/nulling.
3. In the event of a lost CNPC link, the DAA-equipped UA may automatically perform maneuvers to avoid collisions. In the case of a reported loss of link, the PIC will notify ATC of the loss of link and the expected behavior of the UA until the link is reestablished or the UA lands or ends its mission.

K.7 Relationship Between DAA Automation and CNPC Link System RLP

An applicant seeking certification and operational approval of a UAS has a variety of functional allocations and risk mitigations that can potentially be brought forward to make a safety case. The specific performance level required of the CNPC link system is dependent on these other potential mitigations. This subsection addresses the minimum link performances of the CNPC link system when in support of the DAA system of a UAS flying safely in the national airspace.

The designs and collective performance of the CNPC link system and the DAA functions are coupled. The resulting DAA and CNPC link system engineering products are the products of key design and performance trade-offs between DAA and CNPC Link System. For a particular set of CNPC link system and DAA functions, an increase or decrease in the RLP and/or levels of automation for DAA and CNPC functions may allow a trade-off in design complexity provided that the required level of safety is achieved.

Figure K-13 depicts the relationship between CNPC link system RLP, DAA automation performance and the level of operational acceptability that is associated with the joint performance of the coupled system.

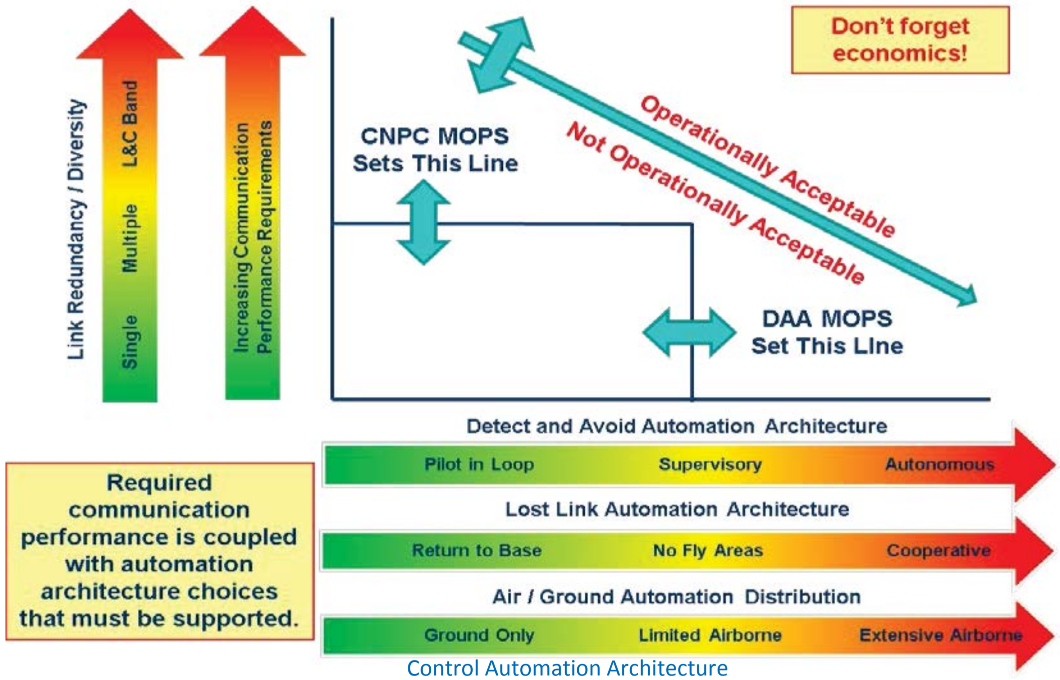


Figure K-13 **Relationship between DAA Automation and CNPC Link System RLP**

On the vertical axis, a series of possible increasing levels of CNPC link system RLP can be seen, from single link architectures through multiple command link/control link architectures to full L-band and C-band diversity. In developing the C2 Data Link MOPS – Terrestrial, a level of link performance (or a series of levels) will be defined for the CNPC radio. Designers can then use this data to determine the RLP of their particular system, which will depend on the characteristics of the message transactions of their system and the level of automation for the operation of their aircraft.

On the horizontal axis a series of possible increasing levels of automation can be seen in three forms:

1. DAA or CNPC function,
2. Lost CNPC link automation, and
3. Distribution of automation between the UA and the CS.

As an example, an exclusive PITL approach would require a higher level of CNPC link system RLP than would be required with greater DAA automation. Perhaps not as intuitively, more extensive airborne automation might mitigate AG requirements.

The blue diagonal line represents the joint level of performance required to provide the applicant with a suitable solution that is operationally acceptable to the certification authorities. As depicted in Figure K-13, it is entirely possible to define a certifiable CNPC link system and a DAA or CNPC link system that when combined do not rise to an acceptable level of joint performance to gain certification and operational approval. Acceptable is somewhere in the middle.

Underpinning the basic trade-offs of CNPC link system RLP versus DAA performance within the framework of operational acceptability, one must also keep in mind the complexity and associated costs of certification and production of associated solution sets.

In making these trade-offs a number of considerations should be kept in mind:

- The discussion of the Operational Hazard and Design Assurance Levels hinges on several things, including (1) the investigation of requirements on loss of the CNPC Link System, (2) traditional mitigations including ATC actions on flight plans, and (3) the traditional navigation backups for the proposed flight, which are still required. The entire DAA and CNPC link system architecture may then serve as mitigation of loss of CNPC Link System.
- Flight management functional allocations, UA vs. CS, or split, are another key consideration. Specifically, where do lost CNPC link system procedures reside? How much is duplicative between UA and CS? Where is the master flight plan?
- Consideration must be given to requirements for availability and continuity of function. The integration of exposure time in the discussion is likely to be controversial in terms of lowering certification requirements.
- From an aircraft certification perspective, the difference between manned and unmanned aviation is the replacement of a physical control link (connecting the pilot with the aircraft control surfaces) with a wireless signal in space to provide that connectivity. What effect does this have on the traditional hazard class determination? Should separate arguments be constructed for loss of UAS telecommand control and telemetry data links and loss of pilot/ATC Communications link?
- From a CNPC link system perspective, an implication of automation is its relationship with transmission bandwidth and resulting communications rate. In general terms, the more automated a UAS becomes, the lower the transmission bandwidth requirements become while still supporting the required CNPC link system RLP.
- The control link thread transmits and receives control instructions to the aircraft for DAA and CNPC. A lost CNPC link system condition should not cause an immediate unstable flight situation or any undue workload for ATC. The criticality of the link is commensurate with the aforementioned assertion. Beyond-Visual-Line-of-Sight (BVLOS) UA’s must have an ability to maintain predictable flight on a planned heading and altitude if they lose the CNPC Link System.
- Any safety assessment would speak to the loss of control thread as loss of pilot and CS intervention on the aircraft. Mitigations considered would be automated onboard DAA and CNPC link system equipment.

The following lists several considerations for levels of automation of the DAA and CNPC functions:

1. Different levels of automation incorporated. The diverse variations in the levels of automation and associated architectures of UAS C2 system offer many choices in distribution of automation between airborne and CS C2 system components, pilot in the loop, and pilot on the loop.
2. Varying the levels of automation of the UAS operation does not affect the CNPC link system availability and continuity parameters characteristics due to multipath and airframe losses.
3. Generally, the more automation on the UA itself, the less the dependency is on the CNPC link system availability, continuity, transaction expiration time, integrity, and the required mitigations.
4. Relationships between CNPC link system integrity and levels of automation. The more automation on the UA itself, the less the stringency is on the CNPC link system integrity. For these MOPS, fully automatic onboard decision making and operation (intelligent operation) – Pilot monitoring of automatic UA operation was not considered

K.8 Conclusion and Recommendations

This subsection summarizes a list of recommendations based on assessment of the CNPC link system RLP results discussed in Subsections K.4 to K.8 of the C2 Data Link MOPS – Terrestrial.

- Conduct the CNPC link system operation within the maximum operating range and minimum operating altitude defined for the intended operational environment based on the CNPC link system RLP assessment equivalent to the validated assessment described in this appendix.
- For a given terrain condition, an aircraft communicating from long range and/or low altitude requires a greater margin to achieve a given level of availability than an aircraft communicating from short range and/or higher altitude due to multipath losses.
- Demonstrate that the UA antenna(s) installation operating in conjunction with the ground radio station(s) provides adequate coverage for minimum antenna gain to achieve the required (e.g., 99.8%) link availability with sufficient link margin for antenna shadowing/nulling.
- The anticipated levels of CNPC round-trip link Availability (A_{RLP}) and Continuity (C_{RLP}) required for safe operations of the DAA PITL system with information display for various terrain environments can be achieved using the CNPC link system described in the C2 Data Link MOPS – Terrestrial with attention paid to the link impairments and appropriate mitigations identified in Subsections K.5, K.6, and K.9.
- In general, the more automation on the UA itself, the less the dependency on the CNPC link system availability, continuity, transaction expiration time, and integrity and the required mitigations.

- This appendix describes acceptable AG channel modeling and OPNET simulation methods and tools that can be used to determine the CNPC link system RLP parameters and characteristics of link availability and continuity due to multipath losses.
- Appendix K of the C2 Data Link MOPS – Terrestrial describes acceptable UA/CS channel modeling and OPNET simulation methods and tools that can be used to determine the RLP parameters and characteristics of link availability and continuity due to multipath effects and RLP transaction expiration times.

K.9 References

[1] NASA/TM—2014-218099, Control and Non-Payload Communications Generation 1 Prototype Radio Flight Test Report, Kurt A. Shalkhauser, Daniel P. Young, Steven C. Bretmersky, Joseph A. Ishac, Steven H. Walker, James H. Griner, and Brian A. Kachmar, October 2014

[2] Detect and Avoid (DAA) White Paper, RTCA Program Management Committee (PMC) Paper No. 074-14/PMC-1200, 18 March 2014

[3] Minimum Traffic Report Information for Detect and Avoid use of Command and Non-Payload Control Datalink, Draft White Paper, SC228-WG1.7 2015-01

This Page Intentionally Left Blank

L APPENDIX L OPEN AND CLOSED LOOP DAA METRICS

L.1 Purpose and Background

This appendix summarizes Special Committee 228 (SC-228) discussions and decisions regarding Detect and Avoid (DAA) open and closed loop performance metrics and includes details for consistent metrics collection. The Technical Performance Metrics (TPMs) defined herein serve as the objective and implementation-independent basis to determine the *open-loop* alerting performance of a specific alerting system implementation and the objective and implementation-independent basis to determine the *closed-loop* performance of a specific system implementation.

During development of these Minimum Operational Performance Standards,(MOPS) TPMs also allow for the quantification of the potential effects that a proposed MOPS requirement may have on achievable performance. TPMs also enable the quantification of how much state uncertainty (e.g., error in position measurements) affects the performance of a particular algorithm implementation.

Additional metrics may be needed to evaluate the interoperability with an independent collision avoidance system (e.g., TCAS II) on the ownship or intruder.

L.1.1 Open Loop Metrics

The open-loop TPMs in this appendix measure unmitigated open-loop alerting system performance.

The fundamental task of an alerting system is to determine whether a particular hazard is present during an operation, given limited information about the environment. This appendix defines the TPMs used to determine how successful a DAA system is at performing this task. This appendix does not define or suggest an alerting system implementation, but does serve as a basis for the DAA MOPS alerting requirements. In some cases the MOPS requirements differ slightly from this appendix, in which case the MOPS supersedes this informational appendix. While these metrics may be used to help designers optimize an alerting implementation, only the requirements in Subsection 2.2 and test vectors in Subsection 2.4 are used for showing compliance with these MOPS.

L.1.2 Closed Loop Metrics

The closed loop TPMs in this appendix measure how well a system performs when maneuvering (mitigating) after an alert. Closed loop TPMs enable the quantification of nominal DAA system performance in the airspace environment; e.g., how state uncertainty coupled with an algorithm implementation affects total system performance.

The collection of these metrics requires a pilot or pilot model. The closed-loop metrics are broken down into two high-level categories: Safety Metrics and Operational Suitability Metrics. Figure L-1 summarizes the closed loop TPMs described in this appendix, and the definitions of all the terms are contained in later subparagraphs.

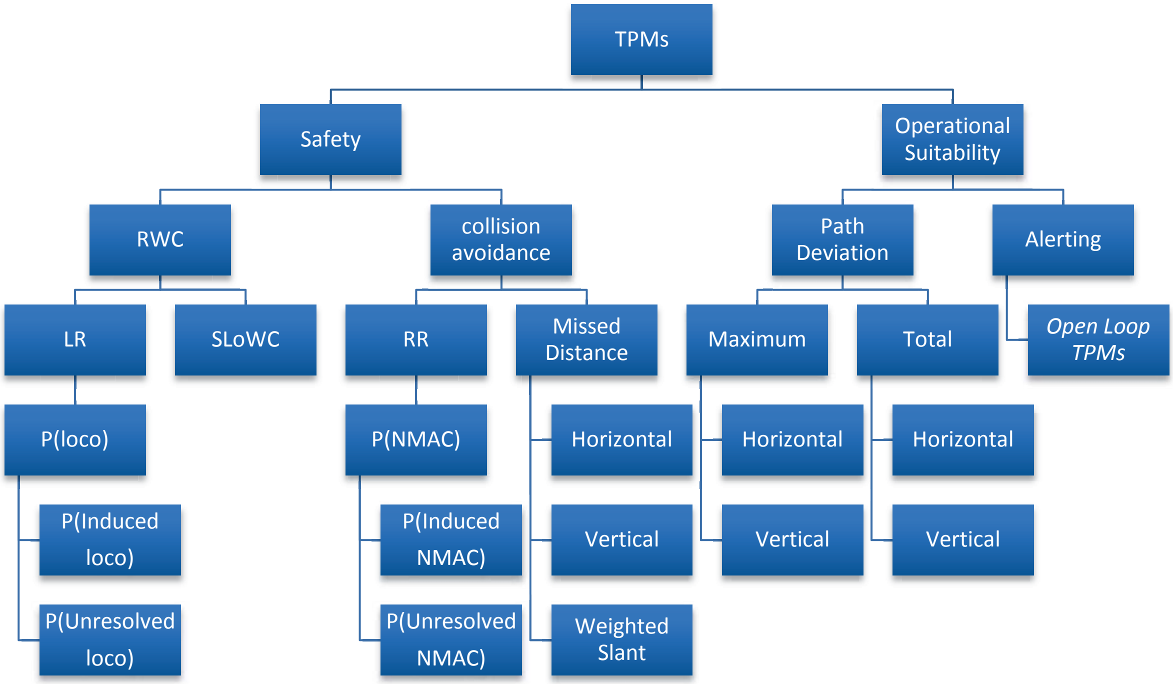


Figure L-1 **Summary of Closed Loop TPMs**

L.2 Hazard Definition and Encounter Characterization for Open Loop Metrics

Figure L-2 shows the encounter characterization method used to objectively define when a hazard is present during an operation – and thus define the desired behavior of an alerting system.

- **Hazard Zone (HAZ):** If an intruder aircraft enters into this zone, the hazard is considered to be present, and therefore an alert should have been issued prior to entering this zone.
- **Non-Hazard Zone (HAZNot):** If an intruder aircraft remains in this zone throughout an encounter, the hazard was never present and an alert is therefore undesirable.
- **May Alert Zone (MAZ):** If an intruder aircraft enters into this zone but not the Hazard Zone, an alert may or may not be necessary and/or acceptable; it is left up to the alerting system manufacturer to determine whether and/or when to issue an alert. Note that alerts may occur in the Non-Hazard Zone as well without penalty.

In the case of a Detect and Avoid (DAA) system, the hazard to be avoided is Loss of DAA Well Clear (LoWC). This is conceptually represented by the Hazard Zone (HAZ) border in Figure L-2.

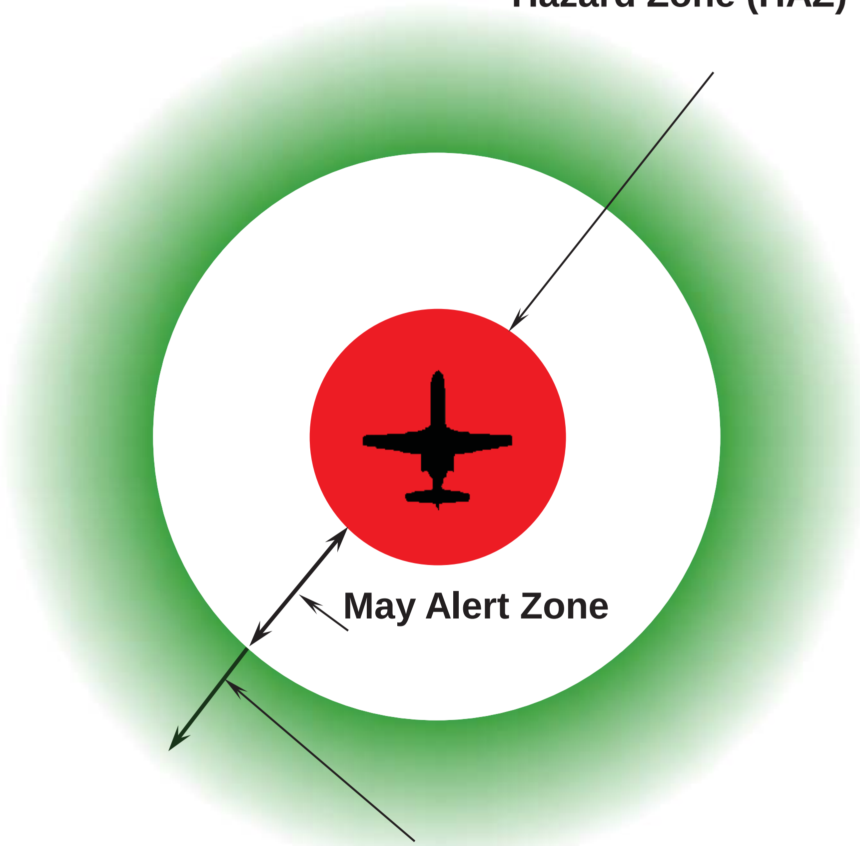


Figure L-2 **Zones Used in Alert Evaluation**

Note: *While the zones are shown as circles, they are not circular in shape since the LoWC volume is dependent on encounter geometry and closure velocity.*

L.2.1 Mathematical Definition of Hazard Zone

The hazard to be avoided is a LoWC for corrective and warning DAA alerts, with a slightly larger vertical size for preventive alerts. The definition of LoWC consists of three conditions; all three must evaluate "True" for a LoWC. The three conditions are formally defined in Appendix C, and are reproduced here and adapted to the Hazard Zone/Non-Hazard zone concept.

The Hazard Zone is said to be violated, for a given time step *i,* if all three of the conditions are met, as defined in Equation L-1 and the following paragraphs:

Equation L-1: Condition that must be met for Hazard Zone to be Violated at Time i

$$[r_i \leq S_i] \text{ AND } \left[HMD_{p,i} \leq HMD^*\right] \text{ AND } \left[d_{h,i} \leq h^*\right] == TRUE$$

L.2.1.1 Condition 1: Horizontal Proximity

This first condition is analogous to the horizontal size of the Hazard Zone. It is equivalent to checking the τ_{mod} condition in other formulations of Well Clear; the Well Clear equation in Appendix C has been solved for range to form the S_i equation to simplify the Hazard Zone equation into three one-sided inqualities. It scales based on horizontal range rate, but is never less than the Distance Modification of Modified Tau (DMOD). It is met when the horizontal separation between two aircraft during an encounter is less than the horizontal size of the Hazard Zone, as defined in Equation L-2:

Equation L-2: Calculation of Horizontal Size of Hazard Zone and Non-Hazard Zone

$$S_i = max\left(DMOD, \frac{1}{2}\left(\sqrt{(\dot{r}_i\tau_{mod}^*)^2 + 4DMOD^2} - \dot{r}_i\tau_{mod}^*\right)\right)$$

$where:$

$i = [t_1, t_2, t_3, \cdots t_{end-1}, t_{end}]$
$\tau_{mod}^*, DMOD:$

Note: *Refer to the parameters in Table L-1 for calculating the size of Hazard and Non-Hazard Zones*

$\dot{r}_i = \left.\frac{d_x \cdot v_{rx} + d_y \cdot v_{ry}}{r}\right|_i$ (horizontal range rate between aircraft)
$r = \sqrt{{d_x}^2 + {d_y}^2}$ (horizontal range between aircraft)
$d_x = x_2 - x_1$ (horizontal separation in x dimension)
$d_y = y_2 - y_1$ (horizontal separation in y dimension)
$v_{rx} = \dot{x}_2 - \dot{x}_1$ (relative horizontal velocity in x dimension)
$v_{ry} = \dot{y}_2 - \dot{y}_1$ (relative horizontal velocity in y dimension)

Note:

1. *$\dot{r}_i$ is negative for closing geometries*
2. *All ranges and range rates are in the horizontal dimension*
3. *and are not slant ranges.*

L.2.1.2 Condition 2: Predicted Horizontal Miss Distance

The second condition evaluates whether the encounter geometry of the aircraft – if left unchanged – will result in a horizontal miss distance less than a threshold value HMD^*, as predicted by a constant velocity calculation. When aircraft are diverging, it collapses to the current horizontal distance between them. For a given time step i, this condition is met when the predicted Horizontal Miss Distance (HMD_p) is less than the threshold value (HMD^*). HMD_p is calculated as shown in Equation L-3:

Equation L-3: Calculation of Predicted Horizontal Miss Distance at Time Step i

$$HMD_p\Big|_i = \sqrt{(d_x + v_{rx}t_{CPA})^2 + \left(d_y + v_{ry}t_{CPA}\right)^2}\Bigg|_i$$

where:

$$t_{CPA} = max(0, -\frac{d_x v_{rx} + d_y v_{ry}}{v_{rx}^2 + v_{ry}^2})$$

L.2.1.3 Condition 3 for Hazard Zone: Vertical Proximity

The third condition evaluates whether the relative altitude is currently less than a threshold value (h*). Relative altitude is calculated as shown in Equation L-4:

Equation L-4: Calculation of Current Vertical Separation

$$d_{h,i} = abs\left(h_{1,i} - h_{2,i}\right)$$

L.2.2 Mathematical Definition of the Non-Hazard Zone

Whether an aircraft is in the Non-Hazard Zone for a given time step *i,* is defined in Equation L-5.

Equation L-5: Conditional Statement for Non-Hazard Zone to be Violated at Time i

$$[r_i > S_i]\ OR\left[HMD_{p,i} > HMD^*\right]\ OR\left[d_{h,i} > V_i\right]\ == TRUE$$

There are, however, two major differences from the Hazard Zone: First, the parameters used in Equation L-2 and Equation L-3 are different than the parameters used for the Hazard Zone, as shown in Table L-1. Additionally, Condition 3 is changed as shown below:

L.2.2.1 Condition 3 for Non-Hazard Zone: Vertical Proximity

The vertical size of the Non-Hazard Zone scales based on the current relative vertical closure rate, but is never less than the Vertical Modification (VMOD), as shown below:

Equation L-6: Calculation of Vertical Size of a Non-Hazard Zone

$$V_i = max\left(VMOD, VMOD - \dot{h}_{r,i}\tau_{mod}^*\right)$$

where:

$$i = [t_1, t_2, t_3, \cdots t_{end-1}, t_{end}]$$

$$\tau_{mod}^*, VMOD:$$

***Note**: Refer to Table L-1 for parameters for calculating the size of Hazard and Non-Hazard Zones.*

$$\dot{h}_{r,i} = \dot{z}_2 - \dot{z}_1 \, (\textit{vertical closure rate between aircraft})$$

Note:

1. *$\dot{h}_{r,i}$ is negative for closing geometries*
2. *Note that the relative vertical position matters*
3. *when calculating $\dot{h}_{r,i}$ to ensure the correct sign.*

L.2.3 Hazard and Non-Hazard Zone Parameters

Table L-1 Parameters for Calculating the Size of Hazard and Non-Hazard Zones

		Preventive Alert	Corrective Alert	Warning Alert
Hazard Zone (HAZ)	**τ^*_{mod} (seconds (sec)**	35 sec	35 sec	35 sec
	DMOD and Horizontal Miss Distance (HMD*) (Feet)	4,000	4,000	4,000
	h* (Fixed)	700’	450’	450’
Non-Hazard Zone (HAZNot or NHZ)	**τ^*_{mod}**	110 sec	110 sec	90 sec
	DMOD and HMD*	1.5 NM	1.5 NM	1.2 NM
	VMOD	800’	450’	450’
Minimum Average Time of Alert	**Seconds before HAZ Violation**	55 sec	55 sec	25 sec
Late Threshold (THR_{Late})	**Seconds before HAZ Violation**	20 sec	20 sec	15 sec
Early Threshold (THR_{Early})	**Seconds before HAZ Violation**	75 sec	75 sec	55 sec

The sizes of the zones are calculated using truth data for a particular encounter. For the Preventive alert, the Hazard Zone parameters shown in Table L-1 are informed by the recommended DAA Well Clear (DWC) volume dimensions from the Sense and Avoid Science and Research Panel (SaRP) and NASA simulations (Santiago 2015, Mueller 2016). For the Corrective and Warning alerts, the parameters are informed by the Federal Aviation Administration (FAA)-adjusted sizing of the LoWC volume. Note that the vertical dimension for the Hazard Zone is fixed at the listed values.

The sizing of the Preventive and Corrective Non-Hazard Zone is based on the NASA controller acceptability study that identified the various acceptable time and distance thresholds associated with the earliest acceptable time of ATC interaction in response to a DAA alert (Mueller 2015). The size of the Warning Non-Hazard Zone was sized using

Subject Matter Expert (SME) judgment to provide a balance between reducing undesirable alerts from an operators point of view and providing flexibility to an algorithm designer. Note that the vertical dimension of the Non-Hazard Zone scales with the relative vertical closure velocity per Equation L-6. When calculating relative vertical closure velocity, the geometry of the aircraft must be taken into account in order to ensure the values are signed correctly (negative for closing geometries). The early alert threshold is about the same as the edge of the Non-Hazard zone for non-accelerating encounters. In accelerating encounters the early alert threshold allows for the issuing of alerts while the aircraft is still in the Non-Hazard Zone.

The average alert time for the Preventive and Corrective alerts consists of the average time for a pilot to respond to a Corrective alert as determined by NASA Part Task 5, (Rorie 2016), about 20 seconds, plus the average time to maneuver to maintain well clear, approximately 20 seconds (midpoint of 10-29 seconds from Appendix D). The value was then increased to 55 seconds to ensure time for the pilot to respond to the Corrective alert prior to receiving a Warning alert. In the case of the Warning alert, the pilot immediately executes the recommended maneuver, and thus the average response time is about 10 seconds plus 15 seconds to maneuver. A system will need to have an average alert time greater than this value. The combination of these individual results into single average alert time results were verified by simulations indicating that additional alerting time did not reduce the incidence of loss of DWC, and that shorter alert times were correlated with increased incidence of loss of DWC (Santiago 2015, Mueller 2016).

The Late Alert Threshold is based on the 10^{th} percentile total response time from Part Task 5 (i.e., 90% of responses during Part Task 5 took longer than this value) (Rorie 2016). Furthermore, alert times under this value were strongly correlated with significantly higher rates of loss of DWC (Santiago 2015, Mueller 2016). As defined here, a late alert is an alert that will likely not provide the pilot sufficient time to prevent violating the Hazard Zone, even if the pilot immediately responds to the alert. However, it does not imply that a non-late alert will never result in a Hazard Zone violation (Santiago 2015).

Lastly, it is also important to note that the zones for the Corrective and Warning alerts metrics are nested. As a result, a violation of the Hazard Zone for the Warning alert will always imply the violation of the Hazard Zone for the Corrective and Preventive alerts.

Figure L-3 shows a top-down visualization of the three zones for a simple co-altitude head-on encounter with about 100’ horizontal offset and 300 kts closing speed. The bottom panel visualizes the horizontal size of the Hazard and the Non-Hazard Zone for Corrective Alerts. In order to visualize that the other two conditions of either zone is met, the horizontal separation line is colored according to the color of the respective zone.

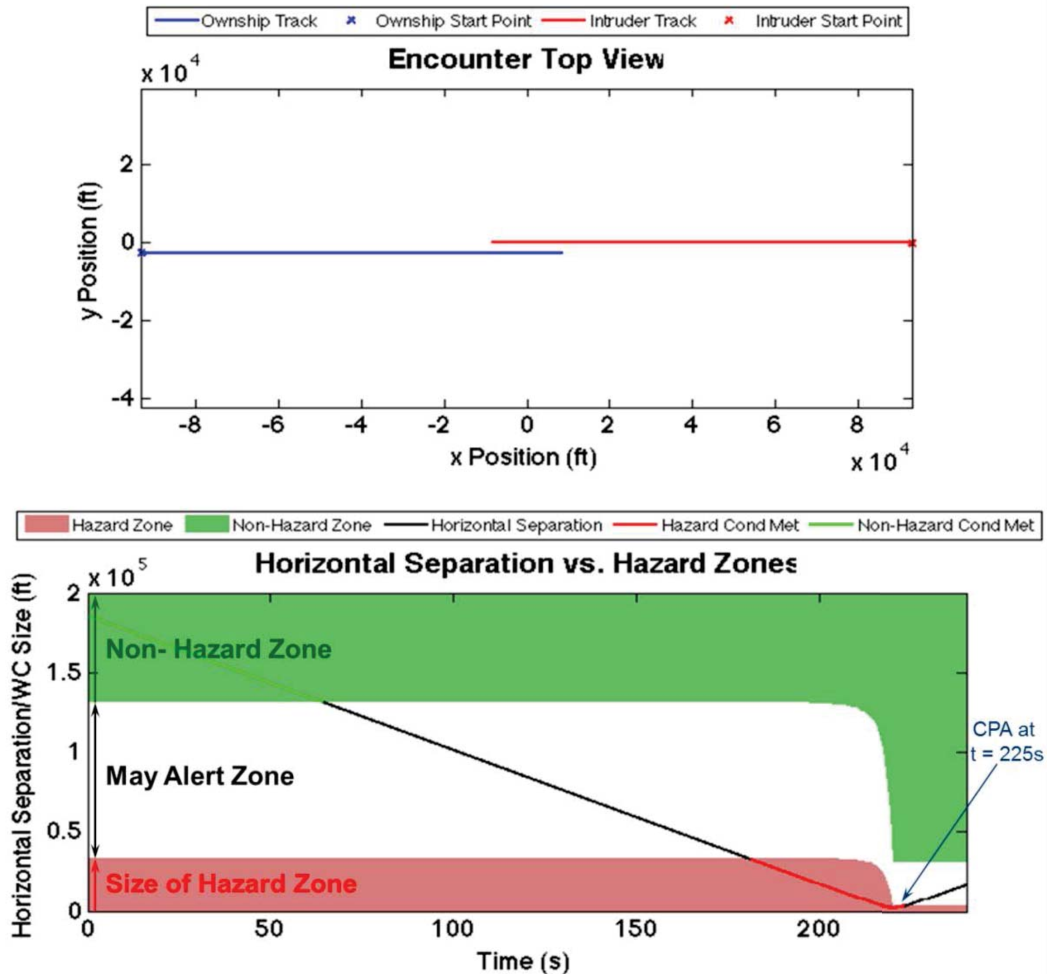


Figure L-3 **Horizontal Expansion of Hazard and Non-Hazard Zones for a Head-on Encounter**

Sources:

Fern, L., Rorie, R. C., and Shively, J. "An Evaluation of Detect and Avoid Displays for Unmanned Aircraft Systems: the Effect of Information Level and Display Location on Pilot Performance." American Institute of Aeronautics and Astronautics (AIAA) Aviation Conference, June 2015.

Mueller, E. R., Santiago, C., and Watza, S., "Piloted 'Well Clear' Performance Evaluation of Detect-and-Avoid Systems with Suggestive Guidance," NASA TM-2016-219396, 2016.

Mueller, E. R., Isaacson, D., and Stevens, D., "Air Traffic Controller Acceptability of Unmanned Aircraft System Detect and Avoid Thresholds," NASA TM-2015-219392, 2015.

Santiago, C., and Mueller, E. R. "Pilot Evaluation of a UAS Detect-and-Avoid System's Effectiveness in Remaining Well Clear," In Air Traffic Management Research and Development Seminar, Lisbon, Portugal, 2015.

Rorie, R. C., Fern, L., and Shively, R. J. "The Impact of Integrated Maneuver Guidance Information on UAS Pilots Performing the Detect and Avoid Task." In Human Factors and Ergonomics Society Annual Meeting, 59(1):55-59, 2015. DOI: 10.1177/1541931215591012.

Rorie, R. C., Fern, L., and Shively, R. J. "The Impact of Suggestive Maneuver Guidance on UAS Pilots Performing the Detect and Avoid Function." AIAA SciTech 2016 Conference, 2016. DOI: 10.2514/6.2016-1002.

L.2.3.1 Output of Encounter Characterization

Using the method described above, the truth data of any encounter can be analyzed to generate an encounter timeline consisting of the following data arrays. The resolution of these arrays must be equal to or greater than the alerting system update rate:

- HZ corresponds to a logical array (i.e., containing only "1" and/or "0") indicating whether Hazard Zone criteria was met (1) or not met (0) at each time epoch
- NHZ corresponds to a logical array indicating whether Non-Hazard Zone criteria was met (1) or not met (0) at each time epoch
- MZ corresponds to a logical array indicating whether the May Alert Zone criteria was met (1) or not met (0) at each time epoch. It is important to note that MZ should be considered as the complement of the union of HZ and NHZ, across a particular encounter (i.e., $(\mathrm{HZ} \cup \mathrm{NHZ})^c$) since there is no mathematical formulation for the May Alert Zone.
- t_{HZ} is an array of time values corresponding to when HZ is TRUE (i.e., equal to 1)
- t_{MZ} is an array of time values corresponding to when MZ is TRUE (i.e., equal to 1)

Each of the above data arrays should be generated for each type of alert and for each encounter.

It is important to understand that if any one element within HZ is equal to 1, HZ is evaluated as true (i.e., (HZ)≡TRUE), otherwise HZ is evaluated as false. Thus, ~HZ is true when all elements of HZ are equal to 0. The same reasoning applies to NHZ, MZ, as well as ALG, defined below.

L.3 Definition of Open Loop Technical Performance Metrics

To calculate open loop TPMs, a particular alerting system implementation must be evaluated on a given encounter set. The output of that system evaluation should generate at least the following outputs, defined here as logical arrays:

- ALG corresponds to a logical array (i.e., containing only 1 and/or 0) indicating whether a particular alerting algorithm is in alert state (1) or did not issue an alert (0) at each time epoch. ALG should be generated for each alert type. Note that due to the hierarchical nature of the alerts, a 1 in the ALG array for Warning alerts implies that ALG is alerted for Preventive and Corrective alerts as well. Likewise a 1 in the ALG array for Corrective alerts implies a 1 for Preventive alerts.

- t_{ALG} is an array of time values corresponding to when ALG is TRUE (i.e., equal to 1), for a particular encounter and alert type.

These arrays must be collected with the same time resolution as the truth encounter characterization arrays, which must be equal to or greater than the alerting system update rate.

Using these variables, logical, set theory-based definitions for each metric are provided in the following paragraph and can be used to analyze system performance for a given encounter. Probabilistic definitions for each metric are also provided to allow for the calculation of aggregate system performance across multiple encounters. Note that these probabilities are based on encounters that violate the HAZ, violate the MAZ but not the HAZ, or remain in the HAZNot. The probabilities are not probabilities across all encounters or alerts.

The formulas and descriptions here are written generically and apply to each type of alert, hence the use of the i subscripts representing the DAA Preventive Alert (PA), the DAA Corrective Alert (CA), and the DAA Warning Alert (WA).

Three main categories of technical performance metrics are listed below, and correspond to the three rows shown in Figure L-4.

1. Performance Metrics Analyzing Tracks with HAZ Violation (Alerts Required)
2. Performance Metrics Analyzing Tracks with MAZ Violation (Permissible Alerts)
3. Performance Metrics Analyzing Tracks remaining in Non-Hazard Zone (Alerts Undesirable)

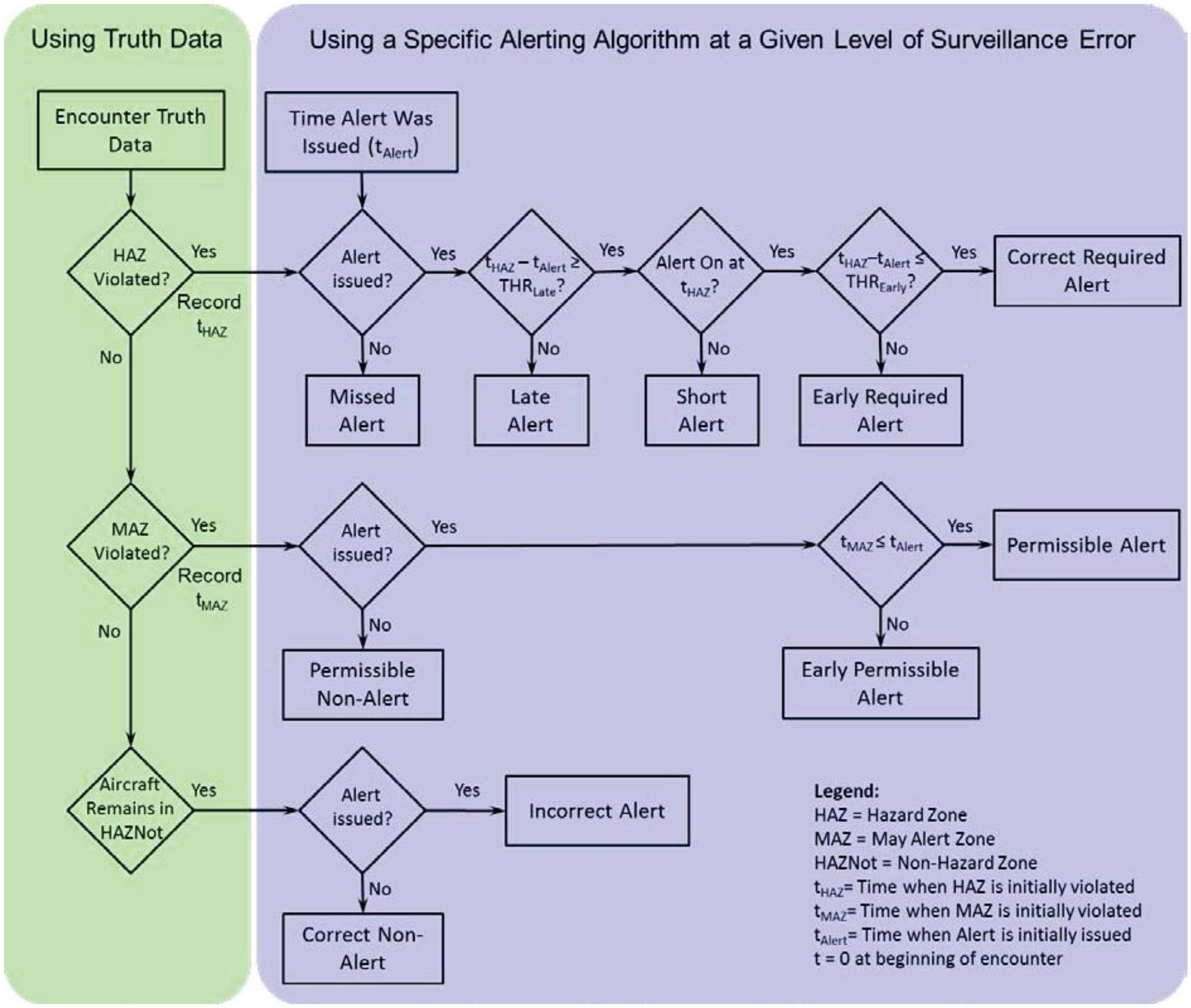


Figure L-4 **Alert Scoring Process**

Note: *Assumes that t_{Alert}, t_{HAZ}, and t_{MAZ} are with respect to an encounter timeline in which t=0 is the start of the encounter and time epochs increase during the encounter.*

L.3.1 Performance Metrics Analyzing Tracks with HAZ Violation (Alert Required)

An alert is required for any encounter where the intruder aircraft violates the Hazard Zone at any given point throughout the encounter. The following performance metrics together quantify an alerting system's performance for required alerts:

- Probability (P) of Missed Alert P(MA)
- Probability of Late Alert P(LA)
- Probability of Short Alert P(SA)
- Probability of Early Required Alert P(ERA)
- Probability of Correct Required Alert P(CRA)

- Average Alert Time Before HAZ violation (AAT)
- Alerting Ratio (AR)

L.3.1.1 Probability of Missed Alerts P(MA)

A Missed Alert occurs for encounters where an intruder aircraft enters the Hazard Zone, but the alerting system does not issue an alert. These are undesirable. Logically, Missed Alerts can be expressed as follows:

Equation L-7: Logical Missed Alert Definition

$$(HZ) \equiv TRUE \ and$$

$$(ALG) \equiv FALSE$$

The aggregate P(MA) across an encounter set is calculated according to Equation L-8:

Equation L-8: Calculation of P(MA)

$$P(MA)|_i = \frac{N_{MA}|_i}{N_{HZE}|_i}$$

$where$:

$i \in [PA, CA, WA]$

$N_{MA} = Number\ of\ Missed\ Alerts\ for\ a\ given\ encounter\ set$

$N_{HZE} = Number\ of\ HAZ\ violation\ encounters\ for\ a\ given\ encounter\ set,$

$i.e., the\ number\ of\ encounters\ where\ (HZ) \equiv TRUE$

L.3.1.2 Probability of Late Alerts P(LA)

A Late Alert occurs for encounter where an intruder aircraft enters the Hazard Zone, but the alerting system issues an alert less than the required time before HAZ violation, as defined in Table L-1. Late alerts may occur after entering the Hazard Zone. These are undesirable. Logically, Late Alerts can be expressed as follows:

Equation L-9: Logical Late Alert Definition

$$(HZ) \equiv TRUE \ and$$

$$(ALG) \equiv TRUE \ and$$

$$((t_{HZ}(1) - t_{ALG}(1)) \geq THR_{Late}) \equiv FALSE$$

Note that this definition differs from the MOPS requirement. The MOPS requirement accounts for dynamic encounters to ensure implementations can have no late alerts when using the test vectors. The aggregate P(LA) across an encounter set is calculated according to Equation L-10:

Equation L-10: Calculation of P(LA)

$$P(LA)|_i = \frac{N_{LA}|_i}{N_{HZE}|_i}$$

$where$:

$i \in [PA, CA, WA]$

$N_{LA} = Number\ of\ Late\ Alerts\ for\ a\ given\ encounter\ set$

$N_{HZE} = Number\ of\ HAZ\ violation\ encounters\ for\ a\ given\ encounter\ set$

L.3.1.3 Probability of Short Alert P(SA)

A Short Alert occurs for encounters where an alerting system is not in alert state at the time at which the intruder aircraft violates the Hazard Zone, but had previously issued an alert. Note that if an alert is issued late and does not persist until the Hazard Zone is violated, the alert is scored as a late alert, as lateness is considered to affect safety more drastically as compared to shortness. These are undesirable. Logically, Short Alerts can be expressed as follows:

Equation L-11: Logical Short Alert Definition

$$(HZ) \equiv TRUE\ and$$

$$(ALG) \equiv TRUE\ and$$

$$\left(\left(t_{HZ}(1) - t_{ALG}(1)\right) \geq THR_{Late}\right) \equiv TRUE\ and$$

$$\left(t_{HZ}(1) \in t_{ALG}\right) \equiv FALSE$$

The aggregate P(SA) across an encounter set is calculated according to Equation L-12:

Equation L-12: Calculation of P(SA)

$$P(SA)|_i = \frac{N_{SA}|_i}{N_{HZE}|_i}$$

$where$:

$i \in [PA, CA, WA]$

$N_{SA} = Number\ of\ Short\ Alerts\ for\ a\ given\ encounter\ set$

$N_{HZE} = Number\ of\ HAZ\ violation\ encounters\ for\ a\ given\ encounter\ set$

L.3.1.4 Probability of Early Required Alert P(ERA)

An ERA occurs for encounters where an intruder aircraft enters into the Hazard Zone, but the system issues an alert prior to the Early Threshold. The Early Threshold is approximately the same as the boundary between the MAZ and HAZNot for non-accelerating cases. These are undesirable. Note that this logic, which works backwards from the HAZ zone time, differs from the Early Permissible Alert (EPA) logic, which is based on the boundary between MAZ and HAZNot. Logically, Early Required Alerts can be expressed as follows:

Equation L-13: Logical Early Required Alert Definition

$$(HZ) \equiv TRUE\ and$$

$$(ALG) \equiv TRUE\ and$$

$$\left(\left(t_{HZ}(1) - t_{ALG}(1)\right) \geq THR_{Late}\right) \equiv TRUE\ and$$

$$(t_{HZ}(1) \in t_{ALG}) \equiv TRUE\ and$$

$$((t_{HZ}(1) - t_{ALG}(1)) \leq THR_{Early}) \equiv FALSE$$

The aggregate probability of an Early Required Alert P(ERA) across an encounter set is calculated according to Equation L-14:

Equation L-14: Calculation of P(ERA)

$$P(ERA)|_i = \frac{N_{ERA}|_i}{N_{HZE}|_i}$$

$where$:

$i \in [PA, CA, WA]$

$N_{ERA} = Number\ of\ Early\ Required\ Alerts\ for\ a\ given\ set\ of\ encounters$

$N_{HZE} = Number\ of\ HAZ\ violation\ encounters\ for\ a\ given\ encounter\ set$

L.3.1.5 Probability of Correct Required Alert P(CRA)

A CRA occurs for encounters where an intruder aircraft enters into the Hazard Zone, and the alerting system issues a timely alert. In other words, a CRA occurs when an alert is neither late, short, nor early. These are desirable and the probability of CRA should be as close to 1 as possible.

Logically, Correct Required Alerts can be expressed as follows. This definition is comprised of the logical definitions for Early, Late, Short, and Missed alerts, with the opposite resulting logical evaluation (i.e., FALSE to TRUE).

Equation L-15: Logical Correct Alert (CA) Definition

$$(HZ) \equiv TRUE\ and$$

$$(ALG) \equiv TRUE\ and$$

$$(t_{HZ}(1) \in t_{ALG}) \equiv TRUE\ and$$

$$((t_{HZ}(1) - t_{ALG}(1)) \leq THR_{Early}) \equiv TRUE\ and$$

$$((t_{HZ}(1) - t_{ALG}(1)) \geq THR_{Late}) \equiv TRUE$$

The aggregate P(CRA) across an encounter set is calculated according to Equation L-16:

Equation L-16: Calculation of P(CRA)

$$P(CRA)|_i = 1 - P(MA)|_i - P(LA)|_i - P(SA)|_i - P(ERA)|_i$$

$where$:

$i \in [\mathrm{PA, CA, WA}]$

$P(LA)|_i = \text{Probability of Late Alert}$

$P(MA)|_i = \text{Probability of Missed Alert}$

$P(SA)|_i = \text{Probability of Short Alert}$

$P(ERA)|_i = \text{Probability of Early Required Alert}$

L.3.1.6 Average Alert Time (AAT) before HAZ Violation

The average time of alert before HAZ violation is defined as the average number of seconds before the violation of the Hazard Zone at which a particular alerting system issues an alert. For a given encounter set, this metric is calculated based only on encounters where the Hazard Zone is violated ($(HZ) \equiv TRUE$) and the alerting system issues an alert ($(ALG) \equiv TRUE$) as shown in Equation L-17. A larger value is desirable, but not at the expense of too many Early or Incorrect Alerts. Equation L-17 assumes that the encounter starts at t=0.

Equation L-17: Calculation of Average Alert Time AAT

$$AAT|_i = \frac{\sum(t_{HZ}(1) - t_{ALG}(1))\,|_i}{\sum N\,|_i}$$

$where$:

$i \in [PA, CA, WA]$

$N = Number\ of\ encounters\ with\ both\ HAZ\ violation\ and\ alert\ issued$

L.3.1.7 Alert Ratio (AR)

The AR quantifies how likely an alerting system is to issue an alert for an encounter with a Hazard Zone violation. It is defined as the probability of an alert given an encounter divided by the probability of Hazard Zone violation given an encounter. Since both probabilities are given an encounter, the number of encounters cancels out if the same data set is used just leaving the number of alerted encounters divided by the number of

HAZ encounters. Ideally this ratio would be close to 1, indicating there is a single alert for each Hazard Zone violation.

Equation L-18: Calculation of Alert Ratio

$$AR|_i = \frac{N_{Alerted\ Encounters}|_i}{N_{HZE}|_i}$$

$where$:

$i \in [PA, CA, WA]$

$N_{Alerted\ Encounters}$
$= Number\ of\ Alerted\ Encounters\ in\ a\ given\ encounter\ set$

$N_{HZE} = Number\ of\ HAZ\ violation\ encounters\ for\ a\ given\ encounter\ set$

L.3.2 Performance Metrics Analyzing Tracks with MAZ Violation (Alerts Permissible)

In cases where an intruder aircraft enters into the May Alert Zone but not the Hazard Zone, the system designer can choose whether a particular implementation will issue an alert or not. The May Alert Zone accounts for the fact that the presence of a hazard can be subjective and depends on the specific encounter; this allows designers to adjust the alerting logic to try to reduce the number of unnecessary alerts, while not immediately being penalized for delaying the issuance of an alert. Note that alerts may occur in the Non-Hazard Zone as well without penalty if at some point the intruder then enters the May Alert Zone. The May Alert Zone is not representative of the physical dimensions of when alerts can occur.

This, however, can result in certain undesirable algorithm behaviors not being directly analyzed when calculating the overall system performance. Thus, in addition to the probability of Permissible Alerts and Permissible Non-Alerts, three additional performance metrics are necessary to counteract such undesirable algorithm behaviors: Average Alert Time, Probability of Early Permissible Alert, and Average Number of Alerts per Alerted Encounter.

- Probability of Permissible Non-Alert P(PNA)
- Probability of Early Permissible Alert P(EPA)
- Probability of Permissible Alert P(PermA)
- Average Number of Alerts Issued per Encounter (ANA)

As introduced earlier, Average Alert Time (AAT) is the average time before HAZ violation when the system issues an alert. Including AAT counteracts a bias of issuing alerts later to avoid incorrect or early alerts. This bias arises due to the presence of the May Alert Zone; reducing the sensitivity of the algorithm can reduce the number of incorrect or early alerts without the immediate expense of higher late/missed alerts. Including AAT as a performance metric introduces a balancing force on this trade-off.

The second metric to be included is the Average Number of Alerts (ANA) issued per alerted encounter. Since alerts issued on encounters where an intruder only enters into the May Alert Zone are not counted as incorrect alerts, a system that may be “trigger-happy” may issue multiple short alerts per encounter and would not be docked for poor alerting logic design. In reality, however, it is an indication of poor alerting algorithm design, namely the lack of appropriate alerting hysteresis.

L.3.2.1 Probability of Permissible Non-Alert P(PNA)

A PNA occurs for encounters where an alerting system does not issue an alert and the intruder aircraft entered into the May Alert Zone but not the Hazard Zone. These are neither desirable nor undesirable. Logically, a Permissible Non-Alert can be expressed as follows:

Equation L-19: Logical Permissible Non-Alert Definition

$$(MZ) \equiv TRUE \ and$$

$$(HZ) \equiv FALSE \ and$$

$$(ALG) \equiv FALSE$$

The aggregate P(PNA) across an encounter set is calculated according to Equation L-20:

Equation L-20: Calculation of P(PNA)

$$P(PNA)|_i = \frac{N_{PNA}|_i}{N_{MZE}|_i}$$

$where$:

$i \in [PA, CA, WA]$

N_{PNA}
$= Number\ of\ Permissible\ Non$
$- Alerts\ for\ a\ given\ set\ of\ encounters$

$N_{MZE} = Number\ of\ MAZ, but\ not\ HAZ, violation\ encounters$
$for\ a\ given\ encounter\ set,$

$i.e., the\ number\ of\ encounters\ where\ (MZ) \equiv TRUE\ and\ (HZ) \equiv FALSE$

L.3.2.2 Probability of Early Permissible Alert P(EPA)

An EPA occurs for encounter where an intruder aircraft enters into the May Alert Zone, but the system issues an alert while the aircraft still meets the criteria for the Non-Hazard Zone. Note that this logic, which is based on the boundary between MAZ and HAZNot, differs from the Early Required Alert (ERA) logic, which is based on a time before HAZ violation. Early Permissible Alerts are undesirable. Logically, an Early Permissible Alert can be expressed as follows:

Equation L-21: Logical Early Permissible Alert Definition

$$(MZ) \equiv TRUE \ and$$

$$(HZ) \equiv FALSE \ and$$

$$(ALG) \equiv TRUE \; and$$

$$(t_{MZ}(1) \leq t_{ALG}(1)) \equiv FALSE$$

The aggregate P(EPA) across an encounter set is calculated according to Equation L-22:

Equation L-22: Calculation of P(EPA)

$$P(EPA)|_i = \frac{N_{EPA}|_i}{N_{MZE}|_i}$$

$where:$

$i \in [PA, CA, WA]$

N_{EPA}
$= Number\ of\ Early\ Permissible\ Alerts\ for\ a\ given\ set\ of\ encounters$

$N_{MZE} = Number\ of\ MAZ, but\ not\ HAZ, violation\ encounters$
$for\ a\ given\ encounter\ set$

L.3.2.3 Probability of Permissible Alert P(PermA)

A Permissible Alert is defined as an alert issued for an encounter where an aircraft enters into the May Alert Zone but not the Hazard Zone, and is not early. These are neither desirable nor undesirable. Logically, a Permissible Alert can be expressed as follows:

Equation L-23: Logical Permissible Alert Definition

$$(MZ) \equiv TRUE \; and$$

$$(HZ) \equiv FALSE \; and$$

$$(ALG) \equiv TRUE \; and$$

$$(t_{MZ}(1) \leq t_{ALG}(1)) \equiv TRUE$$

The aggregate probability of Permissible Alerts *P(PermA)* across an encounter set is calculated according to Equation L-24:

Equation L-24: Calculation of Probability of Permissible Alert P(PermA)

$$P(PermA)|_i = 1 - P(PNA)|_i - P(EPA)|_i$$

$where:$

$i \in [PA, CA, WA]$

$P(PNA)|_i = Probability\ of\ Permissable\ Non-Alert$

$P(EPA)|_i = Probability\ of\ Early\ Permissible\ Alert$

L.3.2.4 Average Number of Alerts per Alerted Encounter (ANA)

The Average Number of Alerts per Alerted Encounter is defined as the average number of alerts a particular system issues on encounters where there is at least one alert. These could be from tracks that violate the HAZ, the MAZ, or remain in the HAZNot. This value is ideally 1.

Equation L-25: Calculation of Average Number of Alerts per Encounter

$$ANA|_i = \frac{N_{Issued\ Alerts}|_i}{N_{Alerted\ Encounters}|_i}$$

$where$:

$i \in [PA, CA, WA]$

$N_{Issued\ Alerts} =$
$Total\ Number\ of\ Alerts\ issued\ for\ a\ given\ set\ of\ encounters$
(i.e., number of times ALG goes from 0 to 1 in each encounter).

$N_{Alerted\ Encounters} =$
$Number\ of\ Alerted\ Encounters\ in\ a\ given\ encounter\ set,$
i.e., encounters where $(ALG)\ \equiv TRUE$

L.3.3 Performance Metrics Analyzing Tracks in Non-Hazard Zone (Alerts Undesirable)

An alert is undesired for any encounter where an intruder aircraft remains in the Non-Hazard Zone. The following two performance metrics together quantify an alerting system's performance for undesired alerts:

- Probability of Correct Non-Alert P(CNA)
- Probability of Incorrect Alert P(IA)

L.3.3.1 Probability of Correct Non-Alert

A Correct Non-Alert occurs for encounters where an intruder aircraft never leaves the Non-Hazard Zone, and the system does not issue an alert. These are desirable and the probability of CNA should be as close to 1 as possible. Logically, Correct Non-Alert can be expressed as follows:

Equation L-26: Logical Correct Non-Alert Definition

$$(NHZ)\ \equiv TRUE\ and$$

$$(MZ)\ \equiv FALSE\ and$$

$$(HZ)\ \equiv FALSE\ and$$

$$(ALG)\ \equiv FALSE$$

The aggregate P(CNA) across an encounter set is defined in Equation L-27:

Equation L-27: Calculation of P(CNA)

$$P(CNA)|_i = \frac{N_{CNA}|_i}{N_{NHZE}|_i}$$

$where$:

$i \in [PA, CA, WA]$

$N_{CNA} = Number\ of\ Correct\ Non-Alerts\ for\ a\ given\ set\ of\ encounters$

N_{NHZE}
$= Number\ of\ encounters\ where\ the\ intruder\ remains\ in\ the\ Non$
$- Hazard\ Zone\ for\ a\ given\ encounter\ set$

$i.e., the\ number\ of\ encounters\ where\ (NHZ) \equiv TRUE, (MZ)$

$\equiv FALSE, and\ (HZ)\ \equiv FALSE$

L.3.3.2 Probability of Incorrect Alert

A corollary to P(CNA) is the Probability of Incorrect Alert, or P(IA). An Incorrect Alert is defined as an alert issued on an encounter for which the intruder aircraft remains in the Non-Hazard Zone. Incorrect Alerts are not referred to as false or nuisance alerts here; False Alerts are defined as occurring as a result of a physical malfunction of the alerting system and are considered as part of the safety case for DAA. Nuisance Alerts require the presence of human judgment in order to be deemed a nuisance and are thus analyzed separately. Lastly, the performance metric is defined as a percentage – for the human factors analysis translating this percentage into a rate in terms of ownship flight hours will be more appropriate. These are undesirable.

Logically, an Incorrect Alert can be expressed as follows:

Equation L-28: Logical Incorrect Alert Definition

$$(NHZ)\ \equiv TRUE\ and$$

$$(MZ)\ \equiv FALSE\ and$$

$$(HZ)\ \equiv FALSE\ and$$

$$(ALG)\ \equiv TRUE$$

The aggregate P(IA) across an encounter set is calculated according to Equation L-29:

Equation L-29: Calculation of P(IA)

$$P(IA)|_i = 1 - P(CNA)|_i$$

$where$:

$i \in [PA, CA, WA]$

$P(CNA)|_i = Probability\ of\ Correct\ Non-\ Alert$

L.3.4 Additional Open Loop Considerations

L.3.4.1 Total Number of Encounters and Total Number of Alerted Encounters

The Total Number of Encounters ($N_{Encounters}$) and The Total Number of Alerted Encounters (those where $(ALG)\ \equiv TRUE$ or $N_{Alerted\ Encounters}$) may also be calculated. These would allow additional metrics to be calculated using these values as the denominators instead of the number of encounters that violate the HAZ, MAZ, or remain in the Non-Hazard Zone. However, these types of metrics will reflect more of the encounter set characteristics than the performance of an alerting system.

L.3.4.2 Multiple Closest Point of Approach (CPA) Scoring

One challenge of evaluating encounters derived from real-world operational data is that in some cases the ownship encounters certain intruders more than once over the duration of a single ownship trip. Though there is a single, “global” CPA for a given set of two flight tracks, the two aircraft effectively re-encounter each other multiple times, generating multiple local CPAs. This results in three challenges when scoring alerts. First, if the system alerts on a local CPA and then re-alerts on the global CPA, the second alert may be scored as late incorrectly. Second, if there is no re-alert on the global CPA but the alerting system simply remains in alert state, the non-alert may be scored as a missed alert incorrectly (not shown). Alternatively, the alert from the initial local CPA could be used for scoring but it may increase the average alert time artificially. Third, any alert issued on a local CPA after the global CPA would be scored as a nuisance alert incorrectly. Highlighted in Figure L-5 is a case where two aircraft are in close proximity for a prolonged period of time.

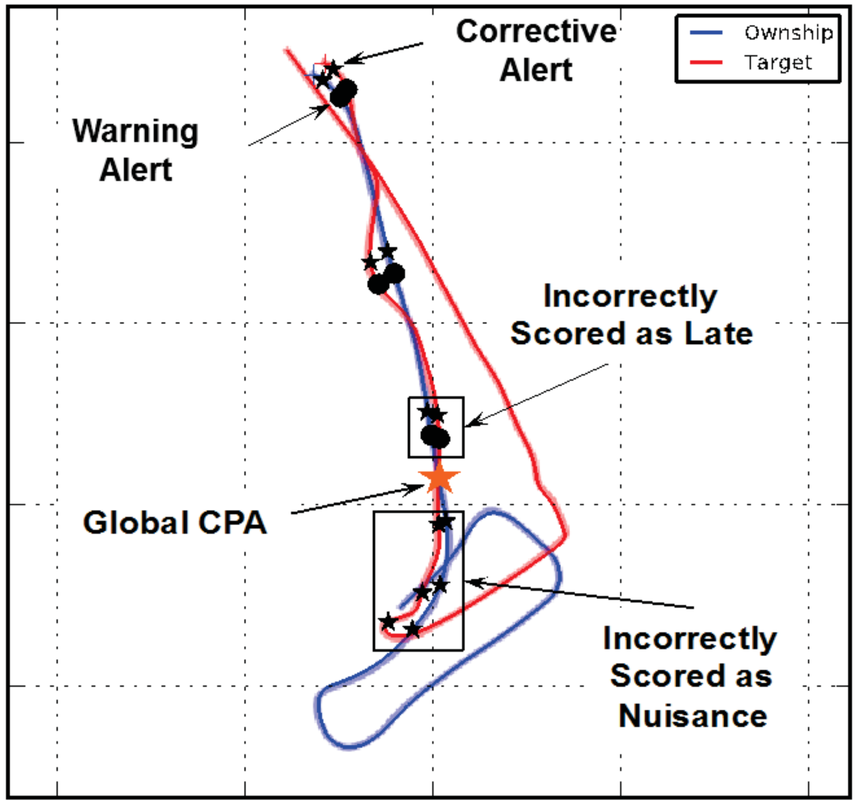


Figure L-5 **Sample Horizontal Plot of Prolonged Proximity Encounter**

To address this, alert scoring is adjusted using the following rules:

1. An encounter is defined as the time period between an aircraft entering and exiting the May Alert Zone as observed in the truth data.
2. The local CPA is defined as the minimum horizontal distance observed in the period identified in Step 1.
3. Once the intruder returns to the Non-Hazard Zone, it is considered a new intruder and any alert thereafter will be evaluated against a new, future local CPA.
4. If an alert is issued before the intruder enters into the May Alert Zone, the intruder must enter the May Alert Zone within the next 110 seconds for the alert to not be considered an incorrect alert.
5. Alerts issued after the CPA are not considered incorrect alerts if they were issued while the intruder was still in the May Alert Zone, but would be considered missed or late if no earlier alerts had been issued.

L.3.4.3 Performance Visualization

Figure L-6 shows a notional method for visualization of the performance after a particular system implantation is evaluated on an encounter set. A point representing a system with perfect alerting performance would be located at the top left corner (100% Correct Required Alerts, 0% Incorrect Alerts). However, due to various effects, the performance of a real-life system will be less than that optimal. The main sources of performance reduction are the effects of predictive uncertainty, measurements uncertainty, and potential negative effects from restrictive MOPS requirements. Each source is addressed individually.

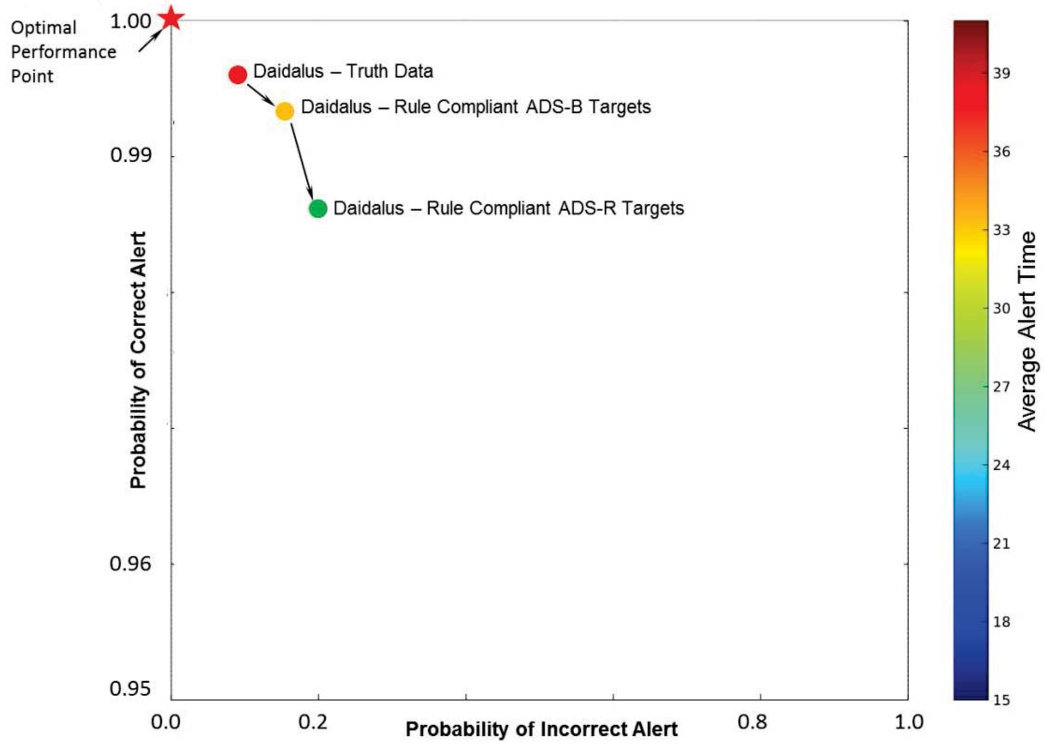


Figure L-6 **Notional Performance Visualization (Not Real Data)**

L.3.4.4 Performance Reduction due to Predictive Uncertainty

To determine the maximum obtainable performance of a particular system implementation, the data set of interest should be analyzed with the system receiving truth data; i.e., without any state uncertainty. Doing so allows for the separation of the effects of predictive errors from the effects of state uncertainty caused by measurement and transmission errors. If undesirable behavior is observed it implies potentially poor performance of the alerting system's predictive engine.

L.3.4.5 Performance Reduction due to Measurement Uncertainty

Once representative measurement and transmission errors are introduced, the additional change in performance is then a measurement of the system's robustness to measurement uncertainty (as opposed to predictive uncertainty). A simple sample alerting algorithm can be used to investigate the effects of different levels of sensor uncertainty.

The level of measurement uncertainty present in the data received from a particular intruder depends on the type of intruder and sensor(s) used. As such, the performance of an alerting system should be analyzed against specific, representative intruders and their associated level of measurement uncertainties. Table L-2 shows a set of sample reference intruders.

Table L-2 Possible Reference Intruders

	ADS-B Only	ADS-R Only	Active Surv. Only	Non-Coop	ADS-B + Active	ADS-R + Active
1090ES	✓	X	X	X	✓	X
UAT	X	✓	X	X	X	✓
Mode C	X	X	✓	X	✓	✓
Radar Validated	X	X	X	✓	X	X

L.3.4.6 Performance Reduction due to Minimum Alerting Requirements

During the development phase of the MOPS, TPMs can also help identify whether a proposed requirement generates too stringent of an alerting requirement, and would thus limit the achievable performance space. As such, the TPMs serve as a basis for the verification and validation of MOPS requirements against a sample algorithm implementation.

L.4 Generating an Encounter Timeline for Closed Loop Metrics

As the basis for calculating the closed loop metrics proposed here, the truth data of any encounter must be analyzed to generate an encounter timeline consisting of the following data arrays. The arrays must be collected for each unmitigated encounter and the associated mitigated encounter. The resolution of these arrays must be equal to or greater than the DAA system update rate:

- UMLOWC (Unmitigated Loss of Well Clear) corresponds to a logical array (i.e., containing only 1 and/or 0) indicating whether LoWC criteria was met (1) or not met (0) at each time epoch for an unmitigated encounter
- UMNMAC (Unmitigated Near Mid-Air Collision) corresponds to a logical array (i.e., containing only 1 and/or 0) indicating whether the NMAC criteria was met (1) or not met (0) at each time epoch for an unmitigated encounter
- LOWC corresponds to a logical array (i.e., containing only1 and/or 0) indicating whether LoWC criteria was met (1) or not met (0) at each time epoch for a mitigated encounter
- NMAC corresponds to a logical array (i.e., containing only1 and/or 0) indicating whether the NMAC criteria was met (1) or not met (0) at each time epoch for a mitigated encounter

LoWC is defined in Appendix C of these DAA MOPS. NMAC is a cylinder ±100’ above and below the ownship and 500’ horizontally around the ownship.

Additionally, the true three-dimensional (3D) position of the ownship and the intruder (lat/long or x/y and altitude) must be recorded at each time epoch for both the unmitigated and mitigated versions of an encounter. This will allow the horizontal and vertical separations (*dx*, *dy*, and *dz*) to be calculated at every time epoch.

TPMs can also be collected for Human-in-the-Loop (HITL) or flight test encounters, but the test designer may need to specify the unmitigated trajectory for each encounter in advance. Data collection with other than fast-time simulations may also not provide statistical significance for these TPMs.

These equations assume the encounters are directly sampled from the desired distribution for simplification. If encounters are not directly sampled and have weighting factors (for example Massachusetts Institute of Technology Lincoln Laboratory (MIT LL) uncorrelated encounters), the calculation of these metrics must also be weighted.

L.5 Closed Loop Safety Metrics

The safety metrics quantify how much safety is improved when a DAA system is used during particular operation and whether a DAA system will meet a particular safety standard. There are two key safety metrics, LoWC Ratio (LR) and NMAC Risk Ratio (RR). The other metrics in this subsection are used to support the calculation of LR and RR and to determine the severity of a LoWC or NMAC.

The safety metrics can be divided into two categories, maintain DWC and collision avoidance. Metrics that quantify performance with respect to maintaining DWC capture the system's performance with respect to the DWC volume that is changing in size based on tau. Collision avoidance metrics are those that quantify performance with respect to the NMAC volume that is fixed in size.

These metrics assume a set of pairwise encounters. In closed-loop simulations with more than one UAS and/or intruder, some of these definitions may need adjusting. For example, the total number of encounters ($N_{Encounters}$) may change due to maneuvers.

L.5.1 Maintain DWC Safety Metrics

L.5.1.1 LoWC Ratio (LR)

The LoWC Ratio (LR) is the key measure for determining the relative improvement in avoiding LoWC when introducing DAA system. A number greater than 1 means the DAA system introduces more LoWC than it resolves. The smaller the ratio, the better the DAA system performs at avoiding a LoWC. It is less dependent on the number of challenging encounters in an encounter set since it is scaled to the number of unmitigated LoWCs.

Equation L-30: Number of Unmitigated LoWC Definition

$$N_{Unmit.LoWC} = count\ of\ [(UMLOWC) \equiv TRUE]\ encounters$$

Equation L-31: Probability of LoWC Definition

$$P(LoWC\_UM) = \frac{N_{Unmit.LoWC}}{N_{Encounters}}$$

Equation L-32: LoWC Ratio Definition

$$LR = \frac{P(LoWC)}{P(LoWC\_UM)} = \frac{N_{LoWC}}{N_{Unmit.LoWC}}$$

where:

$N_{LoWC} = Number\ of\ mitigated\ encounters\ with\ LoWC$

$N_{Unmit.LoWC} = Number\ of\ unmitigated\ LoWCs$

$N_{Encounters} = Total\ number\ of\ encounters$

$P(LoWC) = Probability\ of\ LoWC\ as\ defined\ below$

L.5.1.2 Probability of LoWC (*P(LoWC)*)

The Probability of LoWC (*P(LoWC)*) describes the chance of a LoWC for any encounter represented by an encounter set given the DAA system (enc.) can provide mitigation, also sometimes described as *P(LoWC|enc. with DAA system)*. *P(LoWC)* can be broken down into the probability of Induced LoWC encounters and the probability of Unresolved LoWC encounters. A low number is better, but this metric is influenced strongly by the geometries in the encounter set and how an encounter is defined, so LR is generally a more useful metric since it is not dependent on the number of unmitigated LoWC encounters in an encounter set.

Equation L-33: Number of LoWC Definition

$$N_{LoWC} = count\ of\ [(LOWC) \equiv TRUE]\ encounters$$

Equation L-34: Probability of LoWC Definition

$$P(LoWC) = \frac{N_{LoWC}}{N_{Encounters}} = P(Induced_{LoWC}) + P(Unresolved_{LoWC})$$

where:

$N_{LoWC} = Number$ of $encounters\ with\ LoWC$

$N_{Encounters} = Total\ number\ of\ encounters$

L.5.1.3 Probability of Induced LoWC

The Probability of Induced Losses of Well Clear ($P(Induced_{LoWC})$) describes the chance of a LoWC during an encounter where the truth tracks did not have a LoWC, but where a DAA system issued commands that resulted in a LoWC nonetheless. This number should optimally be 0. A higher number can indicate logical issues with a guidance algorithm.

Equation L-35: Number of Induced LoWC Definition

$$N_{Induced\ LoWC} = count\ of\ [(LOWC) \equiv TRUE\ AND\ (UMLOWC) \equiv FALSE]\ encounters$$

Equation L-36: Probability of Induced LoWC Definition

$$P(Induced_{LoWC}) = \frac{N_{Induced\ LoWC}}{N_{Encounters}}$$

where:

$$N_{Induced\ LoWC} = Number\ of\ encounters\ with\ a\ DAA\ induced\ LoWC$$

$$N_{Encounters} = Total\ number\ of\ encounters$$

L.5.1.4 Probability of Unresolved LoWC

The Probability of Unresolved Losses of Well Clear ($P(Unresolved_{LoWC})$) describes the chance of a LoWC during an encounter where the truth tracks have a LoWC and the DAA system failed to resolve the situation.

Equation L-37: Number of Unresolved LoWC Definition

$$N_{Unresolved\ LoWC} = count\ of\ [(LOWC) \equiv TRUE\ AND\ (UMLOWC) \equiv TRUE]\ encounters$$

Equation L-38: Probability of Unresolved LoWC Definition

$$P(Unresolved_{LoWC}) = \frac{N_{Unresolved\ LoWC}}{N_{Encounters}}$$

where:

$$N_{Unresolved\ LoWC} = Number\ of\ encounters\ with\ an\ unresolved\ LoWC$$

$$N_{Encounters} = Total\ number\ of\ encounters$$

L.5.1.5 Severity of LoWC (SLoWC)

The Severity of LoWC (SLoWC) metric is used to assess the severity of LoWC on a per-encounter basis by capturing the most serious instance of LoWC throughout an encounter. Based on the Well Clear definition, this severity metric is assessed based on the severity of the local penetration into all three of the Well Clear components: Horizontal Proximity, Horizontal Miss Distance Projection and Vertical Separation.

The combined severity at any instance during an encounter from all three components can be expressed as:

Equation L-39: Calculation of SLoWC for Each Time Step

$$SLoWC_i = (1 - RangePen_i \oplus HMDPen_i \oplus VertPen_i) * 100\%$$

$RangePen_i$, $HMDPen_i$, and $VertPen_i$ are defined in the subsequent paragraphs. The Fernandez-Guasti Squircle operator, $\oplus$, is used to combine the normalized penetrations from all three dimensions. Additional discussion on the rationale for the use of the Fernandez-Guasti's Squircle Mapping can be found in Subsection L.6.

Equation L-40: Fernandez-Guasti Squircle Operator Definition

$$x \oplus y \equiv \sqrt{x^2 + (1 - x^2)y^2}$$

The overall SLoWC penetration for the entire encounter is:

Equation L-41: SLoWC Calculation for an Encounter

$$SLoWC = MAX(SLoWC_i)$$

The resulting SLoWC ranges from 0% to 100% with 0% indicating Well Clear, and 100% representing full penetration into the Well Clear protection volume, i.e., both aircraft at the same place at the same time.

Examples of the SLoWC metric against linear encounters with different horizontal and vertical miss profiles along with an example application SLoWC to compare unmitigated and mitigated encounters are also presented in Subsection L.6.

L.5.1.5.1 SLoWC Horizontal Proximity

The normalized horizontal proximity penetration is analogous to assessing the penetration into the τ_{mod} dimension.

The local normalized horizontal proximity penetration is defined as:

Equation L-42: Calculation of RangePen

$$RangePen_i = MIN\left(\frac{r_i}{S_i}, 1\right)$$

Where the required horizontal range, S_i, given the local horizontal range rate and Well Clear's DMOD and τ_{mod}^* yields:

Equation L-43: Calculation of Required Horizontal Range, S

$$S_i = MAX\left(DMOD,\ \frac{1}{2}\left(\sqrt{(\dot{r}_i\tau_{mod}^*)^2 + 4DMOD^2} - \dot{r}_i\tau_{mod}^*\right)\right)$$

where:

$i = [t_1, t_2, t_3, \cdots t_{end-1}, t_{end}]$

DMOD = 4000'

$\tau_{mod}^* = 35\ s$,

r_i = *horizontal range*

$\dot{r}_i$ = *horizontal range rate*

The resultant normalized horizontal penetration produces a value ranging from one to zero with one indicating the edge of τ_{mod}^*, and zero representing full penetration into the horizontal proximity dimension.

L.5.1.5.2 SLoWC Horizontal Miss Distance Projection

The normalized HMD Penetration (HMDPen) is based on the ratio of the local HMD projection versus the Well Clear DMOD requirement:

Equation L-44: Calculation of HMDPen

$$HMDPen_i = MIN\left(\frac{HMD_i}{DMOD}, 1\right)$$

$$HMD_i = \left.\sqrt{(dx + v_{rx}t_{CPA})^2 + \left(dy + v_{ry}t_{CPA}\right)^2}\right|_i$$

where:

$$t_{CPA} = -\frac{d_x v_{rx} + d_y v_{ry}}{v_{rx}^2 + v_{ry}^2}$$

$$HMD|_{t_{CPA} \leq 0} = r_i$$

$$i = [t_1, t_2, t_3, \cdots t_{end-1}, t_{end}]$$

$$dx = Aircraft\ separation\ in\ the\ x - direction\ using\ truth\ data$$

$$dy = Aircraft\ separation\ in\ the\ y - direction\ using\ truth\ data$$

$$v_{rx} = Relative\ velocity\ in\ the\ x - direction\ using\ truth\ data$$

$$v_{ry} = Relative\ velocity\ in\ the\ y - direction\ using\ truth\ data$$

The resultant normalized HMD Penetration yields a value ranging from one to zero with one indicating the edge of DMOD, and zero representing full penetration into the DMOD requirement.

L.5.1.5.3 SLoWC Vertical Separation

The normalized penetration of the vertical component is assessed based on the ratio of local vertical separation, dh_i versus the Well Clear hazard threshold, h^*:

Equation L-45: Calculation of VertPen

$$VertPen_i = MIN\left(\frac{dh_i}{h^*}, 1\right)$$

where:

$$i = [t_1, t_2, t_3, \cdots t_{end-1}, t_{end}]$$

$$h^* = 450'$$

$$dh_i = abs(h1,i - h2,i)$$

Similarly, the resultant normalized vertical penetration produces a value ranging from one to zero, with one indicating the edge of vertical threshold and zero representing full vertical penetration into the h^*requirement.

L.5.2 Collision avoidance Safety Metrics

The collision avoidance safety metrics are analogous to the maintain DWC metrics, with the only difference being the volume that is being avoided. Instead of the DWC volume, collision avoidance safety metrics use the NMAC volume. These metrics can measure both collision avoidance systems, such as the DAA system performing regain well clear, and Collision Avoidance systems, such as TCAS II.

L.5.2.1 Risk Ratio (RR)

The Risk Ratio (RR) is the key metric for evaluating the relative safety benefit of equipping with DAA. It is a measure for determining the relative improvement in avoiding NMAC when introducing a DAA system. The value is the fraction of NMACs that remain after implementing DAA. A number greater than 1 means the DAA system introduces more NMACs than it resolves. The smaller the ratio, the better the DAA system performs at avoiding an NMAC.

Equation L-46: Definition of Number of Unmitigated NMACs

$$N_{Unmit.NMAC} = count\ of\ [(UMNMAC) \equiv TRUE]\ encounters$$

Equation L-47: Definition of Probability of NMAC

$$P(NMAC\_UM) = \frac{N_{Unmit.NMAC}}{N_{Encounters}}$$

Equation L-48: Definition of Risk Ratio

$$RR = \frac{P(NMAC)}{P(NMAC\_UM)} = \frac{N_{NMAC}}{N_{Unmit.NMAC}}$$

where:

$N_{NMAC} = Number\ of\ encounters\ with\ mitigated\ NMAC$

$N_{Unmit.LoWC} = Number\ of\ unmitigated\ NMAC$

$N_{Encounters} = Total\ number\ of\ encounters$

$P(NMAC) = Probability\ of\ NMAC\ as\ defined\ below$

L.5.2.2 Probability of NMAC (P(NMAC))

The Probability of Near Mid Air Collision (P(NMAC), also sometimes described as P(NMAC | enc. with DAA system)), describes the chance of an NMAC for any encounter represented by an encounter set given the DAA system can provide mitigation. P(NMAC) can be broken down into the probability of Induced NMAC encounters and the probability of Unresolved NMAC encounters. A low number is better, but this metric is influenced strongly by the geometries in the encounter set, so Risk Ratio (RR) is generally a more useful metric since it is not dependent on the number of challenging encounters in an encounter set.

Equation L-49: Definition of Number of Mitigated NMACs

$$N_{NMAC} = count\ of\ [(NMAC) \equiv TRUE]\ encounters$$

Equation L-50: Definition of Probability of NMAC

$$P(NMAC) = \frac{N_{NMAC}}{N_{Encounters}} = P(Induced_{NMAC}) + P(Unresolved_{NMAC})$$

where:

$N_{NMAC} = Number$ of $encounters\ with\ mitigated\ NMAC$

$N_{Encounters} = Total\ number\ of\ encounters$

L.5.2.3 Probability of Induced NMAC

The Probability of Induced NMAC ($P(Induced_{NMAC})$) describes the chance of an NMAC during an encounter where the truth tracks did not have an NMAC, but where a DAA system issued commands that resulted in an NMAC. This number should optimally be 0. A higher number can indicate logical issues with a guidance algorithm.

Equation L-51: Definition of Number of Induced NMACs

$$N_{Induced\ NMAC} = count\ of\ [(NMAC) \equiv TRUE\ AND\ (UMNMAC) \equiv FALSE]\ encounters$$

Equation L-52: Definition of Probability of Induced LoWC

$$P(Induced_{NMAC}) = \frac{N_{Induced\ NMAC}}{N_{Encounters}}$$

where:

$N_{Induced\ NMAC} = Number\ of\ encounters\ with\ a\ DAA\ induced\ NMAC$

$N_{Encounters} = Total\ number\ of\ encounters$

L.5.2.4 Probability of Unresolved NMAC

The Probability of Unresolved NMAC ($P(Unresolved_{NMAC})$) describes the chance of NMAC during an encounter where the truth tracks have an NMAC and the DAA system failed to resolve the situation.

Equation L-53: Definition of Number of Unresolved NMACs

$$N_{Unresolved} = count\ of\ [(NMAC) \equiv TRUE\ AND\ (UMNMAC) \equiv TRUE]\ encounters$$

Equation L-54: Definition of Probability of Unresolved NMAC

$$P(Unresolved_{NMAC}) = \frac{N_{Unresolved\ NMAC}}{N_{Encounters}}$$

$where:$

$N_{Unresolved\ NMAC} = Number\ of\ encounters\ with\ an\ unresolved\ NMAC$

$N_{Encounters} = Total\ number\ of\ encounters$

L.5.2.5 Horizontal Miss Distance (HMD) & Vertical Miss Distance (VMD) at Horizontal CPA

The HMD and VMD define the horizontal and vertical separation at Horizontal CPA

Equation L-55: Calculation of HMD

$$HMD = \min_i \left(\sqrt{{dx_i}^2 + {dy_i}^2} \right)$$

$where$:

$i = [t_1, t_2, t_3, \cdots t_{end-1}, t_{end}]$

$dx = Aircraft\ separation\ in\ the\ x - direction\ using\ truth\ data$

$dy = Aircraft\ separation\ in\ the\ y - direction\ using\ truth\ data$

Equation L-56: Calculation of VMD

$$t_{CPA} = t_{HMD}$$

$$VMD = dz(t_{CPA})$$

$where$:

$dz = Aircraft\ separation\ in\ the\ z - direction\ using\ truth\ data$

$t_{HMD} = the\ time\ at\ which\ minimum\ HMD\ is\ reached$

$t_{CPA} = the\ time\ at\ which\ minimum\ HMD\ is\ achieved$

$VMD = \ vertical\ separation\ at\ t_{CPA}$

L.5.2.6 Minimum Weighted Slant Range (WSR)

The Minimum WSR is the minimum distance between the two aircraft, where the distance is weighted to account for the difference in typical vertical and horizontal separation. Since aircraft fly closer vertically than horizontally and because the horizontal size of the NMAC volume is 5 times the vertical size, the horizontal range dimension is adjusted by a factor of 5.

Equation L-57: Calculation of Minimum WSR

$$Minimum\ WSR = \min_i \left(\sqrt{\frac{\left({dx_i}^2 + \ {dy_i}^2\right)}{25} \ + \ {dz_i}^2} \right)$$

$where:$

$$i = [t_1, t_2, t_3, \cdots t_{end-1}, t_{end}]$$
$$dx = Aircraft\ separation\ in\ the\ x - direction\ using\ truth\ data$$
$$dy = Aircraft\ separation\ in\ the\ y - direction\ using\ truth\ data$$
$$dz = Aircraft\ separation\ in\ the\ z - direction\ using\ truth\ data$$

L.5.3 Operational Suitability Metrics

Operational suitability metrics inform whether a system will be deemed suitable for use by operators and ATC.

L.5.3.1 Maximum Horizontal and Vertical Deviations

The Maximum Horizontal Deviation is the furthest horizontal distance from the nominal trajectory when executing a DAA maneuver. Ideally these would be collected until the original course is re-acquired. If simulations are cut short, the results may not be directly comparable with other simulations.

These metrics do not capture the operational suitability impact of speed-only maneuvers. For future versions of the MOPS that enable speed maneuvers, a new metric may be needed.

Recognizing the intent of the deviation metric is to capture the mitigated trajectory's cross-track and vertical deviation orthogonal from the unmitigated path excluding the temporal deviation due to maneuvering, a more elaborate process is required to compute this metric. As shown in Figure L-7, for each mitigated point, one cannot simply rely on matching up the simulation time index or flight data timestamp to compute the deviation. It is recommended for each mitigated trajectory point, the two nearest points from the unmitigated path be extracted; so that the orthogonal vector from the unmitigated path to the mitigated point can be computed. For example, the mitigated point M_{t+2}, the two nearest unmitigated points (U_t and U_{t+1}) should be used to compute the horizontal deviation. In a more generalized form, for each instance, the deviation of the mitigated point M can be calculated based on the two nearest unmitigated points U_1 and U_2.

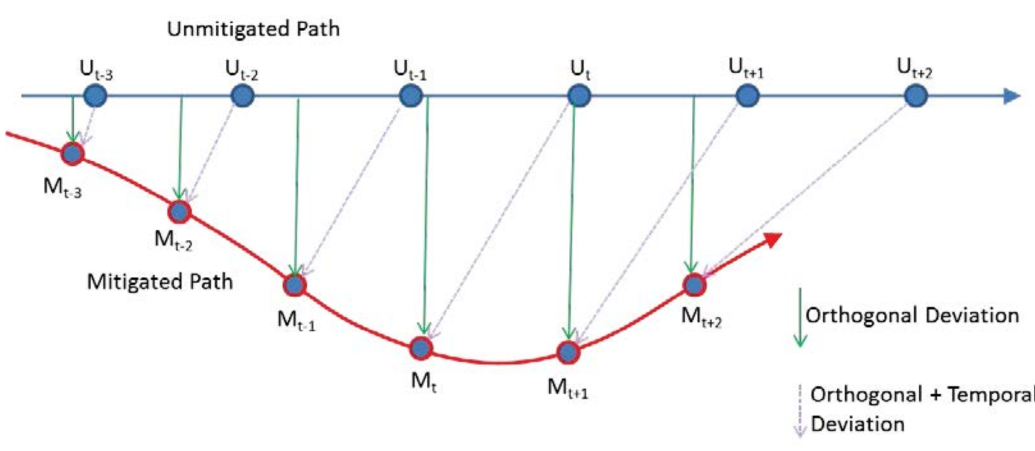


Figure L-7 Deviation Diagram

Two nearest unmitigated points U_1 and U_2 are used to generate a 3-D reference vector to represent the unmitigated direction of travel both horizontally and vertically. The following limitations and features are enumerated:

- Care must be taken to ensure these two points are horizontally separated to prevent division-by-zero.
- The calculations in this paragraph cannot support unmitigated path with purely vertical flight without any horizontal motion.
- Instead of requiring two nearest unmitigated points, the point U_2 can be represented by a unit-vector from U_1 such that the horizontal and vertical directions of travel for the unmitigated path can be characterized.

For each instance, the horizontal deviation of the mitigated point M can be calculated based on the two nearest unmitigated points U_1 and U_2 as shown in Figure L-8.

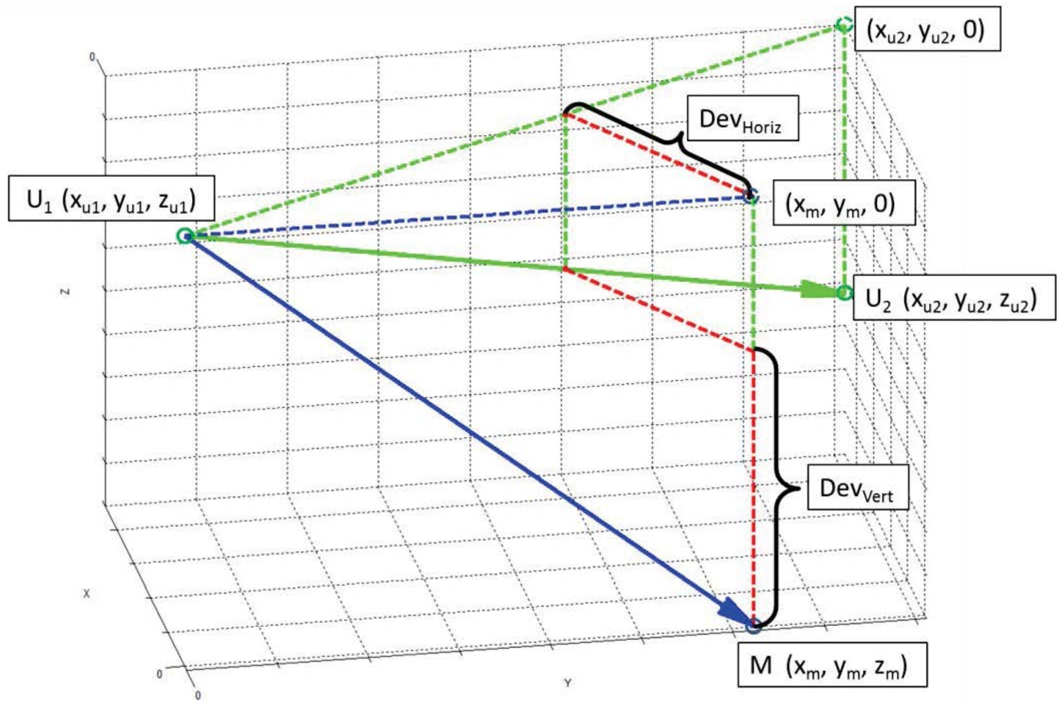


Figure L-8 **Horizontal and Vertical Course Deviations**

Considering only the x-y (horizontal) plane, the horizontal deviation, Dev_{Horiz} can be determined based on the determinant of the cross product $(\overrightarrow{M - U_1} \times \overrightarrow{U_2 - U_1})$. Expressed in local Cartesian coordinate form:

Equation L-58: Horizontal Deviation Calculation

$$Dev_{Horiz} = \frac{\Delta x_u \Delta y_m - \Delta y_u \Delta x_m}{\sqrt{\Delta x_u^2 + \Delta y_u^2}}$$

Where, following the North-East-Down (+NED) convention:

$\Delta x_u = x_{u2} - x_{u1}$

$\Delta y_u = y_{u2} - y_{u1}$

$\Delta z_u = z_{u2} - z_{u1}$

$\Delta x_m = x_m - x_{u1}$

$\Delta y_m = y_m - y_{u1}$

$\Delta z_m = z_m - z_{u1}$

Through 3D vector projections and similar triangles, the local vertical deviation, $\mathrm{Dev_{Vert}}$ can be determined:

Equation L-59: Vertical Deviation Calculation

$$Dev_{Vert} = \Delta z_m - \Delta z_u \left(\frac{\Delta x_u \Delta x_m + \Delta y_u \Delta y_m}{\Delta x_u^2 + \Delta y_u^2} \right)$$

It should be noted the sign of the resultant $\mathrm{Dev_{Horiz}}$ reflects the direction of the horizontal deviation. A positive $\mathrm{Dev_{Horiz}}$ value indicates a local deviation to the right of the unmitigated path while a negative $\mathrm{Dev_{Horiz}}$ value corresponds to a local deviation to the left of the unmitigated trajectory. Similarly, the vertical deviation equation generates signed values as well. Following the +NED convention, a positive $\mathrm{Dev_{Vert}}$ value indicates a local vertical deviation below the unmitigated path while a negative $\mathrm{Dev_{Vert}}$ value corresponds to a local deviation above the unmitigated trajectory. Care should be taken to ensure only the magnitude of the deviation is used to extract the maximum deviation and the total deviation for the entire encounter.

The Maximum Horizontal Deviation and Maximum Vertical Deviation are the furthest horizontal and vertical distance, respectively, from the nominal trajectory when executing a DAA maneuver. Ideally these would be collected until the original course is re-acquired. If simulations are cut short, the results may not be directly comparable with other simulations.

Equation L-60: Maximum Horizontal and Vertical Deviation Calculations

$$Max\ Horizontal\ Deviation = \max_i(|Dev_{Horiz}|)$$

$$Max\ Vertical\ Deviation = \max_i(|Dev_{Vert}|)$$

$where$:

$i = [t_1, t_2, t_3, \cdots t_{end-1}, t_{end}]$

L.5.3.2 Horizontal and Vertical Total Course Deviation

Total course deviation calculates the total deviation that the aircraft endures from its intended path throughout the whole duration of the flight. Ideally these would be collected until the original course is re-acquired. If simulations are cut short, the results may not be directly comparable with other simulations.

Equation L-61: Calculation of Total Horizontal Course Deviation

$$Total\ Horizontal\ Course\ Deviation = \int_0^t |Dev_{Horiz}| dt$$

$where$:

$t = time\ epoch$

Equation L-62: Calculation of Total Vertical Deviation

$$Total\ Vertical\ Course\ Deviation = \int_0^t |Dev_{Vert}| dt$$

$where$:

$t = time\ epoch$

L.5.3.3 Quantified Right-of-Way Compliant Maneuver Rate

The Quantified Right of Way (QROW) Compliant Maneuver Rate reflects how well a DAA system does at maneuvering in accordance with ROW rules. However, since Phase 1 DAA equipment is not providing directive maintain DWC maneuvers, this metric is not applicable to Phase 1. Additionally, as is documented in Appendix H, the direction of QROW compliant maneuvers is only defined for head-on and overtaking encounters, which comprise a very small subset of overall encounters. Therefore, this metric would only reflect the behavior in those encounters and does not reflect well the overall operational suitability of the DAA system.

L.6 Severity of LoWC (SLoWC) Details

The SLoWC metric was developed by Jacob Kay and Ethan Pratt with the assistance of Cesar Munoz and Anthony Narkawicz.

L.6.1 Fernandez-Guasti's Squircle Mapping

A numerical operation to combine the normalized penetrations from all three dimensions is required to arrive at the overall Well Clear penetration. The Fernandez-Guasti Squircle operator, $\oplus$, is introduced here to combine the normalized penetrations. The combined severity at any instance during an encounter from all three components can be expressed as:

$$SLoWC_i = (1 - RangePen_i \oplus HMDPen_i \oplus VertPen_i) * 100\%$$

And the overall penetration for the entire encounter is:

$$SLoWC = MAX(SLoWC_i)$$

The resulting SLoWC ranges from 0% to 100% with 0% indicating Well Clear and 100% representing full penetration into the Well Clear protection volume.

Based on the Fernandez-Guasti's Squircle mapping, the Fernandez-Guasti Squircle operator, $\oplus$, is used to blend together normalized components:

$$x \oplus y \equiv \sqrt{x^2 + (1 - x^2)y^2}$$

This operation is suited for combining the three normalized severity components with the following necessary properties:

- $x \oplus y = y \oplus x$ (commutative)
- $x \oplus (y \oplus z) = (x \oplus y) \oplus z$ (associative)
- $1 \oplus x = 1$ for any x
- $0 \oplus x = x$ for any x
- $0 \oplus x = 0$ if and only if $x = 0$

An example of this Squircle mapping is shown below:

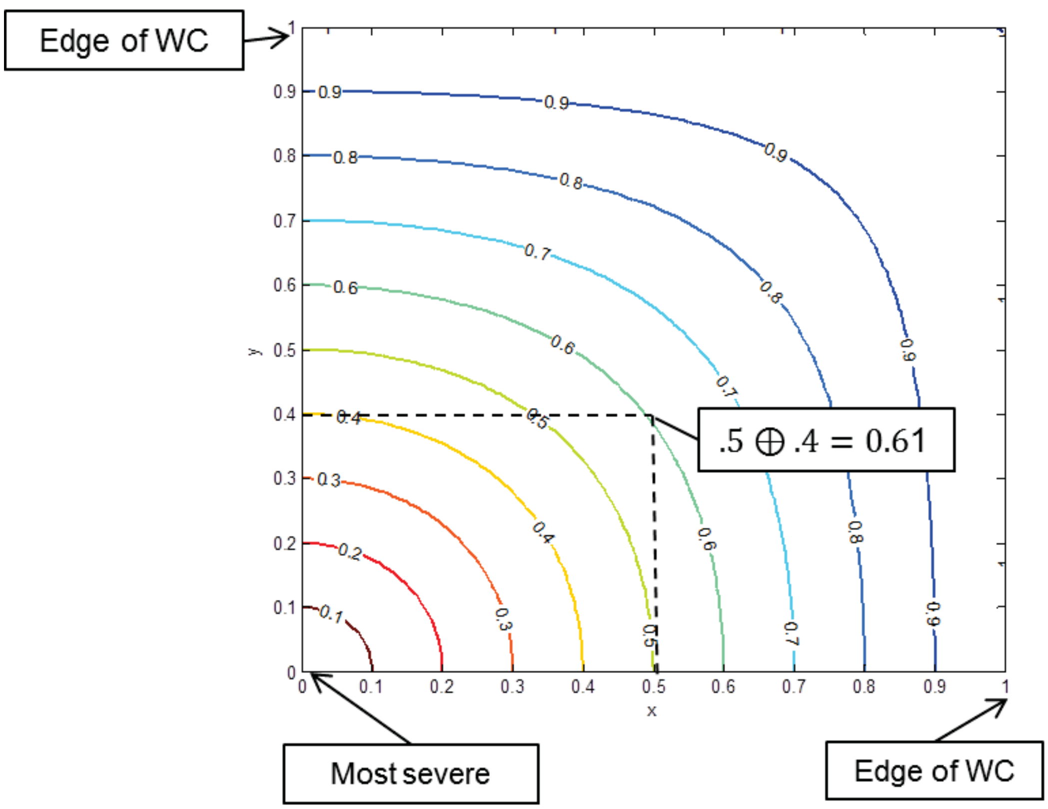


Figure L-9 **Fernandez-Guasti's Squircle Mapping**

L.6.2 SLoWC Examples

A series of example encounter trajectories with their assessed SLoWC values are presented in this paragraph to illustrate the features of the proposed metric. Additionally, the example statistical distribution for SLoWC against unmitigated and mitigated Monte Carlo encounters are also provided to illustrate the utility of this metric.

L.6.2.1 Co-altitude Head-on Examples

Examples of SLoWC propagation for a series of co-altitude head-on (100 kts + 100 kts) aircraft encounters with different horizontal miss distances is shown in Figure L-10, below. The maximum severity over the closing phase as well as the separating phase is captured to indicate the overall severity for the encounters. Additionally, gray X's with size corresponding to the local severity are plotted on the top-down view.

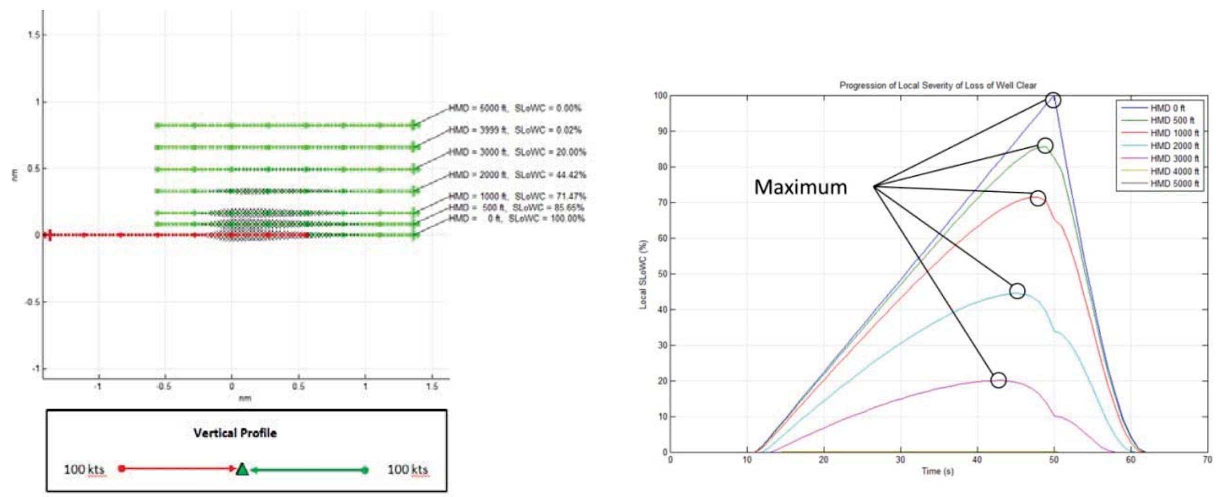


Figure L-10 SLoWC Propagation for Co-altitude Head-on Intruders with different HMDs

L.6.2.2 Level Head-on with 100' Vertical Offset Examples

The SLoWC for a series of head-on encounters with 100' vertical offset at different HMDs is shown below. While similar to the co-altitude head-on examples earlier, these encounters are assessed slightly lower severity due to the 100' vertical offset.

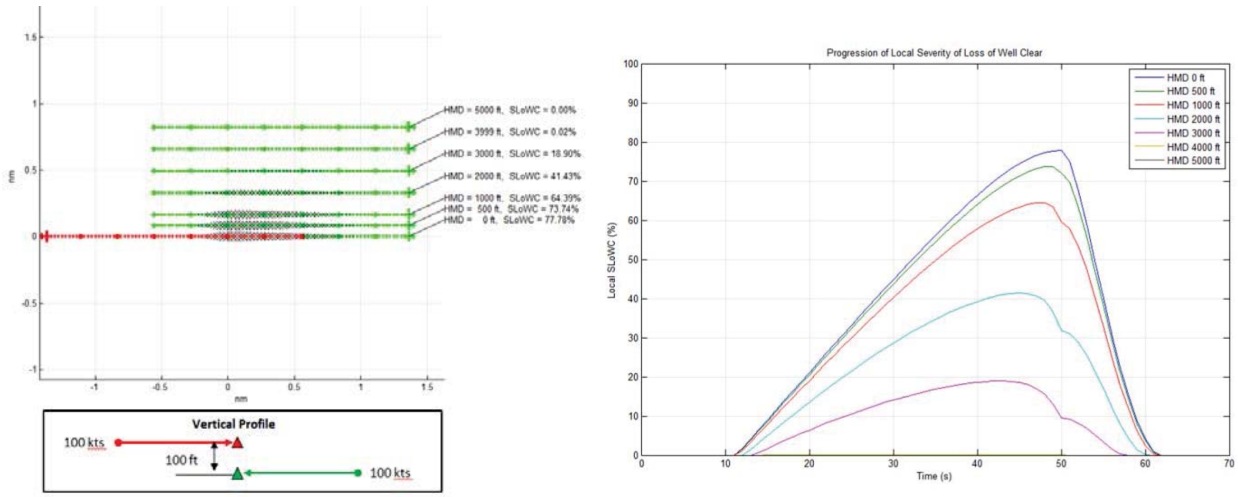


Figure L-11 **SLoWC Propagation for Head-on Intruders with 100' Vertical Offset and Varying HMDs**

L.6.2.3 Vertically Converging Head-on with Altitude Crossing before CPA

In these vertically converging head-on examples, the SLoWC for different HMDs are presented as shown below. It should be noted the geometry involved 3000-fpm vertical closure with altitude crossing two seconds prior to reaching horizontal CPA. This resulted in a 100' vertical offset as the two aircraft reach their horizontal CPA. It should be further noted, due to the altitude crossing occurring 2 seconds prior to reaching horizontal CPA, the peak Well Clear penetration severity occurred prior to CPA as well.

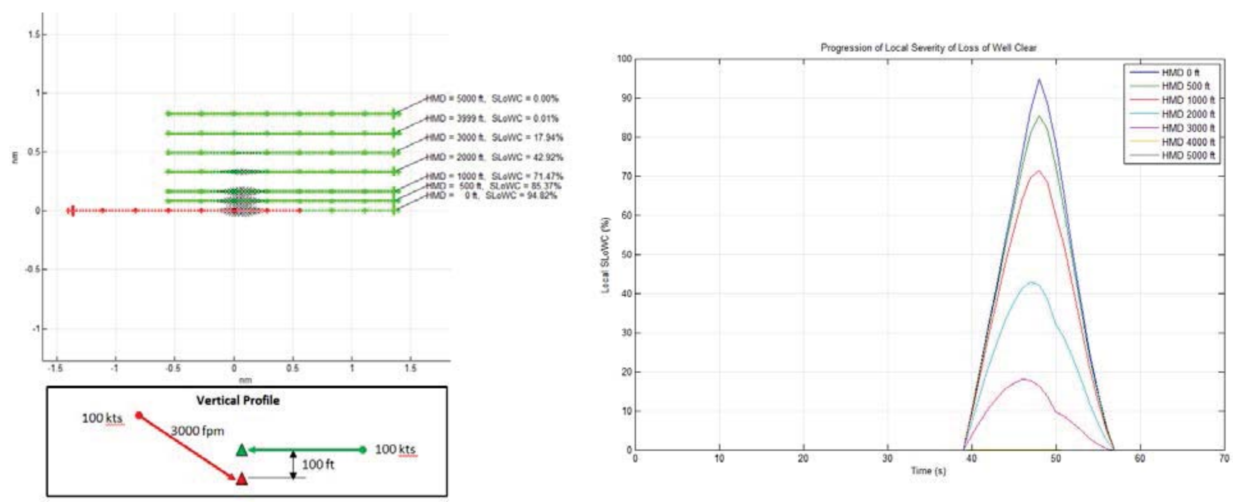


Figure L-12 **SLoWC Propagation for Vertically Converging and Alt-crossing Head-on Intruders with different HMDs**

L.6.2.4 Vertically Converging Head-on with Altitude Crossing after CPA

In these vertically converging head-on examples, the SLoWC for different HMDs are presented as shown below. It should be noted that the geometry involved 3000-fpm vertical closure with altitude crossing 2 seconds after the horizontal CPA. This resulted in a 100’ vertical offset at the two aircraft reach their horizontal CPA. It should be further noted, due to the altitude crossing occurring after horizontal CPA, the peak Well Clear penetration severity occurred after the CPA as well. Due to the vertical penetration component growing increasingly severe after the horizontal CPA, it is conceivable certain horizontal-closure rate and vertical closure-rate combinations may naturally yield double peaks. Again, the proposed metric retains the maximum local severity to represent the entire encounter.

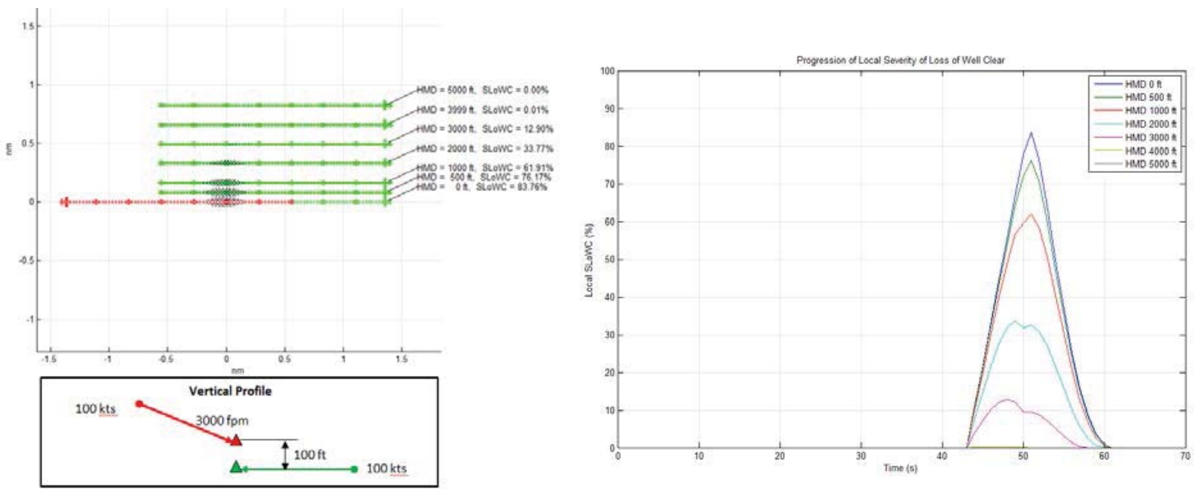


Figure L-13 **SLoWC Propagation for Vertically Converging Head-on Intruders with Alt-crossing after CPA**

L.6.2.5 Co-altitude Head-on Examples with 3-deg/sec Turning Maneuver

In this series of head-on encounters, one of the aircraft executes a 3-deg/sec (standard rate) turn 30 seconds prior to reaching the horizontal CPA simulating a horizontal turning mitigation maneuver. Although some penetrated the Well Clear boundary, many resulted in significantly reduced severity assessments compared to the unmitigated head-on encounters shown previously. Additionally, the effects of the horizontal turning can be seen affecting the large-HMD encounters more immediately after the start of the maneuver at 20 seconds simulation time.

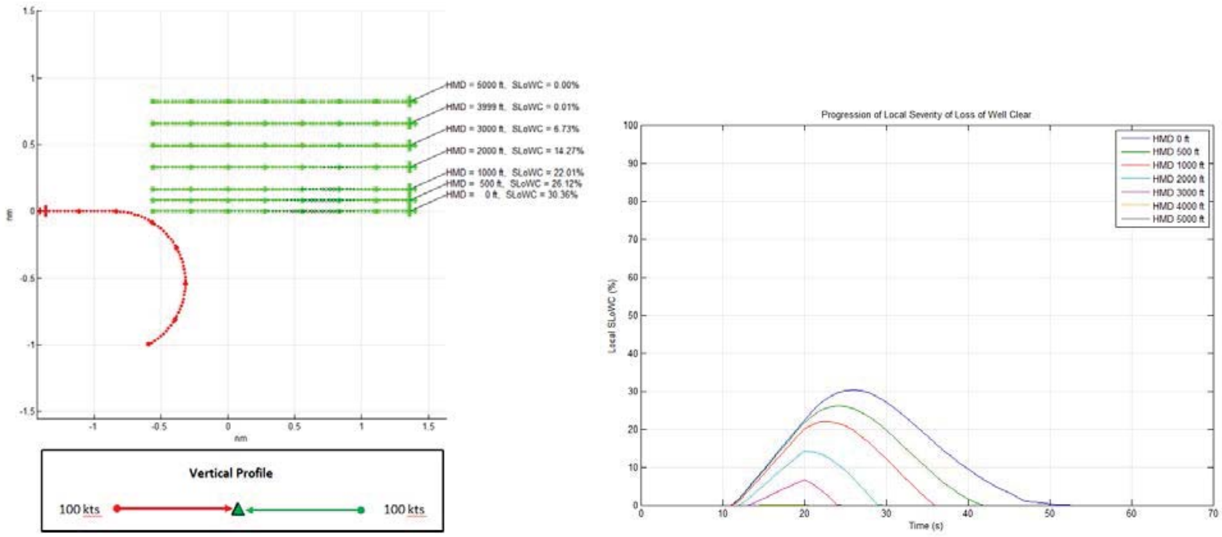


Figure L-14 SLoWC Propagation for Turning Away Against Head-on Intruders at different HMDs

L.6.2.6 Co-altitude Level Perpendicular Examples

In these 100-kt vs. 100-kt co-altitude level perpendicular (abeam) examples, the SLoWCs for different HMDs are presented as shown below. Compared to the co-altitude head-on examples presented earlier, these encounters with zero-HMD were assessed slightly lower severities due to the lower closure rate.

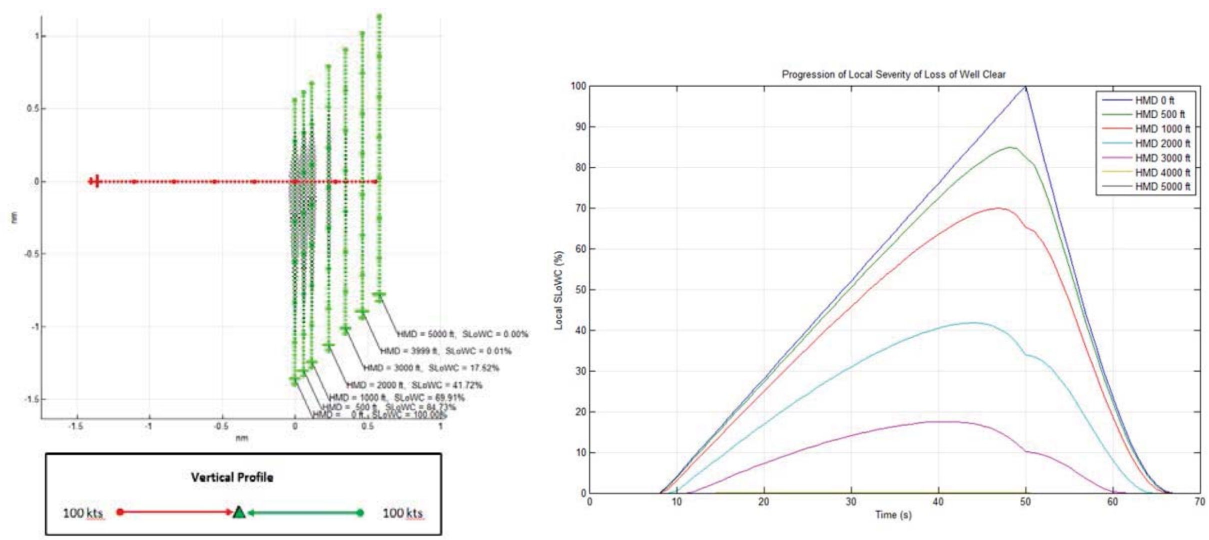


Figure L-15 SLoWC Propagation for Co-altitude Crossing Intruders

L.6.2.7 Co-altitude Overtake Examples

Examples of SLoWC for different HMDs given co-altitude overtaking geometry (150-kt vs. 100-kt) are shown below. Compared to the comparable HMD counterparts in the co-altitude level head-on and the level-abeam geometries discussed earlier, these overtake encounters were assessed somewhat lower penetration severity score due to the slower closure rate.

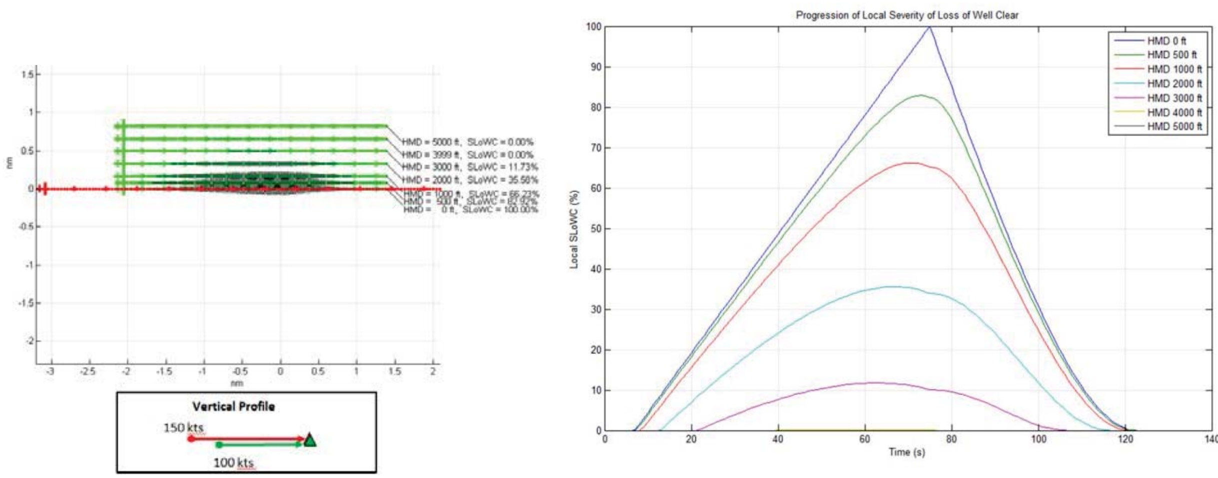


Figure L-16 **SLoWC Propagation for Co-altitude Overtaking Geometries**

L.6.3 SLoWC Metric Distribution Against Unmitigated Uncorrelated Encounters

The SLoWC metric was used to evaluate 15,000 unmitigated encounters that resulted in LoWC. The resultant histogram is shown below, along with encounters that also violated NMAC (within 500’ H and 100’ V) highlighted in red. As expected, encounters with severe Well Clear penetration, as indicated by high SLoWC values, and NMAC events become increasingly correlated for SLoWC reaching above 80%. It should be noted that the theoretical lowest SLoWC value for an encounter that can result in an NMAC is 71.9%.

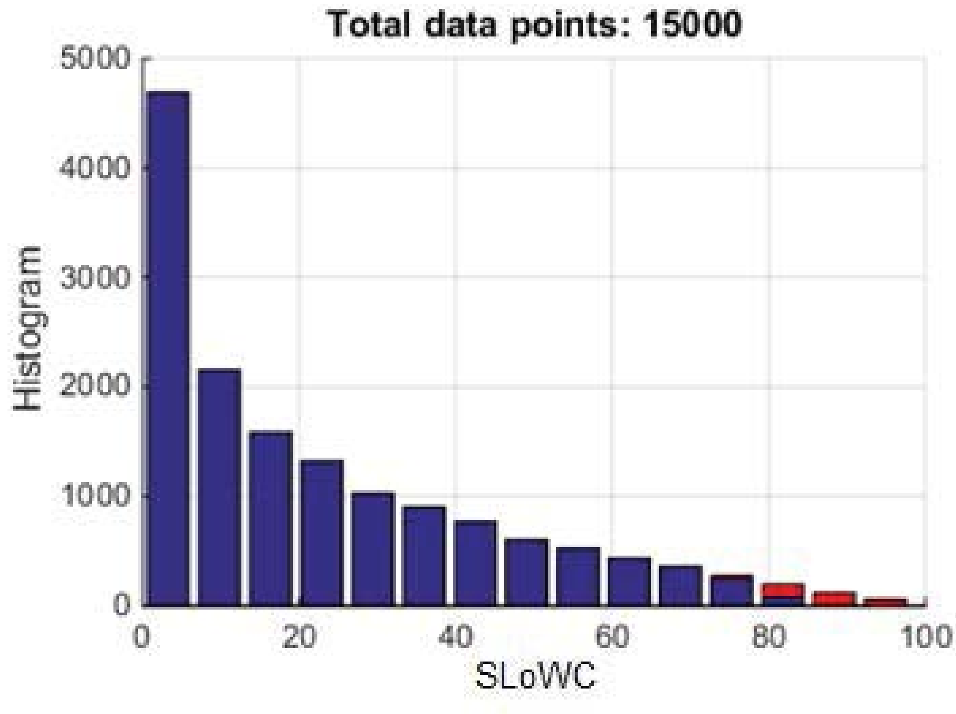


Figure L-17 SLoWC Distribution for 15,000 Unmitigated Encounters with LoWC

L.6.3.1 Mitigated and Unmitigated Distribution Against Correlated HALE Encounters

The SLoWC metric was applied to evaluate 1,000,000 Correlated High-Altitude Long-Endurance (HALE) aircraft encounters with mitigated maneuvers using an example DAA algorithm designed to maintain DWC to confirm the expected improvement in the SLoWC statistics. This sample, non-MOPS compliant DAA system provides significant improvements in the overall number of LoWC encounters, reducing the number to less than one-third the original number. More importantly, the instances of severe LoWC, corresponding to the high SLoWC values, are practically eliminated. Over 85% of the remaining LoWC cases involved less than 10% penetration into the Well Clear Volume.

L.6.4 Potential for Over-Assessing Penetration

During the development and evaluation of the SLoWC metric, it was observed for high highly-dynamic encounters with high closure rates, that momentary LoWC could result in substantial SLoWC assessment for encounters that eventually result in large horizontal miss distances or vertical separation. An example of this observed momentary LoWC followed by regaining Well Clear before reaching CPA is illustrated below. In this case, the geometry and the resultant closure rate exceeded 500 knots, and the 3-deg/sec turn rate produced 9 seconds of momentary LoWC when the two aircraft were still over 5 to 3.8 NM apart. As the turning continued, Well Clear is regained, producing in a horizontal miss distance of 1.7 NM.

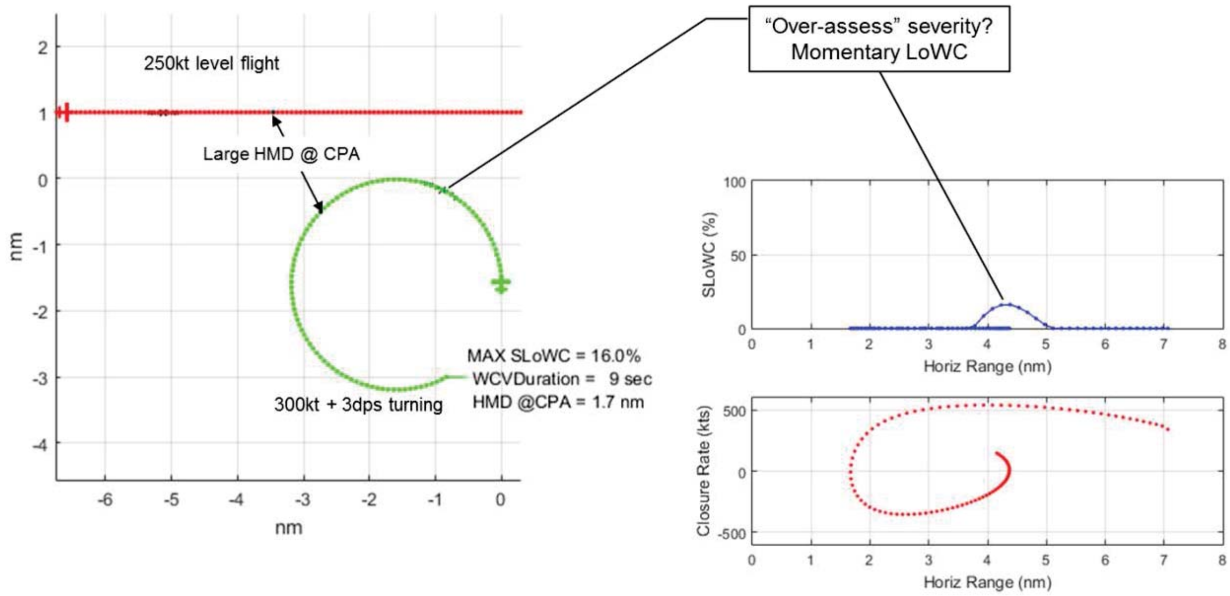
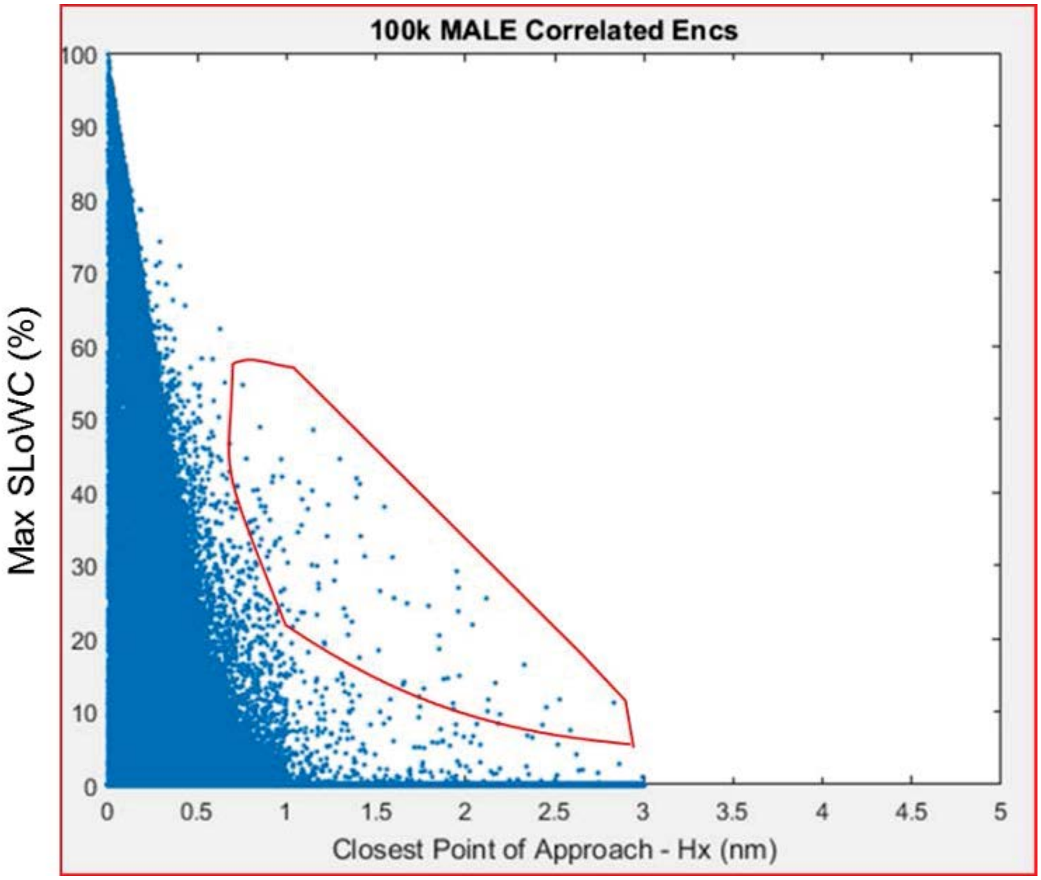


Figure L-18 **SLoWC Assessed Against Turning Geometry with Momentary LoWC**

Concerns were raised that momentary LoWC while still far apart may over-assess the encounter's Well Clear penetration in lieu of the eventual regaining of Well Clear with sufficient horizontal and/or large vertical margins at the CPA. The statistical likelihood of this issue is shown below using 100,000 unmitigated correlated Medium-Altitude Long-Endurance (MALE) encounters. Each blue dot represents an encounter with its SLoWC value plotted in the vertical axis and its eventual horizontal miss distance at the CPA plotted in the horizontal axis. While most encounter points cluster closely within the tapered distribution indicating a strong correlation between high-SLoWC and small HMD at the CPA, a small fraction of outliers are highlighted to illustrate the scarcity of this concern.



<u>Figure L-19</u> **SLoWC vs Horizontal CPA for 100K Unmitigated MALE Correlated Encounters**

This issue was exhaustively analyzed and debated within the ad hoc work group. Ultimately, it was determined regaining Well Clear at the CPA does not diminish the severity of Well Clear penetration earlier in the encounter. This concern is documented here for completeness.

This Page Intentionally Left Blank

M APPENDIX M INTER-SPECIAL COMMITTEE REQUIREMENTS AGREEMENT (ISRA) FOR PHASE 1 UAS DAA MOPS

M.1 Purpose and Scope

M.1.1 Introduction

This appendix presents high-level requirements (i.e., Minimum Aviation System Performance Standards (MASPS)-level requirements) for the interoperability of airborne Collision Avoidance (CA) systems. It specifies system characteristics that should be useful to designers, manufacturers, installers and users of the equipment. When some requirements cannot be fully defined, explanatory text is included to describe the basis on which requirements are to be developed.

Compliance with these standards is recommended as one means of assuring that the equipment interacts acceptably and does not degrade the operation of other CA systems. Any regulatory application of this appendix is the sole responsibility of the appropriate governmental agencies.

This appendix considers an equipment configuration consisting of a CA system with optional connections to a Mode S transponder or Automatic Dependent Surveillance-Broadcast (ADS-B) transmitter/receiver. Operational performance standards for functions or components referring to equipment capabilities that exceed the stated minimum requirements are identified as optional features.

The word "equipment" as used in this appendix includes all components and units necessary for the system to properly perform its intended function. For example, the equipment may include a Traffic Alert and Collision Avoidance System (TCAS) unit coupled to a Mode S transponder. In this example, all of the foregoing components and units comprise the equipment. It should not be inferred from this example that each CA system design will necessarily include all of the foregoing components or units. This will depend on the specific design chosen by the manufacturer.

Subsection M.2 of this appendix provides information needed to understand the rationale for equipment characteristics and requirements stated in the remaining subdivisions. It describes typical equipment operations and operation goals, as envisioned by the members of RTCA Inc. Special Committee 147 (SC-147) (TCAS), and establishes the basis for the standards stated in Subsections M.3 to M.8. Subsection M.16 contains references.

All CA systems are expected to include a computer software package, therefore the guidelines contained in RTCA Document No. 178C (RTCA DO-178C) and RTCA Document No. 254 (RTCA DO-254) should be considered.

M.1.2 Background

The airborne CA system TCAS has been in service since 1990, during which time it has been the only system that generates CA Resolution Advisories (RAs). There are other systems that track proximate traffic and provide a variety of displays or alerts but none of these advises the pilot how to avoid collision with a threat aircraft. Now a new CA system is under development, Airborne Collision Avoidance System X (ACAS X), and there are moves in the United States (US) and in Europe to develop CA systems for Unmanned Aircraft Systems (UAS)/Remotely Piloted Aircraft (RPA) in conjunction with

Detect and Avoid (DAA) systems required to facilitate their entry into non-segregated airspace. The developers of TCAS determined, 35 years ago, that the separate RAs generated on two aircraft in conflict need to be coordinated, so that if one aircraft is aiming to pass above the other, the other aircraft will aim to pass below the first. TCAS achieves this vertical coordination by sending and receiving messages that convey the senses of the RA maneuvers that the two TCAS recommend.

The TCAS CA logic, i.e., the algorithms that determine RAs, has undergone a series of revisions over the past 25 years, and each revision has been demonstrated to be interoperable with the preceding versions before final approval. The validation work for these revisions has always assumed that the RAs on the two aircraft in conflict are coordinated, with the method of ensuring that coordination being the unaltered standard TCAS scheme.

The developers of ACAS X assumed that ACAS X would use the TCAS scheme for coordination, as indeed will be the case for ACAS X_A. However, that scheme requires Secondary Surveillance Radar (SSR) interrogations and replies at 1030 and 1090 Megahertz (MHz) respectively, presenting problems for some variants of ACAS X that were envisioned as relying on ADS-B, and were thus envisioned to not be equipped with an interrogator. To accommodate these variants of ACAS X, variations of the standard coordination scheme have been developed that are compatible with TCAS and use ADS-B rather than interrogation and reply to coordinate.

The Federal Aviation Administration (FAA) white paper titled “Coordination Between Airborne Collision Avoidance Systems,” dated 3 May 2013, addressed the question of coordination between TCAS or ACAS X and other novel airborne collision avoidance systems, in particular, the vertical component of DAA. The paper raised and addressed several questions. The most marked conclusion was that, on the basis of simulations, coordination of vertical RAs is essential. Indeed, better overall performance is achieved when the second aircraft in an encounter has no CA system than is achieved when it is equipped but fails to coordinate its RAs. This work was briefed to European Organization for Civil Aviation Equipment (EUROCAE) Working Group 73 (WG-73) and RTCA SC-228, both of which are developing standards for UAS DAA systems

It was recognized that the issue of interoperability is broader than coordination alone. It might be essential that RAs are coordinated, but it is certain that more is required, which is why (as mentioned above) it is standard practice to ensure that new versions of TCAS perform well in encounters with previous versions of TCAS. Evidence for this emerged after both SC-228 and WG-73 had, in their own ways, agreed on the need for advice on interoperability between the systems they are standardizing and other CA systems.

Work on one of the interim versions of ACAS X_A, known as Run 11, showed marked incompatibility between Run 11 and TCAS even though perfect coordination was assumed and both worked well in encounters with their own kind [1]. This work compared the performance of TCAS in encounters with Run 11 against its performance in encounters with TCAS; it found that the rate of RA sense reversals by TCAS increased by a factor of 3 and the rate of RAs to cross in altitude increased by a factor of 2. This effect of Run 11 on the performance of TCAS was judged unacceptable. These results demonstrated the potential for two good CA systems that coordinate perfectly in encounters with their like to prove incompatible with each other nonetheless.

Following discussions with WG-73, the WG-75 Terms of Reference include the deliverable, "Requirements providing interoperability between ACAS of differing design." This appendix is the first version of that document.

M.1.3 SC-228/SC-147 Inter-Special Committee Requirements Agreement

More recently, SC-228 and SC-147 have drafted an Inter-Special Committee Requirements Agreement (ISRA), which recognizes that "DAA will need to coordinate and be fully interoperable with TCAS and future CA systems, such as ACAS X. SC-147 and SC-228 will develop an interoperability standard for CA systems to support … development of the … DAA MOPS." It delegates to SC-147 the task of producing "Interoperability and Coordination Requirements to ensure that any new Collision Avoidance, Self-Separation, or integrated DAA system (comprising both [maintain DAA Well Clear (DWC) and] CA) will not adversely affect the performance of TCAS or other CA systems." This appendix, produced jointly by WG-75 and SC-147 with SC-228 participation, aims to meet both these requirements.

DAA and CA system designers have a wide range of options. The requirement to be fully interoperable with existing CA systems applies equally to every option. Implications for specific implementations using TCAS are discussed in Subsections M.11 through M.13.

M.2 Goals for Airborne Collision Avoidance Interoperability

The requirements contained in this appendix are intended to ensure interoperability between all CA systems operated in the airspace.

The CA interoperability requirements apply to any equipment that generates resolution advisories during the CA horizon. The CA horizon includes both the CA protected region and the timeframe used to provide CA RAs by existing systems.

For this purpose, interoperability is defined to include the concept of forward and backward compatibility and has the following specific goals:

1. New CA systems entering the airspace should not degrade the performance of existing CA systems.
2. Existing CA systems should not be required to change (e.g., hardware, software, formats) to interoperate with the new CA systems.
3. To the extent possible, new CA systems should not restrict future CA systems from taking advantage of technological advances and innovative designs.

The high-level requirements contained in Paragraph M.2.1 are intentionally broad in order to capture the intent of the generic interoperability requirements without limiting potential approaches to developing interoperable systems. At the time these MOPS were published, TCAS was the only existing CA system that generated RAs. As such, the only accepted methods to meet the high-level requirements are those used for TCAS as described below. Nonetheless, improved and simplified methods are desirable.

Note: *While updates to TCAS were designed to interoperate with previous TCAS versions, it is not expected that TCAS will be redesigned to accommodate new system requirements.*

M.2.1 High-level Interoperability Requirements

Coordination of RAs is expected to remain the core enabler of CA interoperability as it allows the selection of compatible RAs between two disparate systems. Coordination **shall (**Requirement 2.1 or RM.2.1) be required between all potential pairings of aircraft equipment that generate CA advice.

M.2.1.1 Coordination Requirements

1. Any two systems that generate RAs or directive guidance during a CA horizon shall (RM.2.2) ensure compatible RAs or guidance using a standardized coordination protocol.
2. The coordination protocols between peer aircraft (as described in Subsection M.9) shall (RM.2.3) be capable of arbitrating incompatible initial RAs and updating subsequent RAs in order to remain compatible.
3. The coordination protocols between non-peer aircraft shall (RM.2.4) be capable of selecting compatible RAs and updating subsequent RAs in order to remain compatible.
4. In an encounter between non-peer aircraft, the less capable system shall (RM.2.5) not initiate changes in coordinated RAs that may alter compatibility.
5. All systems shall (RM.2.6) have the capability to select the coordination protocol that is appropriate for use with each potential intruder from among the coordination protocols defined in this appendix.
6. All systems shall (RM.2.7) make information available to determine and use the appropriate coordination protocols.

The use of coordinated RAs directly influences the performance and acceptability of individual CA systems. However, coordination alone is not sufficient to ensure the interoperability of two CA systems. CA efficacy on the ownship is influenced by the behavior of the CA system on the intruder, each of which can be degraded by the operational environment.

M.2.1.2 Non-Coordination Requirements

1. The combined efficacy of two coordinated CA systems shall (RM.2.8) exceed the efficacy of each individual system with an unequipped intruder in otherwise identical encounters.
2. The use of the 1030/1090 MHz SSR spectrum shall not (RM.2.9) materially degrade the performance of other users of the same frequencies.
3. The use of Mode S messages (such as TCAS Broadcast Interrogation Messages (TBIM) [3]) shall not (RM.2.10) materially degrade the performance of users of the same messages.

M.2.2 Established Methods to Achieve High-Level Requirements

Developers of new CA systems or those desiring to equip new platforms with existing systems may refer to Subsection M.10 through Paragraph M.13.6 for guidance on available paths to meet these interoperability requirements.

The remaining subsections contain specific information and requirements for the methods used by TCAS and ACAS X to produce interoperable systems for vertical collision avoidance. Subsections M.5 and M.8 contain requirements to ensure that the high-level coordination requirements have been met completely in a robust manner. Methods to meet the high-level non-coordination requirements, including metrics and tests, can be found in Subsections M.6 and M.7. Interoperability is not limited to vertical RAs; therefore Subsection M.4 contains anticipated requirements for alternatives including horizontal RAs.

M.3 Vertical RA Coordination Protocols

Coordination, as used in this appendix, is defined as the process of ensuring that the CA systems on any two conflicting aircraft select complementary avoidance RAs.

For coordination of vertical RAs, CA systems **shall (**RM.3.1) use *explicit coordination*, meaning that the two aircraft select RAs based on a real-time exchange* of the sense (i.e., up/down) of their avoiding action.

<u>Note</u>

1. *The primary coordination information exchanged is in the form of a complement; e.g., for vertical RAs, a Vertical Resolution Advisory Complement (VRC) is exchanged, conveying either "Do not pass above" or "Do not pass below." A CA system receiving a VRC will restrict its choice of RA sense according to the requirements in Subparagraphs (M.3.1.1, M.3.1.2, and M.3.1.3.*
2. *The exchange can be in both directions, as in Active Coordination (M.3.1.1) and Passive Coordination (M.3.1.2); or in one direction, i.e., from a more capable aircraft to a less capable aircraft, as in Responsive Coordination (M.3.1.3).*

Multi-aircraft coordination: In a multi-aircraft situation, a CA system shall (RM.3.2) coordinate with each equipped threat individually. The coordination process is referred to as a pair-wise process. This means that when a CA system has declared two or more CA-equipped intruders to be threats simultaneously, the ownship CA system will coordinate with each intruder in turn individually. Consider an encounter in which the ownship CA system is between two intruders vertically. Here, the ownship CA system is likely to select a climb sense against the lower-altitude intruder and a descend sense against the higher-altitude intruder, causing the ownship CA system to send a "do not pass above" VRC to the lower-altitude intruder and a "do not pass below" VRC to the higher-altitude intruder. In this case, the ownship multi-aircraft logic will combine its two selected senses (climb and descend) into a composite RA (e.g., "do not climb/do not descend') for display to the pilot.

In an encounter involving three ACAS equipped aircraft in which each recognizes both of the others as a threat, at least one aircraft will receive conflicting VRCs and thus be required to pass above one and below the other. Optimizing the vertical miss distance from both threats will typically involve some limited movement in a sense contrary to one of the VRCs. For example, in these specific encounters, it is permitted for ACAS to issue a climb RA temporarily when a VRC commanding "*do not pass above*" has been received, provided that the ownship passes below the relevant threat at closest point of approach with a safe vertical miss distance.

In very rare geometries, it is possible for a multi-aircraft encounter to result in a lock-up condition where all aircraft have both "*do not pass above*" and "*do not pass below*" VRCs. The CAS logic should be able to detect and overcome this lock-up condition.

Note: *TCAS II is not able to detect and overcome this lock-up condition. ACAS X does follow this recommendation.*

M.3.1 Types of Coordination

CA systems shall (RM.3.3) use one of three types of explicit coordination for coordination of vertical RAs:

Active (RM.3.1.1)

Passive (RM.3.1.2)

Responsive (RM.3.1.3)

The intent is to allow coordination among CA systems installed on aircraft with widely varying performance capabilities and/or equipment configurations, including small aircraft with performance limitations, aircraft with ADS-B In and Out capability (either 1090ES or UAT) but no active 1030/1090 MHz interrogation/reply capability, aircraft with 1030/1090 MHz Interrogation/Reply capability, and aircraft with either ATCRBS or Mode S transponders.

Note *Passive or responsive coordination using ADS-B on frequencies other than 1030/1090MHz is permitted.*

Coordination will be made possible among various CA systems by the transmission and reception of ADS-B CA Coordination Capability Bits (CCBs), which will be included in the ADS-B aircraft operational status message, per RTCA DO-260C. To meet requirement RM.3.7, all CA systems should use ownship and the intruder CA CCBs in order to determine the required form of coordination. Note that CA CCBs equal to all zeroes will identify a TCAS aircraft. A CA system will be required to perform regular automatic self-tests of its transmitted CA CCBs; failure to transmit the correct CCBs will result in a declared failure of the CA system.

M.3.1.1 Active Coordination

Active coordination (Figure M-1) **shall (**RM.3.4) be used when the two aircraft are considered peers and both aircraft have a Mode S transponder and 1030/1090 MHz discrete interrogation/reply capability.

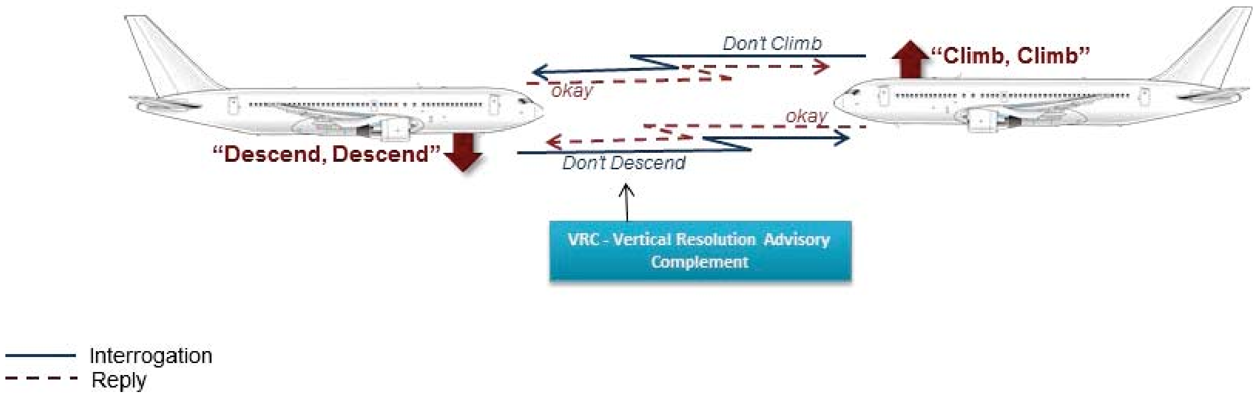


Figure M-1 Active Coordination

The protocol for active coordination is as follows:

- Priority **shall (**RM.3.5) be established between the two aircraft for use in coordination. The aircraft with the lower 24-bit International Civil Aviation Organization (ICAO) address **shall (**RM.3.6) be designated the master, and the aircraft with the lower 24-bit ICAO address **shall (**RM.3.7) be designated the slave. The slave shall (RM.3.8) ensure that its RA sense is compatible with that of the master.
- The two aircraft **shall (**RM.3.9) exchange coordination information via Mode S discretely-addressed 1030/1090 MHz interrogations/replies as defined in RTCA DO-185B.
- Each aircraft, once it has selected an RA, **shall (**RM.3.10) transmit a coordination interrogation to the other aircraft nominally once per second for the duration of the RA. The coordination interrogation includes a Vertical RA Complement (VRC), which contains the complement (i.e., opposite vertical sense or direction) of the RA selected by the transmitting aircraft. Its purpose is to limit the RAs available to the other aircraft. For example, a CA system selecting an upward sense RA (e.g., climb) will transmit a downward sense VRC (e.g., do not pass above) to the equipped intruder.
- The recipient of the coordination interrogation **shall (**RM.3.11) respond with a coordination reply, essentially a "handshake" that confirms receipt, and **shall (**RM.3.12) make use of the received VRC in its RA sense selection process. Unless rejected by the master aircraft, the first aircraft to select a vertical sense **shall (**RM.3.13) prevail in its choice; the second aircraft **shall (**RM.3.14) conform to this choice and limit its RA selection accordingly.
- If the two aircraft simultaneously select the same sense, then the master **shall (**RM.3.15) prevail, and the slave **shall (**RM.3.16) reverse the sense of its RA.
- In active coordination, the master is able in specific deteriorating geometries to issue a sense reversal, called a geometric reversal. In this case, the master **shall (**RM.3.17) send a coordination interrogation to the slave containing the new VRC and canceling the existing VRC. The slave **shall (**RM.3.18) then reverse its RA sense to remain compatible with the master.

M.3.1.2 Passive Coordination

Passive coordination (Figure M-2) **shall (**RM.3.19) be used when the two aircraft are considered peers and both aircraft have ADS-B In and Out but no 1030/1090 MHz discrete interrogation/reply capability.

Passive coordination uses a process called Active Coordination Emulation [6], which replicates, to the extent possible on a broadcast link, the coordination interrogations and replies that occur on the addressed link.

Figure M-2 **Passive Coordination**

The protocol for passive coordination is as follows:

- Priority **shall (**RM.3.20) be established between the two aircraft for use in coordination. For passive coordination, master/slave designation can be determined by the 24-bit ICAO address (as in active coordination) or by a potential future priority scheme based on the ADS-B CA CCBs broadcast by each CA system. The slave will ensure that its RA sense is compatible with that of the master.
- The two aircraft **shall (**RM.3.21) exchange coordination information by broadcasting the ADS-B Operational Coordination Message (OCM) over a common frequency, e.g., 1090ES or UAT. The OCM contains essentially the same information[63] as the coordination interrogation used in active coordination, including the VRC.
- Each aircraft, once it has selected an RA, **shall (**RM.3.22) transmit the OCM at regular intervals for each threat for the duration of the RA.
- Unless otherwise validated, the first aircraft to select a vertical sense **shall (**RM.3.23) prevail in its choice; the second aircraft **shall (**RM.3.24) conform to this choice and limit its RA selection accordingly.
- If the two aircraft simultaneously select the same sense, the master **shall (**RM.3.25) prevail, and the slave **shall (**RM.3.26) reverse the sense of its RA.
- In passive coordination, as in active coordination, the master is able in specific deteriorating geometries to issue a sense reversal, called a geometric reversal. In this case, the master **shall (**RM.3.27) send an OCM to the slave containing the

63 The ICAO 24-bit addresses of both the sending aircraft and the (intended) receiving aircraft are contained in the OCM. Thus, even though all aircraft equipped with an ADS-B receiver receive an OCM, only the aircraft for which it is applicable will use that message.

new VRC and canceling the existing VRC. The slave **shall (**RM.3.28) then reverse its RA sense to remain compatible with the master.

M.3.1.3 Responsive Coordination

Responsive coordination **shall (**RM.3.29) be used between two CA-equipped aircraft when one aircraft has active (1030/1090 MHz discrete interrogation/reply) capability and the other aircraft has passive (only ADS-B In/Out) capability. Here the aircraft with active capability takes on a dominant/senior role, and the aircraft with passive capability takes on a subservient/junior role.

Responsive coordination **shall (**RM.3.30) employ one-way communication of coordination information from the dominant/senior CA system to the subservient/junior CA system.

The terms "senior" and "junior" are used purposely in responsive coordination to reflect the difference in capability between the two aircraft. In responsive coordination, the junior aircraft does not transmit coordination information to the senior aircraft and thus cannot influence the senior aircraft's choice of RA sense.

Responsive coordination was developed with the following encounter situations in mind:

1. There can be limited communications paths between the two aircraft. For example, TCAS is designed to obtain coordination information only from received 1030 MHz coordination interrogations, and a junior aircraft with only ADS-B In/Out capability cannot transmit 1030 MHz interrogations.
2. A junior aircraft with only ADS-B In/Out capability would not be able to actively validate the position of its intruders. Thus the junior aircraft's RAs could be considered less reliable than those of the senior aircraft. Certification authorities could decide to prohibit the junior aircraft from influencing the senior aircraft's choice of RA sense by requiring the junior aircraft to perform responsive coordination.

In responsive coordination, the junior aircraft **shall (**RM.3.31) ensure that its RA sense is compatible with that of the senior aircraft.

The junior aircraft may select an RA prior to the senior aircraft's selection of an RA, but if so, the junior aircraft **shall (**RM.3.32) reverse sense if its selected sense turns out to be incompatible with the sense selected later by the senior aircraft.

In responsive coordination, the junior aircraft **shall (**RM.3.33) use, i.e., listen for and receive, one of three coordination messages in order to ensure that its RA sense is compatible with that of the senior aircraft. The message used is determined by the equipage of the two aircraft, as described in detailed in Subsection M.10. The three messages are:

1. The 1030 MHz Mode S discrete coordination interrogation ("TCAS Resolution Message")
2. The 1090 MHz ADS-B Operational Coordination Message
3. The 1090 MHz ADS-B TCAS RA Broadcast Message

Figure M-3 illustrates Message 1 above, showing an encounter in which a TCAS-equipped aircraft transmits a 1030 MHz Mode S discrete coordination interrogation to a passive ACAS X_u equipped aircraft with a Mode S transponder.

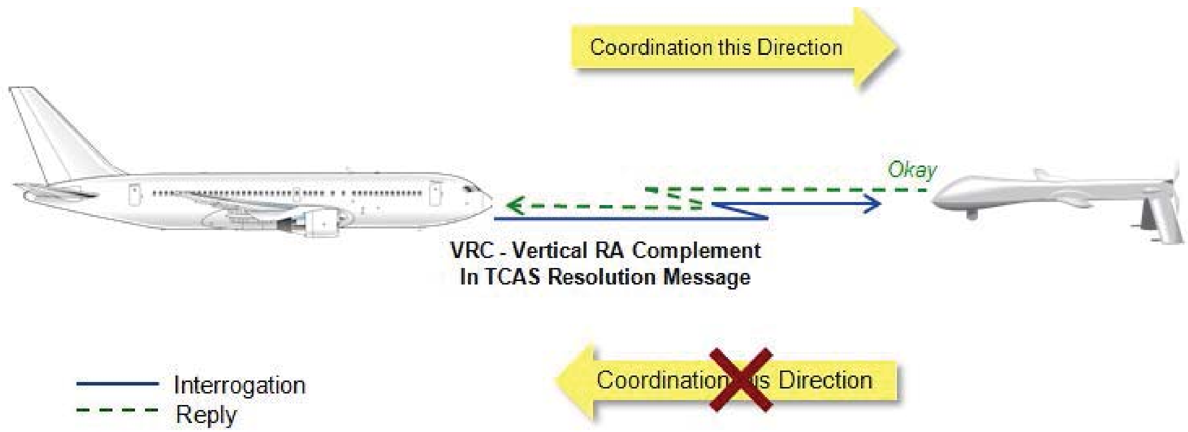


Figure M-3 **Responsive Coordination: TCAS vs. Passive ACAS Xu with Mode S**

M.4 Non-Vertical Interoperability

Other sections of this appendix consider almost exclusively the interoperability of vertical RAs. Non-vertical RAs are similarly required to use standardised coordination protocols to meet requirement RM.3.2, and may use adaptations of the vertical protocols defined in Paragraph M.4.1

- Horizontal RAs on one aircraft and vertical RAs on the other
- Horizontal RAs on both aircraft
- Speed RAs on one or both aircraft
- In the case of multiple RA dimensions (e.g., speed, horizontal and vertical RAs) the interoperability requirements for each RA dimension **shall (**RM.4.1) apply

The interaction between CA systems and conflict management systems is also examined.

M.4.1 Horizontal Maneuvers and Vertical RA Interoperability

In an encounter where one aircraft can only issue vertical RAs and the other aircraft can only issue horizontal RAs or directive guidance, despite the orthogonality of actions, CA performance can be degraded. For example the change of turn rate in a vertically maneuvering aircraft may reduce the effectiveness of a horizontal RA, or the change in vertical velocity in a horizontally maneuvering aircraft may reduce the effectiveness of a vertical RA. Since TCAS is already in service and is very difficult to change, systems capable of horizontal maneuvers must expect to adapt themselves when necessary.

Whenever a system capable of horizontal maneuvers detects RAs issued against the ownship, it **shall (**RM.4.2) limit its RAs or maneuvers so that any change in vertical rate is compatible with the RAs issued against the ownship.

A study was undertaken to determine the sensitivity of TCAS and ACAS X to changes in vertical rates by an aircraft issuing horizontal RAs [15]. The study concluded that for intruders with vertical rates limited to 1500 fpm, changes in vertical rate of less than 500 fpm performed at the time of a typical horizontal CAS maneuver did not degrade safety as compared to typical ACAS X or TCAS encounters.

Aircraft that are not limited to vertical rates of 1500 fpm (see note 3) or with CAS that can cause changes in vertical rates of the ownship of more than 500 fpm as a result of their horizontal maneuvers **shall (**RM.4.3) monitor signals from CA systems on surrounding aircraft for RAs against the ownship.

Note:

1. *Horizontal maneuvers change the Time to Closest Approach (TCA) and thus alter the effectiveness of a vertical RA on the other aircraft. For example, a maneuver to pass behind the threat aircraft rather than in front of it may reduce TCA and act counter to an altitude-crossing RA maneuver by the other aircraft, potentially making it dangerous. At the time these MOPS were published, it was not clear what could be done about this. For example, the coordination messages do not convey whether or not the RA is altitude-crossing; that is something that would need to be diagnosed by the aircraft making the horizontal maneuver.*
2. *Horizontal CAs might compensate for any reduction in vertical collision avoidance. However, the performance of the horizontal CAS would have to be demonstrated through comprehensive simulations and subsequent operational validation.*
3. *Further studies could be undertaken to refine the need for aircraft capable of more than 1500 fpm vertical rates to follow requirement M.4.3.*

M.4.2 Horizontal RA Interoperability

M.4.2.1 Coordination Protocols for CAS that Generate Horizontal RAs

In an encounter where both aircraft have horizontal RA capability, it is hypothesized, based on experience in the vertical plane, and ACAS III studies, that coordination is required to provide better CA performance than against an unequipped intruder. The developer of MOPS for the first horizontal RA system that does not use explicit coordination must show that implicit coordination is sufficient and define the implicit coordination rule set (these MOPS may be updated as necessary).

Experience with horizontal CA coordination was very limited at the time these MOPS were published. No such protocols existed for maritime traffic. Only the ACAS III/ TCAS IV protocol had been officially defined by ICAO/ RTCA.

Arguably, the first horizontal CA system to be widely implemented will define the protocols to be used. As a backstop, the existing ACAS III protocol [4] should be considered, unless arguments are provided for something better. (Should the commercial air transport system wish to have a horizontal RA capability, it would wish it to be at least as good as the existing ICAO standard). With the work on several UAS CA systems moving ahead rapidly, there is a limited time window to propose a new protocol that is not only more efficient but also open to future developments.

The protocol is expected to be explicit, not only because that is the case with ACAS III, but also because some horizontal RAs will require explicit (TCAS type) coordination with vertical RAs. Furthermore, explicit coordination has been shown to be both effective and flexible in the vertical plane, working with different CA algorithms. The use of implicit coordination requires CA systems to operate on a common set of rules, and this requirement may limit future systems and conflict with the goals of interoperability.

Further research is needed in the field of horizontal coordination. This was outside the remit of SC-147 at the time these MOPS were published.

If explicit coordination is used, horizontal CA systems **shall (**RM.4.4) implement explicit coordination using the ACAS III protocol.

DAA systems without CA **shall (**RM.4.5) listen for horizontal CA coordination bits transmitted by other aircraft, and ensure that any horizontal guidance is compatible.

Potential areas for improvement include the design of a coordination protocol that could work not only for CAS but also for DAA systems and allow for negotiation within the protocol.

M.4.2.2 Logic Interoperability between Horizontal RAs

Regardless of the coordination protocol, encounter model tests of interoperability must be undertaken.

Horizontal CA systems **shall (**RM.4.6) test their interoperability with all existing horizontal CAS (including themselves) by a series of encounter model simulations. These simulations **shall (**RM.4.7) be similar to those described in Subsection M.7, but adapted to test performance of horizontal RAs in environments where those RAs are known or expected to occur.

M.4.3 Speed RA Interoperability

Some aircraft, notably helicopters, may consider speed changes as viable RAs. If CA systems are built that use speed changes to avoid collisions, they will need to ensure their interoperability with other CAS that use either horizontal or vertical RAs. Changing speed will change TCA, thereby altering the effectiveness of vertical or horizontal maneuvers.

When the ownship has a speed RA capability and the intruder has either vertical or horizontal RA capabilities, then the speed RAs **shall (**RM.4.8) cause negligible degradation of the CA safety performance of the intruder.

Simulations of representative encounters **shall (**RM.4.9) be performed to demonstrate the effect of speed RAs upon operational CAS.

Note:

1. *These simulations should to be similar to those described in Paragraph M.4.3. Acceptability criteria for the simulations should be developed prior to the simulations being run.*

2. *The topic is not mature; there is limited knowledge of what is necessary. Any implementation must be done in a way that does not degrade existing systems and this must be demonstrated through simulation models.*

When the ownship has a speed RA capability, an implicit or explicit coordination method shall (RM.4.10) be applied to encounters in which the intruder also has a speed capability.

M.4.4 Maintain DAA Well Clear (DWC) Function Interoperability with CAS

An aircraft may contain a DAA system that provides a recommended maneuver to change its path when an intruder has an RA against it. Even though the DAA function may be designed to minimize interference with CA, it is inevitable that sometimes alert timings will overlap. In such cases, CA performance can be degraded by unexpected maneuvers of an intruder. It is highly desirable to improve safety in such situations by ensuring that when DAA systems are aware of RAs in surrounding traffic, they do not perform incompatible actions.

Note:

1. *Turns and climbs from an FMS would be excluded, as their function is navigation rather than conflict management. Furthermore, their integration into automatic responses to RAs has already been addressed [14]. Implementation of flow control maneuvers might be part of a DAA system.*
2. *It is expected that DAA systems will include functions to keep well clear of other aircraft.*
3. *Any maneuvers within 50 seconds of TCA are likely to interfere with ACAS CA [15]. DAA functions shall not (RM.4.11) recommend any new maneuver that is incompatible with RAs issued against the ownship.*

With current rules, pilots can maneuver at any time if they decide it is correct, without the above requirements. Requirement RM4.11 becomes appropriate when an electronic system is making maneuver decisions or recommendations. In such cases it would be irresponsible to take or recommend an action that is expected to have a significant associated risk of collision.

DAA systems may use similar coordination protocols to CAS. However, vertical maneuvers may degrade safety if the DAA system unduly restricts the choices available to CAS on intruder aircraft.[64]

Modifications to indicate that the data exchange is for a purpose other than CA would be necessary.

A unified coordination scheme for CAS and DAA could be envisioned for horizontal maneuvers.

[64] For example, if the DAA-equipped aircraft is the master aircraft, TCAS II on the other aircraft will not be able to issue a reversal that otherwise it might consider essential for collision avoidance.

M.5 Transmission and Antenna Performance

M.5.1 Introduction

In order to coordinate the selection of CA RAs, two interoperable CA systems must be able to transmit and receive all defined coordination messages as needed in accordance with a coordination protocol as defined in Subsection M.3. It is important that each aircraft has the ability, equipage and transmission power to reliably communicate with intruding aircraft at ranges necessary to support coordinated avoidance RAs.

The design, safety performance and robustness of each coordination protocol have previously been studied and tested using range and reliability performance based on specific assumptions regarding transmit and receive power and detection. Therefore, CA systems must adhere to the relevant requirements assumed in order to achieve the expected performance and robustness of coordination communication between two CA systems.

The TCAS II MOPS contain many examples of requirements that may be adapted to new systems.

Transmission and reception reliability for coordination related messages **shall (**RM.5.1) meet or exceed all performance requirements defined for the selected coordination protocol. This includes all requirements regarding signal formatting, signal power, receiver sensitivity, and associated antenna requirements.

Systems or platforms which deviate from these requirements **shall (**RM.5.2) justify that the deviation does not degrade the performance of existing systems.

Note:

1. *For example, systems that intend to use the TCAS coordination protocol with TCAS/ACAS XA intruders as peer aircraft shall meet or exceed the transmission and reception performance requirements for coordination messages as defined in RTCA DO-185B/ACAS X MOPS.*
2. *The requirements contained in this subsection pertain exclusively to the transmission and reception of messages required to use an accepted coordination protocol (including identifying the proper protocol). The surveillance transmission and reception requirements necessary to acquire and track an intruding aircraft may be defined distinctly from those necessary to perform coordination. While systems can define a single set of transmission and reception requirements, future systems may desire surveillance performance beyond that required for coordination or vice versa.*

M.5.2 Transmit Requirements

This equipment **shall (**RM.5.3) transmit all interrogations and broadcasts with the appropriate frequency and formatting as defined by each coordination protocol to ensure compatibility with elements of the Air Traffic Control (ATC) system and standardization of interface signals between ACAS and other systems on the ACAS-equipped aircraft.

Considerations related to coordination transmissions include:

1. Transmit Frequency and Tolerance
2. The equipment must be capable of accepting signals with small variations in the transmit frequency.
3. Active Transmit Power
4. Transmit power requirements must ensure that there is sufficient Effective Radiated Power (ERP) to coordinate with an intruder.
5. Inactive Transmit Power
6. This power restriction is necessary to ensure that a CAS does not prevent other onboard equipment, such as a Mode S transponder, from meeting its sensitivity and interference rejection requirements.
7. Transmit Spectrum
8. The equipment must be capable of limiting the spectrum of the transmitted signal so as to be accepted by the intended recipient and not interfere with systems on other frequencies.
9. Transmit Timing
10. The transmission time of each coordination interrogation or broadcast must prevent synchronous interference with other airborne interrogators or those in the Control Station (CS).

M.5.3 Receive Requirements

This equipment **shall (**RM.5.4) receive, accept and process all radio frequency replies and broadcasts used by each coordination protocol as defined by the coordination protocol to ensure availability of transmitted coordination information and intruder CA capability.

Reception requirements to be met by a CA system for reception of coordination-related transmissions may include but are not limited to:

1. RF Receive Interface
2. The RF receive interface must be capable of detecting, demodulating, and decoding all signals necessary in accordance with the defined coordination protocols.
3. Reception Sensitivity and Interference Rejection
4. The receive interface must be capable of receiving and responding to coordination related transmissions with the minimum sensitivity defined by the coordination protocol. The interface must maintain the defined robustness to interference and noise as provided by the defined protocols. Increased sensitivity and decoding performance may be necessary to demonstrate comparable system performance and robustness.

M.5.4 Antenna Requirements

The performance and robustness of the transmission and reception of coordination-related information is largely dictated by the design and placement of the transmitting and receiving antennas.

Transmission requirements to be met by a CA system for coordination-related transmissions may include but are not limited to:

1. Antenna Directionality and Diversity
2. Coordination protocols may require use of directional antennas and/or the use of both top and bottom antennas (diversity) to ensure robust reception of coordination-related transmissions.
3. Antenna Radiation Pattern
4. The radiation patterns of both transmit and receive antennas must provide adequate performance in all directions defined by the coordination protocol. Adequate performance includes the required coverage and antenna gain in all azimuths and elevations as described by the coordination protocol
5. Antenna Location

   Placement of the transmitting and receiving antennas on a platform can impact the probability a transmitted signal is received and decoded properly. Obstructions in the direction of transmission or reception can degrade the signal power at the receive interface and must be limited. Reflections on either the transmitting or receiving aircraft can degrade the ability to detect and decode a transmitted signal and must also be limited.

   When antenna diversity is used, antennas must be arranged so that receptions and transmissions from each antenna do not introduce biases or interference at the receive interface of the ownship or intruding aircraft.

M.6 1030/1090 MHz Channel Utilization Interoperability Requirements

This subsection provides high-level 1030/1090 MHz channel utilization interoperability requirements for airborne systems.

M.6.1 Background

Control stations and TCAS equipment use the 1030 MHz and 1090 MHz frequencies. Interrogations are performed at 1030 MHz. The interrogations elicit replies on the 1090 MHz channel from SSR transponders. Additionally, aircraft automatically transmit 1090 MHz squitters, both acquisition squitters, which are used by TCAS to acquire the discrete address of nearby Mode S equipped aircraft, and extended squitters, which are primarily used for conveying ADS-B information.

M.6.1.1 1030 MHz Utilization

1030 MHz interrogations from one system can result in interference against other interrogating systems in the following ways:

1. Interrogation Overlap or Channel Occupancy – The 1030 MHz interrogation signals may overlap one another and render one or both of the interrogations undetectable by a particular receiver.
2. Transponder Utilization or Occupancy – Every TCAS or SSR interrogation received by a transponder results in the transponder being unavailable to reply to another subsequent interrogation for some period of time.

3. Transponder Mutual Suppression – Pulsed transmitting L-band equipment such as TCAS, transponder, and distance measuring equipment are connected via a suppression bus on an aircraft. Every time one of these systems transmits, the suppression bus is activated to disable other transmitters and allow them to protect their receivers if necessary. While the suppression bus is asserted other equipment cannot transmit. Transponder Mutual Suppression is the result of the onboard TCAS or DAA transmitting 1030 MHz interrogations, suppressing the ownship transponder when transmitting. This activity on the Transponder Suppression bus results in the ownship transponder being unavailable to reply to other interrogating systems (TCAS, DAA, or SSR).

M.6.1.2 1090 MHz Interference

1090 MHz signals generate interference primarily as a result of signal overlap or channel occupancy. A 1090 MHz signal may overlap another 1090 MHz signal, rendering one or both signals undetectable. Replies unintended for a receiver are referred to as False Replies Unsynchronized In Time (FRUIT) replies.

M.6.1.3 TCAS Interference Limiting

RTCA DO-185B specifies algorithms that limit the interrogation rate of TCAS. The algorithms, as a goal, limit the amount of unavailability due to all TCAS operating within the range of an SSR transponder to 2%.

Note The regulatory requirement on TCAS is to implement the algorithms; individual TCAS are not required to achieve the 2% goal.

The interference limiting algorithms reduce transmit power and reduce receiver sensitivity in order to attempt to achieve the goal outlined above. The algorithms use information about the number and distribution of other TCAS in the area and monitor the number and power of ownship transmissions to determine if and to what extent the ownship surveillance should be limited (transmit power, rate, and receiver sensitivity).

Of special note – the algorithms significantly reduce transmit power when observing that a uniform range distribution of TCAS-equipped aircraft are operating within 6 NM of the ownship.

M.6.2 Spectrum Interoperability Guidance

The system **shall (**RM.6.1) employ measures to minimize 1030 MHz and 1090 MHz utilization (considering safety and performance requirements).

A DAA system that interrogates SSR transponders shall (RM.6.2) manage its interrogation activity so that limiting is provided as the combination of TCAS and DAA equipped aircraft operating in an area increases. Each DAA system **shall (**RM.6.3) monitor the presence of TCAS-equipped and DAA-equipped aircraft operating in its surrounding area and reduce its interrogations to adapt its interrogation rate based on the combined TCAS and DAA activity. The limiting algorithms should be consistent with TCAS operational goals such that any area in which TCAS and DAA systems operate does not result in more than 2% unavailability of any victim transponder. Also, the ownship mutual suppression as a result of DAA interrogations should not exceed 1% or 10,000 microseconds unavailability to the onboard transponder.

The above limits should not be exceeded and should not be viewed as channel utilization that has been allocated.

Note: *This limit was the design goal for the TCAS system and TCAS Interference Limiting algorithms contained in RTCA DO-185B were incorporated to protect the spectrum. The limits were based on the assumption that with a 5% transponder unavailability due to ground-based SSR interrogations and suppressions with worst case maximum ground-based SSR assumptions, the 2% unavailability contribution due to TCAS provided sufficient margin to support the performance requirements of these systems. In the past it has been demonstrated that this design goal is not met in some conditions without inducing identified issues with SSR performance. It is expected that SSR performance needs and demands will not increase as the result of increased use of ADS-B surveillance.*

The DAA system **shall (**RM.6.4) use passive acquisition of Mode S transponder equipped aircraft to minimize interrogation rates. The DAA system **shall (**RM.6.5) use passive acquisition to limit active interrogation activity using techniques as provided by RTCA DO-300A. It should be a goal through improved surveillance techniques and increased use of passive surveillance that the DAA systems minimize active interrogation activity and efficiently manage operations on the 1030/1090 MHz channels.

The DAA system **shall not** (RM.6.6) directly or indirectly degrade the range performance of CA-equipped aircraft below levels required to provide adequate CA protection.

M.6.3 Areas of Special Attention

Both the TCAS and interrogating DAA system must take into account the number of TCAS and DAA systems in the vicinity to ensure that neither system interferes with the other or ATC surveillance. The DAA system **shall (**RM.6.7) transmit the TBIM) or equivalent broadcast.

If a DAA system performs active surveillance it is required to transmit a TBIM. This ensures proper interference limiting. Additional methods of interference limiting may be necessary when the system is intended for formation flight or other operations that may result in excessive TCAS range reduction.

Note: *As is done presently for military formations of TCAS-equipped aircraft, if the DAA uses the TBIM in the same manner that TCAS does and the DAA-equipped aircraft fly in formations, then some formation members should expect to be prohibited from transmitting TBIM messages. This prohibition prevents unnecessary range reduction in other TCAS-equipped aircraft flying within close proximity, but at the expense of increased interference for ground sensors [1]. (The increased interference for ground sensors may be of less concern with the introduction of RTCA DO-300A TCAS.)*

M.7 Logic Interoperability Metrics and Tests

M.7.1 Overview

Logic interoperability of CA systems introduced into the airspace **shall (**RM.7.1) be tested and evaluated to ensure that new systems do not degrade the performance of any existing CA systems. Designers of CA systems have selected surveillance and CA algorithms with specific performance characteristics in order to meet the safety needs of their particular user classes. These algorithms are likely to have made performance tradeoffs necessary to balance safety, operational suitability, complexity and cost. New CA systems which enter the airspace are able to use alternative approaches, design choices, and meet different performance goals than existing systems.

The possibility exists that a new CA system interacting with an existing system in a potentially threatening encounter can result in neither system meeting its desired performance goals. The RA timing or sense of one CA logic may be viewed as unsafe or undesirable by the second CA logic, resulting in degraded performance for both CA systems. Logic interoperability ensures that the overall CA performance of two disparate CA systems in potentially unsafe encounters is not degraded.

Logic interoperability can be evaluated through Monte Carlo simulations assessing key performance metrics of each CA system. The CA logic must be evaluated pairwise with each existing CA algorithm that may be certified to operate in a common airspace. All relevant combinations of equipages or platforms must be considered as part of each pairwise evaluation.

Note:

1. *Clearly, adverse maneuvers by the threat aircraft at about the time the ownship generates an RA or during a CA maneuver will undermine the effectiveness of the ownship's avoidance. However, it has been found that adverse interaction between two CA logic designs can be much more subtle than this simple observation. Thus, even when coordination is perfect, tests that two systems work well together are required.*
2. *This appendix represents an initial step in defining what level of logic interoperability evaluation is needed, but practical challenges remain to enable intra-manufacturer evaluations of CA logic interoperability. Remaining challenges include: reasonable availability of correct CA systems for evaluation, agreement regarding what qualifies as "existing CA systems" and when deprecated systems no longer need to be considered.*

M.7.2 Logic Interoperability Evaluation

Pairwise logic interoperability **shall (**RM.7.2) be evaluated through large-scale encounter simulation using standardized encounter sets and metrics. Unlike simulations performed during development of a CAS decision logic, logic interoperability simulations evaluate the effect of one CA system on the safety and operational suitability performance of a second CA system.

M.7.2.1 Simulation Framework

Metric evaluation **shall (**RM.7.3) be performed in a simulation framework which incorporates realistic aircraft dynamics, pilot response and non-response, and relevant measurement noise models. The simulations **shall (**RM.7.4) be for operationally realistic trajectories for both aircraft, and the simulations **shall (**RM.7.5) cover the full range of operationally possible trajectories. Aircraft state and CA guidance **shall (**RM.7.6) be updated at the rate defined by each system under test. Simulation **shall (**RM.7.7) only provide the CAS logic information available at the system's defined input interface.

M.7.2.2 Encounter Models

The required encounter sets that must be evaluated in simulation must statistically represent all relevant airspaces and all subclasses of encounters considered important for safety or operational suitability. Required encounter sets available at the time these MOPS were published included:

- US Airspace Safety (LLCEM): The Lincoln Laboratory Correlated Encounter Model (LLCEM) is a probability distribution of safety-critical encounter parameters for aircraft receiving air traffic services in US airspace.
- US Airspace Suitability (TRAMS): The TCAS RA Monitoring System (TRAMS) records aircraft tracks and RA downlinks from TCAS equipped aircraft receiving RAs in the coverage area of 21 terminal area radars in the US. Encounters created from these recordings are useful in gauging CA operational suitability metrics.
- European Airspace Safety – ACAS on VLJs and LJs –Assessment of safety Level (AVAL)
- Stressing Encounters (TCAS Encounter Generator)
- Hazardous Encounters (Safety issue SA01 described in RTCA DO-298)

While encounters involving two aircraft represent the most common encounters, encounters involving multiple aircraft occur. As multi-threat encounters can be challenging to resolve safely, they **shall (**RM.7.8) be included as a relevant encounter set.

Assessment of logic interoperability of CA systems **shall (**RM.7.9) include evaluation of safety, operational suitability and stressing system performance.

M.7.3 Safety Performance Metrics

Evaluation of the interoperability of two CA systems **shall (**RM.7.10) include analysis to ensure that:

1. The safety of an existing CA system is not degraded in encounters between aircraft equipped with the existing CA system and aircraft equipped with a new system, as compared to its safety in encounters between the existing CA system and unequipped aircraft.
2. The safety performance of a new CA system in equipped-equipped encounters with an existing system is considered as part of the overall safety metric.

Important metrics for safety evaluation **shall (**RM.7.11) include:

Probability of Near-Midair Collision (NMAC): The probability of observing an NMAC in an encounter between aircraft. The multiplication of the probability of NMAC and the encounter rate in an airspace results in the probability of NMAC in the airspace. The probability of NMAC calculation should include the effects of altimeter bias (if the system uses an altimeter). The probability of NMAC should be assessed for various pilot response models.

Probability of Reversal: The probability that a CA system will reverse the sense (vertical direction for TCAS and ACAS X) during an encounter. Reversals may be considered either coordination reversals (forced sense reversal due to a coordination protocol) or a geometric reversal (sense reversal due to encounter geometry or detected maneuver).

M.7.4 Operational Suitability

Operational suitability refers to the set of performance metrics that capture a CA system's (CAS) compatibility with safe pilot and ATC operations. The more compatible a CAS is with these operations, the less disruptive it will be to them. Because the bulk of any disruption that a CAS might bring about will be caused by the resolution advisories (RAs) that it issues or fails to issue, RA behavior is typically the primary focus of operational suitability analyses.

For the purposes of interoperability, consideration of operational suitability is focused on the impact of one system on a second system. Any pair of distinct CA systems can be expected to issue different alerts at different times under the same circumstances in some encounters. This mutual difference in alerting behavior has the potential to influence the operational suitability performance of both systems in mixed equipage encounters. The extent of this effect is captured in an operational suitability interoperability analysis.

In the development of ACAS X, the primary source of operational suitability data has been the results of fast-time simulations of aircraft encounters. These simulations have largely consisted of two-aircraft encounters in which the CAS equipage (equipped with CAS or unequipped), altitude encoding, and master/slave assignments of the two aircraft vary in a way that reflects aircraft encounter data recorded in the National Airspace System (NAS). The analyses of these encounters have focused on the performance areas and metrics outlined below.

Note that a Lincoln Laboratory journal article [9] an Air Traffic Management seminar paper [11], each contain information on the techniques used to evaluate the performance of ACAS X, including its operational suitability. These techniques will likely provide valuable insight to those seeking to evaluate the performance of DAA or other CA systems.

M.7.4.1 Operational Suitability Metrics

This paragraph includes a list of operational suitability metrics that apply to CA Interoperability. These do not represent the Operational Suitability Metrics for a DAA system.

M.7.4.1.1 Alert Frequency

Overall alert frequency is a fundamental metric of operational suitability, with a CAS that safely resolves an encounter or set of encounters using fewer RAs being more operationally suitable than one that safely resolves the same encounter or set of encounters using more RAs. Overall alert frequency is also typically decomposed by alert type, such as in the following list for vertical RAs, ordered loosely from least to most disruptive:

1. Preventives (monitor vertical velocity, maintain climb/descend)
2. Level-off
3. Climb/Descend (±1500 fpm)
4. Increase Climb/Descend (±2500 fpm)

Also of concern are specific types of potentially disruptive single alerts or alert sequences, including:

- Strengthenings: transitions from one RA to another of the same sense (e.g., up or down) that requires a change in the rate of the maneuver.
- Geometric reversals: transitions from one RA to another of the opposite sense. Note that geometric reversals are distinct from coordinated reversals, which are caused by RA coordination rules and are considered less disruptive.
- Split RAs: RA sequences that include an intermediate declaration of *Clear of Conflict* followed shortly thereafter by the declaration of a threat on the same intruder.
- Altitude crossings: RAs that command the aircraft to climb or descend towards and through the altitude of an intruder.
- Corrective RAs opposite in direction to an aircraft's current trajectory.

M.7.4.1.2 Alert Timing

The way that alerts are timed relative to one another and to the events in an encounter is also highly relevant to operational suitability. Alerts or alert sequences should be short enough to discourage excess deviation, but also long enough to address the threat of an intruder for as long as it persists in the perception of both the alerting logic and the pilots using the system. Furthermore, alerts should be timed such that they allow pilots a chance to respond to them before they transition to other alerts or to a *Clear of Conflict* state. Otherwise, pilots may perceive them as unnecessary or poorly timed, degrading their trust in the system.

M.7.4.1.3 Encounter Classes and Locations

There are many classes of encounters in a large airspace, each with its own parameters for acceptable alerting behavior. The following are three example encounter classes typically observed in the NAS:

- 500' IFR/VFR encounters
- 1000' IFR/IFR encounters
- Closely Spaced Parallel Operations (CSPO)

In 500' and 1000' encounters, for example, climb and descend RAs are typically considered more disruptive than level-off RAs, which often correspond with intended pilot action in these encounters.

The locations in the airspace where alerting behavior is observed are also important. Given an appropriate encounter set, one can analyze alerting behavior by airspace class, altitude layer, and even at specific Terminal or En Route areas.

M.7.4.1.4 Aircraft Categories

Alerting behavior can also be evaluated for specific categories of users, given an appropriate encounter set. In the analysis of TCAS II and ACAS X, these categories have included:

- Major air carriers
- Regional air carriers
- Business jets
- Helicopters

M.7.4.2 List of Metrics

The following is a non-exhaustive and non-prioritized list of the operational suitability metrics included in analyses of TCAS II and ACAS X. While all of these metrics are relevant in the context of collision avoidance for manned aircraft some will be more or less important in other contexts. This includes operations with unmanned aircraft, where responses to resolution advisories may be automatic[65] rather than pilot in-the-loop; and it includes the Maintain DWC function, which is associated with longer time scales and longer distances than collision avoidance.

- Total alert frequency
- Alert frequency in CSPO encounters
- Alert frequency in 500' and 1000' encounters
- Climb/Descend alert frequency in 500' and 1000' encounters partitioned by geometry type (Level-Level, Level-off-Level, Level-Level-off, Level-off-Level-off)
- Geometric reversal frequency
- Altitude crossing frequency
- Split RA frequency
- Weakening alert frequency
- Strengthening alert frequency
- Timing of first strengthening in sequence after preceding alert
- Timing of final strengthening in sequence relative to TCA
- Alert frequency by airspace class
- Alert frequency by aircraft category
- Time between TCA and *clear of conflict*
- Time between initial alert and TCA
- Duration of alert sequences
- Alert frequency by altitude layer

M.7.4.3 Operational Suitability and Interoperability

An operational suitability interoperability analysis is an extension of the kind of operational suitability analysis outlined earlier. Instead of any equipped-equipped

[65] The Phase 1 DAA MOPS does not include automatic response to DAA guidance

encounters consisting solely of two aircraft equipped with the same CAS, these encounters must instead consist of at least some aircraft pairs with mixed CA equipage. The ratio of mixed to unmixed encounters is a parameter of interoperability analysis that can be adjusted to reflect different levels of integration of the two CA systems in the airspace. Also, because some alerting decisions depend on whether or not the ownship is the master or slave in an encounter, the master/slave relationship of the two encountering aircraft should also be varied as part of this analysis.

Although the entire set of operational suitability metrics are valid for an interoperability analysis, some are especially sensitive to the master/slave relationship of a pair of aircraft as well as the choice and timing of alerts made by a CAS-equipped intruder. Among these metrics are the following:

- Strengthenings
- Altitude crossings
- Geometric reversals

Note that in the context of equipped-equipped encounters with TCAS or ACAS X, a *geometric reversal* is a change in the RA vertical sense of both aircraft initiated by the master as a result of changing encounter circumstances. This is as opposed to a *coordination reversal*, which is a change to the slave's RA vertical sense imposed on it by the master as a result of conflicting RAs issued at the same time or as part of the forced alerting functionality in place for altitude crossing encounters.

M.7.5 Logic Interoperability Stress Testing

Rigorous stress testing on challenging encounters is necessary for any release of CAS logic. Examining the behavior of CAS on "edge cases" often uncovers unexpected and dangerous behaviors. An extension of this concept, which has been applied to consecutive versions of TCAS in the past, is to simulate the challenging encounters varying the CAS logic onboard each aircraft to look for combinations of equipage that underperform. For example, using the same encounter model, and two different CA systems (CAS-A and CAS-B) simulations are run using:

1. Both aircraft equipped with CAS-A
2. Master aircraft equipped with CAS-A, slave aircraft equipped with CAS-B
3. Master aircraft equipped with CAS-B, slave aircraft equipped with CAS-A
4. Both aircraft equipped with CAS-B

Simulation Runs 1 and 4 provide the bounds of expected CAS behavior and are used for comparison with simulation Runs 2 and 3. High-level comparisons, such as counts of encounters with induced NMACs, unresolved NMACs, alerts that reverse sense or alerts that strengthen, provide an indication of the overall performance difference with interoperating CAS candidates. Deeper comparison of individual encounters with differing behavior depending on equipage (1, 2, 3, 4) enables identification of undesirable behavior either with the coordination process or the interaction of the two CAS logic versions due to initial alert timing or sense selection differences. Both types of differences will have an impact on the interoperability of CAS-A and CAS-B.

Past studies have indicated that small variations in the timing of received coordination messages and sense selection can introduce undesirable behavior. In particular, simultaneous maneuver selection or time delays between the receipt and availability of the intruder's intended sense in the CA logic can induce sense reversals and potentially unresolved NMACs. Therefore, realistic timing delays and asynchronous behavior must be considered in stress testing the interaction of the coordination mechanism and the CA logic [12].

M.8 Coordination Tests

Coordination testing has two main purposes:

1. Validation that the design, as defined in standards documentation, performs the intended function, i.e., ensures that the collision avoidance systems on any two conflicting aircraft select complementary avoidance RAs; and
2. Verification that this design is correctly implemented in avionics equipment.

Validation is generally performed by the organization responsible for the logic design – the FAA in the case of TCAS and ACAS X. Verification is generally performed by CAS manufacturers.

M.8.1 Validation of the Coordination Design

CA systems **shall** (RM.8.1) undergo validation to demonstrate that the coordination design performs the intended function and does so robustly under challenging conditions.

Such validation **shall (**RM.8.2) include at a minimum:

1. A structured and systematic examination of the coordination design, e.g., the following steps:
    a. Break the coordination design into detailed steps
    b. Identify possible errors in each step
    c. Estimate the frequency of errors and severity of consequences; calculate risk
    d. Prioritize risks
    e. Identify avoidance measures and/or mitigations
    f. Implement avoidance measures and/or mitigations

AND

1. Simulation of the coordination logic, using as input large numbers of equipped-equipped encounters
    a. Include encounters that represent typical aircraft performance (e.g., vertical rate and acceleration) as well as encounters that exceed typical aircraft performance
    b. Execute the simulation while systematically varying the timing of coordination interactions between the two aircraft
    c. Demonstrate proper coordination functioning and message exchange (sequence, timing, content).

References [9] and [12] describe the FAA ACAS X coordination validation process, which is similar to the TCAS coordination validation performed in the 1980s [16].

M.8.2 Verification of the Coordination Implementation

M.8.2.1 Tests of Basic Coordination Functionality

CA systems **shall (**RM.8.3) undergo coordination/interoperability testing at both the component and installation levels. A description of required coordination testing at the time these MOPS were published is given in the following paragraphs.

Coordination/interoperability testing required by the FAA for certification of TCAS avionics includes both component level testing under the Technical Standard Order (TSO) approval process and airworthiness/installation testing under the Type Certificate (TC) or Supplemental Type Certificate (STC) approval process. The primary document referenced in the TSO process is the Minimum Operational Performance Standards (MOPS); the primary document referenced in the TC or STC process is the FAA Advisory Circular (AC).

There are three distinct types of coordination/interoperability tests required for certification:

1. For TSO approval: TCAS MOPS Volume 1, Subparagraphs 2.4.2.2.3, 2.4.2.2.4, and 2.4.2.2.5. These sections contain 36 tests, mainly checking for proper content, format, and timing in the air-to-air, air-to-CS, and CS-to-air exchange of coordination-related data. The tests require use of the actual avionics equipment (TCAS unit and associated Mode S transponder), cabled together and operating in a laboratory environment.
2. For TSO approval: TCAS MOPS Volume 1, Subparagraph 3.4.4.3, Coordination Flight Tests. These tests are included under the heading “Installed Equipment Performance” and require flights with two TCAS-equipped aircraft.
3. For TC or STC approval: FAA Advisory Circular 20-151, §2-15, Equipment Compatibility Requirements. This section requires an applicant to perform both a “TCAS to TCAS coordination demonstration, or equivalent, with at least one other manufacturer’s approved TCAS system” and “TCAS/transponder interoperability bench tests using the same TCAS/transponder pairing (the same part numbers) as the installation seeking certification.”

M.8.2.2 Tests of Coordination Functionality under Stressing Conditions

Operational experience shows that serious manufacturer implementation errors can exist despite the fact that the CA units successfully pass MOPS and AC tests. The errors occur in flight, most often during periods of high aircraft density and/or stressful timing conditions (e.g., simultaneous coordination by both aircraft in a coordinated encounter).

Therefore, CA systems **shall (**RM.8.4) undergo stress testing of the coordination implementation using actual avionics hardware and software. In addition to stressful coordination timing situations, these tests **shall (**RM.8.5) mimic a high-volume surveillance environment, with at least one multi-threat encounter among three ACAS X aircraft.

Details of stress testing for coordination validation are documented in Reference [12].

M.9 Protocols for Responsive Coordination

The following assumptions apply to this subsection: The two aircraft are CA-equipped. The senior aircraft has 1030/1090 MHz discrete interrogation/reply capability. The junior aircraft has only ADS-B In/Out capability, i.e., no 1030 MHz transmission capability. Both aircraft are transmitting and receiving ADS-B CA CCBs, which are used by the CA logic to select the proper type of responsive coordination, detailed in Paragraphs M.9.1, M.9.2, and M.9.3 below.

As stated in Subparagraph M.3.1.3, in responsive coordination, the junior aircraft uses one of three coordination messages in order to ensure that its RA sense is compatible with that of the senior aircraft. The three messages are:

1. The 1030 MHz Mode S discrete coordination interrogation ("TCAS Resolution Message")
2. The 1090 MHz ADS-B Operational Coordination Message (OCM)
3. The 1090 MHz ADS-B TCAS RA Broadcast Message.

The messages are listed in order of desirability for use in coordination. That is, if possible, it is desirable to use the discrete TCAS Resolution Message for coordination. This message uses double layers of parity protection for the coordination information, and interrogations are re-transmitted 6-12 times over a 100-millisecond (ms) interval if necessary to ensure quick reception by the intruder aircraft. TCAS Resolution Messages contain all necessary information in the case of multi-threat encounters. (That is, in the case of multiple CA-equipped intruders, a TCAS Resolution Message is sent to each intruder separately.)

Next is the ADS-B Operational Coordination Message or OCM. It is less desirable than the TCAS Resolution Message only because the OCM is a broadcast transmission, meaning that there is no immediate re-transmission if the intruder does not receive the message; the message will be broadcast at the next scheduled time. This can cause a delay in receipt of coordination information. The other two features, double parity layers and handling of multi-threat encounters, are both true for the OCM.

The least desirable message is the ADS-B TCAS RA Broadcast Message. Its message format is identical to that of the TCAS RA Report at the time these MOPS were published, and is intended to allow ADS-B ground stations to monitor RA activity in the airspace. It was not intended for coordination use and has some limitations for coordination use, mainly because it does not contain all necessary information in the case of multi-threat encounters. (The ADS-B TCAS RA Broadcast Message can identify only one intruder, and the RA contained in the message is the composite RA shown to the pilot, thus potentially obscuring the sense chosen by the transmitting aircraft against each individual threat. For example, the RA field could contain *don't climb/don't descend*, meaning that the transmitting aircraft has selected a climb sense against one threat and a descend threat against the other threat. A receiving threat aircraft would not know which sense is applicable to it.)

The ADS-B TCAS RA Broadcast Message is used for coordination purposes only when absolutely necessary, as in the case of a TCAS aircraft encountering a CA-equipped intruder with only ADS-B In/Out capability.

Paragraphs M.9.1, M.9.2, and M.9.3 below describe protocols for three responsive coordination types.

M.9.1 Responsive Coordination Type 1

In Type 1 responsive coordination, the senior aircraft transmits a Mode S discrete coordination interrogation (TCAS Resolution Message) to the junior aircraft. Type 1 responsive coordination is used when the following two conditions are true:

1. The junior aircraft is equipped with a Mode S transponder, and
2. The senior aircraft's CA system (e.g., ACAS Xa) is capable of receiving ADS-B CA CCBs, thus knowing that responsive Type 1 coordination is to be performed and knowing that it (the senior aircraft) should transmit a TCAS Resolution Message to the junior aircraft for coordination.

M.9.2 Responsive Coordination Type 2

In Type 2 responsive coordination, the senior aircraft transmits an ADS-B Operational Coordination Message (OCM) to the junior aircraft. Type 2 responsive coordination is used when the following two conditions are true:

1. The junior aircraft is not equipped with a Mode S transponder, and
2. The senior aircraft's CA system (e.g., ACAS Xa) is capable of receiving ADS-B CA CCBs, thus knowing that responsive Type 2 coordination is to be performed and knowing that it (the senior aircraft) should transmit an ADS-B Operational Coordination Message to the junior aircraft for coordination.

M.9.3 Responsive Coordination Type 3

In Type 3 responsive coordination, a senior TCAS aircraft transmits an ADS-B TCAS RA Broadcast Message, which is used by the junior aircraft for coordination purposes. Type 3 responsive coordination is used when the senior aircraft is TCAS-equipped, (meaning it is not capable of receiving and using ADS-B CA CCBs to understand that it is dealing with a CA-equipped intruder).

M.9.3.1 Limitations in Using ADS-B TCAS RA Broadcast Messages for Coordination

As described above, the ADS-B TCAS RA Broadcast Message has some limitations for coordination use, mainly because it does not contain all necessary information in the case of multi-threat encounters. In a Type 3 responsive coordination situation in which the senior aircraft indicates a multi-threat encounter, it is likely that the junior aircraft will not be allowed to issue an RA, but will be required to rely on the senior aircraft to provide CA protection.

M.10 SC-147 ISRA Annex

The following paragraphs of this appendix are incorporated from the following RTCA Special Committee 147 (SC-147) document: [SC147_ISRA_Annex_v5.1.doc], submitted to SC-228 for inclusion in the UAS DAA MOPS in August 2016.

RTCA SC-147 and EUROCAE Working Group 78 (WG-78) have drafted a Minimum Aviation System Performance Standards (MASPS) for the Interoperability of Airborne CA Systems. The SC-228 Phase 1 Detect and Avoid (DAA) Minimum Operational

Performance Standards (MOPS) considers DAA with and without an optional Traffic Alert and CA System (TCAS II) operating in Traffic Advisory/Resolution Advisory (TA/RA) mode. Both implementations are subject to the Interoperability MASPS, and two Interoperability MASPS requirements in particular are having an immediate effect on the development of Phase 1 DAA systems:

- ***For DAA systems <u>without Class 2 DAA system</u>, maintain DWC functions that give guidance in the CA region must be aware of TCAS RAs.***

  The Interoperability MASPS state that DAA systems must be compatible with TCAS RAs if the DAA systems alert or cause maneuvering within the CA region. This includes the Maintain DWC function because it may alert in the CA region. The practical result of this requirement is that a DAA system without an accompanying CA function must ensure that its guidance is compatible with RA intent messages sent by intruder CA systems. Paragraph M.13.1 comments on the various means by which an aircraft without CA might become aware of TCAS RAs.

- ***For DAA systems <u>with a Class 2 DAA system</u>, logic interoperability testing is necessary to ensure interoperability with existing CA systems.***

- The more likely solution is to pair the Maintain DWC function with a CA function, and give CA priority over Maintain DWC at all times. By definition, a CA function is aware of RAs from TCAS per the requirements in Section 5 of the Interoperability MASPS. Thus, CA will likely be included in Phase 1 DAA systems despite being an optional function according to the Phase 1 DAA MOPS.

- TCAS II is a certified airborne CA system, but it is designed for manned aircraft and optimized for large, turbine-powered transport aircraft. TCAS installed on Unmanned Aircraft Systems (UAS) is considered sufficiently different from its intended installation that it is subject to the logic interoperability tests required of new CA systems per Section 9 of the interoperability MASPS. Subsection M.17 includes preliminary results of these logic interoperability tests and describes the further work needed to approve the use of TCAS on UAS.

The remainder of this portion of the appendix is divided into three major subsections:

Subsection M.11**:** Alternate (i.e., other than TCAS) development paths for interoperable CA systems

Subsection M.12**:** Additional considerations for DAA systems that include TCAS

Subsection M.13**:** Additional considerations for DAA systems that do not include TCAS

This portion of the appendix is meant to aid in Phase 1 DAA compliance with the Interoperability MASPS requirements documented in M.1 through M.8. For the remainder of this document, those Interoperability MASPS sections will be referred to as "MASPS."

M.11 Alternate Development Paths for Interoperable CA Systems

While Subsections M.10 through M.15 concentrate on using TCAS II as the means to provide CA functionality and comply with interoperability requirements for CA, the development paths for two other CA options are summarized here. The most generic is a newly developed CA function, and a flexible long-term solution is the Airborne Collision

Avoidance System X for unmanned aircraft (ACAS X_U), the variant of ACAS X specifically designed for UAS. The following paragraphs offer two roadmaps, specifying for each option the requirements or sections of the Interoperability MASPS that must be satisfied. Subsection M.12 does the same for TCAS on UAs in much greater detail.

M.11.1 Generic CA Function Installation

A newly-developed CA function must meet the high-level requirements included in Subsection M.2 of the MASPS, Goals for Airborne Collision Avoidance Interoperability. In order to be accepted, any new approach must meet or exceed the protocols described in Subsection M.3 of the MASPS (Vertical RA Coordination Protocols), the relevant non-vertical interoperability requirements found in Subsection M.4 of the MASPS, (Non-Vertical Interoperability), and the performance requirements contained in Subsection M.5 of the MASPS (Transmission and Antenna Performance), and Subsection M.6 (1030/1090 Channel Utilization Interoperability Requirements). The new CA logic must be evaluated pairwise against each existing CA algorithm, considering all relevant combinations of equipages and platforms in accordance with Subsection M.7 of the MASPS. Finally, the CA logic's use of coordination information must be validated, demonstrating that its coordination design performs the intended function and does so robustly under challenging conditions as outlined in Subsection M.8 of the MASPS.

M.11.2 ACAS Xu Installation on UAs

The ACAS X program inherits the TCAS legacy of validation processes for coordination design and expands upon it. This includes the hazard and operability process as well as the testing of the coordination design in simulated two-aircraft encounters. As ACAS X logic is tuned and specified in the SC-147 MOPS, new revisions are tested for interoperability with all existing CA logic as described in MASPS Subsection M.7.

ACAS X_U also undergoes all of the coordination and interoperability testing performed as part of the ACAS X program. To meet these tests it is specifically designed to be used on UAs, so it is tuned to aircraft performance and includes automatic response. In addition to active coordination, ACAS X_U can employ passive or responsive coordination for aircraft that cannot operate as a peer to TCAS-equipped transport aircraft. The coordination validation and interoperability tests for the ACAS X_U system design are performed by the Federal Aviation Administration (FAA). Tests required by TSOs, TCs, and STCs are still performed by the manufacturer.

M.12 SC-228 Phase 1 DAA MOPS – With TCAS

The SC-228 Phase 1 DAA MOPS requires a DWC function and provides requirements for an optional CA function. Subsection M.2 of this appendix discusses two potential certification paths for an optional CA function, both of which must demonstrate compliance with the MASPS. A third option is the installation of TCAS II on UAs, which requires careful consideration of whether such an installation meets both the Interoperability MASPS and the TCAS II MOPS.

TCAS II is a certified airborne CA system for the NAS, but it is optimized for large, manned, turbine-powered transport aircraft. Its design includes assumptions that may not be true of UAs. Thus, an installed TCAS system that meets all the requirements of RTCA Document 185B (RTCA DO-185B) may still fall short of the Interoperability MASPS. Areas in which meeting TCAS II MOPS alone may be challenging and/or insufficient to meet the Interoperability MASPS are summarized in Table M-1.

Table M-1 Traceability of TCAS on UAs Equipage to Interoperability MASPS

Interoperability MASPS (Appendix M) Section	Comments on Traceability
Subsection M.2 (Goals for Airborne CA Interoperability)	As long as the DAA platform is considered a peer to a manned aircraft, then equipping with TCAS II satisfies the high-level interoperability requirements found in Subsection M.2.
Subsection M.3 (Coordination Protocols)	See Subparagraph M.3.1.1 of this appendix for a description of active coordination, which will be used by DAA systems with TCAS. Maintain DWC guidance must be consistent with RAs issued by the CA function aboard the ownship and the intruder. Details are contained in Table M-3.
Subsection M.4 (Non-Vertical Interoperability)	The Maintain DWC function described in the DAA Phase 1 MOPS must include requirements to ensure that any horizontal directive guidance issued within the intruder's CA region is in compliance with the MASPS. Maintain DWC guidance must always be compatible with RAs issued by the CA function aboard the ownship and the intruder. Details are contained in Table M-3.
Subsection M.5 (Transmission and Antenna Performance)	It is anticipated that it will be difficult for a TCAS antenna installation on a UAS platform to meet the TCAS MOPS requirements. Initial observations of performance challenges support this view. Platforms unable to meet the requirements of the TCAS MOPS will likely require use of an alternative CA function or extensive research to validate system performance.
Subsection M.6 (1030/1090 Channel Utilization Interoperability Requirements)	TCAS has been allocated use of the 1030 Megahertz (MHz) and 1090 MHz frequencies for the CA function. Use of this TCAS allocation for new user classes such as UAS must be coordinated with the TCAS Program Office. As of the publishing date of these MOPS, allocation of the 1030 MHz and 1090 MHz frequencies outside of the TCAS CA function and approved user classes must be approved by the FAA Spectrum Office.

Interoperability MASPS (Appendix M) Section	Comments on Traceability
Subsection M.7 (Logic Interoperability Metrics and Tests)	The DAA MOPS will need requirements to address platform and performance differences between manned aircraft and UAs. See Paragraph M.13.2 of this appendix.
Subsection M.8 (Coordination Tests)	DAA systems seeking to include TCAS II as a CA function would benefit from its fully-specified RA coordination design, avoiding the coordination validation tests described in Interoperability MASPS M.8.1 and the coordination TSO tests described in M.8.2.1 and M.8.2.2. The airworthiness/ installation testing under the TC or STC approval process described in M.8.2.1 would still be required.

M.12.1 Coordination Protocols for DAA Systems with TCAS

DAA systems with TCAS have a reliable means of interoperability with other aircraft via active coordination, as illustrated in Figure M-4. The DAA system must indicate "CA equipage with TA/RA capability" in its transponder air-to-air surveillance replies, causing other TCAS to transmit 1030 MHz coordination interrogations to the UA. The transponder on the UA would respond with a coordination reply and pass the received VRC on to the UA's TCAS for use in its RA sense selection.

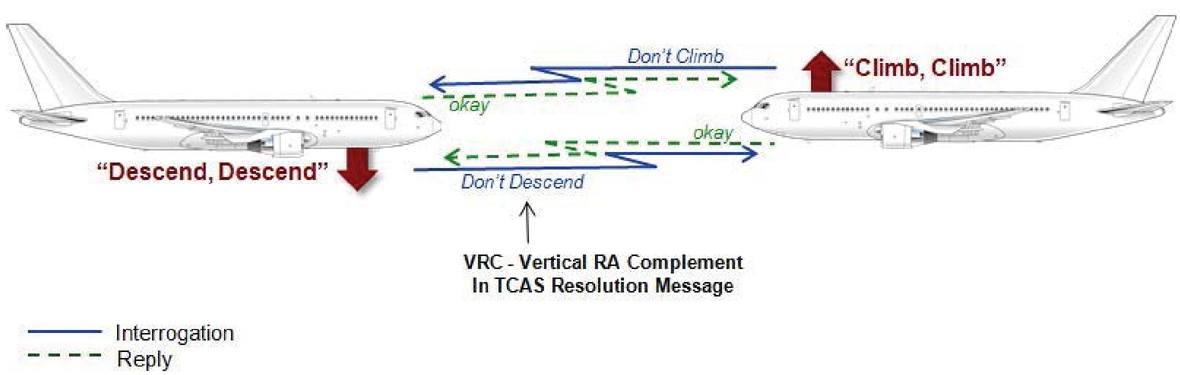


Figure M-4 Active Coordination for DAA Systems with TCAS

M.12.2 Logic Interoperability Tests for TCAS on UAs

The most burdensome task for DAA systems seeking to include TCAS II are the logic interoperability tests (MASPS Subsection M.7). Historically, each revision of TCAS was demonstrated to be interoperable with the preceding versions before final approval, and a TCAS installation on UAs would be no exception. The differences in TCAS installation on an unmanned aircraft require evaluation against existing CA systems. These differences may lead to (1) automatic maneuvers in response to TCAS RAs to address the latency in a potential pilot in-the-loop system or (2) automatic switching into TA only mode due to limitations in the ability of the UAS to execute TCAS RA maneuvers. These issues would be revealed by the pairwise logic interoperability tests and could reduce the ease of certification referenced above.

As of the publishing date of these MOPS, the FAA TCAS Program Office has conducted a limited set of studies on the safety and operational suitability of TCAS installation on UAs. These studies all concern manned vs. unmanned encounters and the potential degradation to legacy TCAS. They examine the impact of:

- Low altitude cutoff/climb limits
- Limited climb and descend performance
- Symmetric/asymmetric climb and descend performance
- Coordination of master/slave relationship
- Horizontal maneuvering against vertical CA systems

The studies are not in themselves sufficient for certification of a TCAS installation on UAs. Further specific analysis and data on a wide range of issues would be required to ensure that installation and operational use is safe and effective. The potential issues are summarized in Table M-2, and a list of references to previously-completed studies by the FAA TCAS Program Office and their impacts is provided in Subsection M.18. Not all of these issues are applicable to the Phase 1 DAA MOPS.

Table M-2 Areas of Consideration for TCAS on UAs

Area	Issues	TCAS Program Office Research
Surveillance Performance	• Does installed performance meet TCAS II requirements?	No work completed or planned, will be vehicle-specific
Coordination	• Safety and suitability with UAS as both Master and Slave in coordinated encounters	Master/Slave examined in ongoing studies; should be re-evaluated with characteristics of final system (surveillance performance, response strength/delay, vertical performance)
Surveillance Logic	• Safety and suitability with degraded surveillance (if any)	No work completed or planned

Area	Issues	TCAS Program Office Research
Threat Logic	• Limited vehicle climb/descend performance (safety) • Limited vertical acceleration (safety) • Response latency (safety and suitability) • Suitability in traffic pattern operations • Safety and suitability for hover operations • What is required level of safety performance?	Studies examined safety across a range of UA vertical rate limits and effects of low altitude cutoff. An initial study was conducted on response latency Planned work on limited climb performance
Displays and Controls	• Define the role of the pilot and any limitations • RA guidance – is the existing TCAS display on the Primary Flight Display (PFD)/ Navigation Display (ND) appropriate for UA pilots given the potential for automatic response? • Traffic Situation Display – what is the intended function and minimum requirement set?	No work completed or planned

Area	Issues	TCAS Program Office Research
Vehicle Control	• Requirements for automatic response/maximum latency/link reliability • Concept of operation for CA during lost CNPC link • Transition between manual and automatic response • Behavior after clear of conflict • Can logic be in the control station or should it be on the vehicle? • Priority of TCAS RAs with other vehicle limitations/alerting systems • FAA certification should define the conditions for TA-only mode to be selected when a platform is temporarily unable to achieve climb/descend performance. Examples include operation at altitude ceiling or in certain flight configurations	No work completed or planned Note: Auto TCAS RA guidance material is contained in the autoflight MOPS
Pilot Role in Safety Case	• Assessment of assumed benefit of the pilot in the safety case and the impact of losing that benefit	No work has been completed as of the publication date of these MOPS. The FAA SRMD should address this issue.

M.13 SC-228 Phase 1 DAA MOPS – Without TCAS

A DAA system installed without a CA function must include requirements to ensure that any horizontal or vertical directive guidance issued within an intruder's CA region is in compliance with the MASPS. Two options exist:

1. Listen for intruder equipage and/or coordination information and limit Maintain DWC guidance accordingly
   a. If intruder is NOT equipped with a Collision Avoidance system, Maintain DWC guidance is not limited.
   b. If intruder is equipped a Collision Avoidance system, the Maintain DWC function must listen for coordination information from intruder using one of the methods described in Paragraph M.13.1, determine RA sense against the ownship, and remain complementary[66] to any intruder RAs.
2. Limit Maintain DWC guidance[67] in the CA region

The collision avoidance region for a given intruder is defined as having modified tau less than 50 seconds with DMOD of 1.1 NM (with at least 5% certainty), and either vertical tau (time to co-altitude) less than 50 seconds or current vertical separation of 800' (with at least 5% certainty).[68] Paragraph M.13.6 provides additional information regarding the definition of the collision avoidance region.

If the DAA Phase 1 MOPS Maintain DWC function is unable to determine intruder equipage or unable to determine RA sense against the ownship (for any of the reasons described in Paragraph M.13.1), it must default to Option 2.

M.13.1 Options for DAA and CA System Interoperability

This paragraph describes the means by which a DWC function without an accompanying CA function may be aware of the VRC from intruder aircraft transmitting "Do not pass above" or "Do not pass below." If for any reason the DAA function cannot sense the VRC from an intruder aircraft, it must restrict its guidance within the CA region for that intruder. Table M-3 is reproduced from Table 2-24 of the SC-228 DAA MOPS and summarizes the interoperability protocols available to DAA systems.

66 If the VRC from a vertical RA-capable intruder can be determined, the vertical guidance to maintain DWC shall be modified as follows:
a. "Do not pass above" VRC: vertical velocities > 0 fpm and altitudes above current altitude displayed as not acceptable.
b. "Do not pass below" VRC: vertical velocities < 0 fpm and altitudes below current altitude displayed as not acceptable.

67 If the vertical RA-capable intruder is within the collision avoidance region and VRC is unknown, the vertical guidance to maintain DWC shall be modified as follows:
a. All vertical speed guidance outside of the current vertical speed ±500 fpm displayed as not acceptable, and
b. All absolute or relative altitude-based vertical guidance removed.

68 Efforts are underway to parameterize the definition of the collision avoidance region based on altitude bands. It is anticipated that the parameterized definition will take the form of the table below.

Parameterized Collision Avoidance Region Definition

Altitude Band (ft)	DMOD (NM)	ZTHR (ft)	TAU (s)
1000-2350	.2	600	TBD
2350-5000	.35	600	TBD
5000-10000	.55	600	TBD
10000-20000	.80	600	TBD
20000-42000	1.1	700	TBD
>42000	1.1	800	50

Table M-3 DAA Vertical Interoperability and Coordination Summary

		DAA Ownship Type	
		DAA Only (Equipment Class 1) (or Class 2 in TA Mode)	**DAA with CA in RA Mode (Equipment Class 2)**
Intruder Equipage	**No Altitude (Mode C, S, or Non-cooperative)**	DAA Only	DAA Only
	Mode C	DAA Only	DAA and CA
	Mode S	DAA Only	DAA and CA
	TCAS II No 1090ES	DAA while maintaining ±500 fpm of the current vertical sense in the CA region of the intruder	DAA modified by coordination VRC from intruder and coordinated CA from the ownship TCAS II
	TCAS II and ACAS X with RTCA DO-260B	DAA modified by RA broadcast VRC* from intruder (or maintaining ±500 fpm of the current vertical sense in the CA region during an MTE)	DAA modified by coordination VRC from intruder and coordinated CA from the ownship TCAS II
	Airborne Collision Avoidance System with updated architecture (ACAS X_a)/ Airborne Collision Avoidance System with operation-specific alerts (ACAS X_o) with RTCA DO-260C	DAA modified by coordination VRC from intruder obtained by active surveillance	DAA modified by coordination VRC from intruder and coordinated CA from the ownship TCAS II
	Future Passive CA Systems	DAA modified by coordination VRC from intruder OCM	DAA modified by coordination VRC from intruder OCM and CA from the ownship TCAS II

* VRC is inferred by the intruder's vertical sense.

Four options have been identified for Maintain DWC-only systems to receive or derive the VRC from intruder aircraft, and this paragraph comments on the practicality of each:

- Option 1: Receive VRC directly via TCAS Resolution Message
- Option 2: Convert the Active RA (ARA) field of the Automatic Dependent Surveillance-Broadcast (ADS-B) 1090ES TCAS RA message into the equivalent of a VRC
- Option 3: Receive VRC directly via future Operational Coordination Message (OCM), expected to be included in the next revision of ADS-B MOPS, RTCA DO-260C
- Option 4: Interrogate register 3,0 of the transponder on the intruder aircraft with TCAS, and convert the ARA field into the equivalent of a VRC

M.13.2 Option 1: TCAS Resolution Message

It is anticipated that most DAA systems will be equipped with a Mode S Transponder. Any CA systems that can receive and decode the DAA bits, included in the ADS-B Aircraft Operational Status Message per RTCA DO-260C, would know to send a TCAS Resolution Message to the Maintain DWC-only system. The TCAS Resolution Message contains the VRC and Mode S address pertaining to the DAA-only system, so it is the desired option whenever the equipment allows it.

M.13.3 Option 2: ADS-B TCAS RA Broadcast Message

The second option available to DAA-only systems is to use the ADS-B TCAS RA Broadcast Message defined in RTCA DO-260B. This message is broadcast for the duration of a TCAS RA and is intended to allow monitoring of RA activity by ADS-B ground stations. It contains the TCAS Active RA (including a bit to indicate whether the RA has an up or down sense) and the identity of the intruder causing the RA. All aircraft equipped for ADS-B In per RTCA DO-260B would receive this message. An aircraft with a DWC-only DAA system would examine the message's intruder identity field; if it recognized its own address, it would know to use the coordination information in the message. Potential issues and proposed resolutions have been identified for this option, as described below.

M.13.3.1 Option 2 Potential Issues

1. While the TCAS Program Office has performed initial research into the use of ADS-B TCAS RA Broadcast Messages for responsive coordination, further research and development of specific MOPS requirements are still required. One issue is the need to validate the accuracy and reliability of the content of these messages as broadcast by existing avionics systems. The information in the ADS-B TCAS RA Broadcast Message is taken from transponder register 3,0, which is also the source of information for the discrete 1090 MHz RA Report. Problems in monitored RA Reports suggest that the same problems would exist in the ADS-B TCAS RA Broadcast.
2. Even if the message content were correct, existing tests (which assume monitoring-only applications) will likely need to be upgraded to include the rigor that normally is used for coordination.
3. A larger issue with the use of 1090ES TCAS RA Broadcast Messages is that in MTEs, the message does not contain all of the information needed for coordination. For example, if TCAS is in an MTE between two intruders vertically, TCAS would likely select an up sense against one intruder and a down sense against the second

intruder. However, the ADS-B TCAS RA Broadcast Message would contain a composite ARA (e.g., don't climb/don't descend) and would contain the address of just one of the intruders, thus making sense selection problematic for both of the intruders.

4. To address this situation, a set of "sense selection rules" [8] was devised, allowing the responsive system to use a combination of current and archived ADS-B TCAS RA Broadcast Messages along with ADS-B Airborne Position Messages to determine the encounter geometry and thus the RA sense appropriate for each intruder. However, these rules had not undergone validation and validation at the time these MOPS were published so these rules were not considered for use.

5. Note that permitting DAA systems that rely on the ADS-B TCAS RA broadcast message has regulatory implications. This approach will provide effective coordination, and thus safe collision avoidance, only where the CA equipped aircraft is also equipped with RTCA DO-260B ADS-B. Thus, the authorization of such a passive DAA system should occur only in airspace with an existing rule that requires all CA equipped aircraft to install ADS-B, or upgrade existing ADS-B, to provide the necessary ADS-B TCAS RA broadcast message.

   Earlier TCAS studies have noted concern about the use of broadcasts, as opposed to discrete transmissions, for communication of coordination information, citing the lack of a handshake to confirm coordination.

M.13.3.2 Option 2 Resolutions

Option 2 is considered an acceptable approach if the following four conditions are satisfied:

1. The accuracy and reliability of the message content is verified by certification authorities; and
2. The ADS-B TCAS RA broadcast message is NOT reporting an MTE (if an MTE is being reported, the DAA system must restrict its guidance within the CA region); and
3. CA-equipped aircraft in the airspace are equipped with RTCA DO-260B; and
4. Safety studies confirm sufficient probability of reception of ADS-B TCAS RA Broadcast Messages by the DAA system.

M.13.4 Option 3: Operational Coordination Message

The Operational Coordination Message (OCM) is expected to be added to the upcoming revision of the ADS-B MOPS, RTCA DO-260C. It will be broadcast by an ACAS X system to a threat DAA-only aircraft if the DAA-only aircraft indicates, via broadcast DAA bits, that it is NOT equipped with a Mode S transponder and is capable of receiving an OCM. Table M-4 shows the contents of this message, which are identical to the contents of the TCAS RA message sent in active coordination. Since it contains the VRC directly instead of the ARA, it does not have a problem in MTEs like the TCAS RA broadcast (Option 2). It would use information in new transponder registers (e.g., 3,1 or 3,2), which would have more appropriate testing to ensure reliable content for use in coordination.

M.13.4.1 Option 3 Potential Issues

1. Since it is a broadcast message, the OCM would still lack the handshaking that makes active coordination so robust.
2. Using the OCM will provide effective coordination, and thus safe collision avoidance, only where the CA equipped aircraft is equipped with both ACAS X and with RTCA DO-260C ADS-B.

M.13.4.2 Option 3 Resolutions

Option 3, use of the OCM, is considered an acceptable approach if the following two conditions are satisfied:

1. Safety studies confirm sufficient probability of the DAA system's reception of ADS-B TCAS RA Broadcast Messages; and
2. CA-equipped aircraft in the airspace are equipped with RTCA DO-260C

Table M-4 Future Operational Coordination Message (OCM) sent over 1090ES

OCM Bits	Field Name	Value
1-5	Type Code (30)	11110
6-8	Subtype Code (0)	000
9	Reserved	0
10	Multiple Threat Bit (MTB)	As defined in International Civil Aviation Organization (ICAO) Annex 10, Volume (Vol.) IV, §4.3.8.4.2.3.2.1
11-12	Cancel VRC (CVC)	As defined in ICAO Annex 10, Vol. IV, §4.3.8.4.2.3.2.3
13-14	Vertical RA Complement (VRC)	As defined in ICAO Annex 10, Vol. IV, §4.3.8.4.2.3.2.2
15-17	Cancel HRC (CHC)	As defined in ICAO Annex 10, Vol. IV, §4.3.8.4.2.3.2.5
18-20	Horizontal RA Complement (HRC)	As defined in ICAO Annex 10, Vol. IV, §4.3.8.4.2.3.2.4
21-25	Horizontal Sense Bits (HSB)	As defined in ICAO Annex 10, Vol. IV, §4.3.8.4.2.3.2.7
26-29	Vertical Sense Bits (VSB)	As defined in ICAO Annex 10, Vol. IV, §4.3.8.4.2.3.2.6
30-32	Reserved	000
33-56	Mode S Address	

M.13.5 DAA Option 4: Mode S Crosslink

The fourth option is to use the crosslink capability inherent in many Mode S transponders. The protocol is as follows: The Crosslink Capability (CC) field in Downlink Format 0 (DF=0) air-to-air surveillance replies is used to indicate the ability of the transponder to support crosslink capability, i.e., the ability of the transponder to decode the contents of the Comm-B Data Selector (BDS) field in an Uplink Format 0 (UF=0) interrogation and respond with the contents of the specified transponder register in the MV field of the corresponding DF=16 reply. Thus, if a CA-equipped intruder reports CC =1 (capability supported), the DAA system could transmit a UF=0 interrogation with BDS field = 3,0 (the transponder register containing the TCAS RA Broadcast Message), and the intruder's transponder would reply with a DF=16 air-to-air surveillance reply containing the contents of register 3,0 in the reply's 56-bit MV field. The DAA system would then convert the ARA field into the equivalent of a VRC.

M.13.5.1 DAA Option 4 Potential Issues

There are four main issues with Option 4. First, the DAA system must be able to transmit 1030 MHz discrete Mode S interrogations and receive 1090 MHz discrete Mode S replies. Second, not all Mode S transponders support crosslink capability. Third, the contents of transponder register 3,0 are not guaranteed to be meaningful unless the aircraft is concurrently reporting that it has an active RA. Thus, the interrogating DAA system must be able to know when an RA is active on the intruder aircraft. Finally, register 3,0 is the source of information in the TCAS RA broadcast, so it has the same limitation in multi-threat encounters as described in M.13.3.1.

M.13.5.2 DAA Option 4 Resolutions

Option 4, use of Mode S crosslink capability, is considered an acceptable approach when the following four conditions are satisfied:

1. The DAA function supports 1030/1090 MHz discrete interrogation/reply capability; and
2. The transponder on the intruder aircraft supports crosslink capability; and
3. The contents of register 3,0 are NOT reporting an MTE (if an MTE is being reported, the DAA system must restrict its guidance within the CA region); and
4. The intruder aircraft is reporting that it has an ARA.

An aircraft indicates that it has an ARA by two means.

First, the transponder indicates in DF=4, 5, 20, and 21 replies to a Mode S ground sensor that it has an RA report available for read-out. This information would generally not be available to a DAA system.

Second, the transponder indicates that it has an ARA in ADS-B Aircraft Operational Status Messages and ADS-B Target State and Status Messages. This information should be available to most DAA systems.

M.13.6 Collision Avoidance Region

The collision avoidance region is introduced in Subsection M.13 to define a region in which incompatible directive maneuvers or RAs initiated by an intruder could degrade the performance of the ownship collision avoidance system. It is intended to be a conservative boundary inside of which compatible maneuvers are required, and outside of which may not be considered collision avoidance.

The collision avoidance region for a given intruder is defined as having modified tau less than 50 seconds with DMOD of 1.1 NM (with at least 5% certainty), and either vertical tau (time to co-altitude) less than 50 seconds or current vertical separation of 800' (with at least 5% certainty).

The definition of the collision avoidance region was selected based on the Horizontal vs. Vertical study described in M.18 (Study #5) which informed when an uncoordinated vertical maneuver degraded the safety performance of TCAS and ACAS X.

During development of the interoperability standard, contributors discussed the possibility of reducing the RA region by parameterizing the definition based on altitude. This approach would be consistent with how TCAS defines alerting times, and had potential value to simplify future DAA systems.

In order to explore this issue, the results of the Horizontal vs. Vertical study were broken out by altitude layer as defined by TCAS II. Specifically, the alerting times for both ACAS X and TCAS were evaluated, as the study found that uncoordinated vertical maneuvers immediately prior to the initial alert led to degraded performance.

As shown in the figures below, the initial TCAS and ACAS X alerting time (seconds prior to CPA) for each encounter in the study are broken out by altitude layer as defined by TCAS Sensitivity Level (SL). As expected, The figure shows that the TCAS alerting times were significantly altitude dependent and displayed a clustering around the tau values defined for each sensitivity layer. ACAS X, on the other hand, did not display such altitude dependence. The distributions of ACAS X alerting times shown in Figure M-6 showed little deviation across all altitude layers. This is not unexpected as ACAS X does not use an altitude dependent logic and has a longer alerting timeline at lower altitude layers.

This study concluded that it is not possible to reduce the RA region using parameterization by altitude as uncoordinated maneuvers could degrade the safety performance of ACAS X at lower altitude layers.

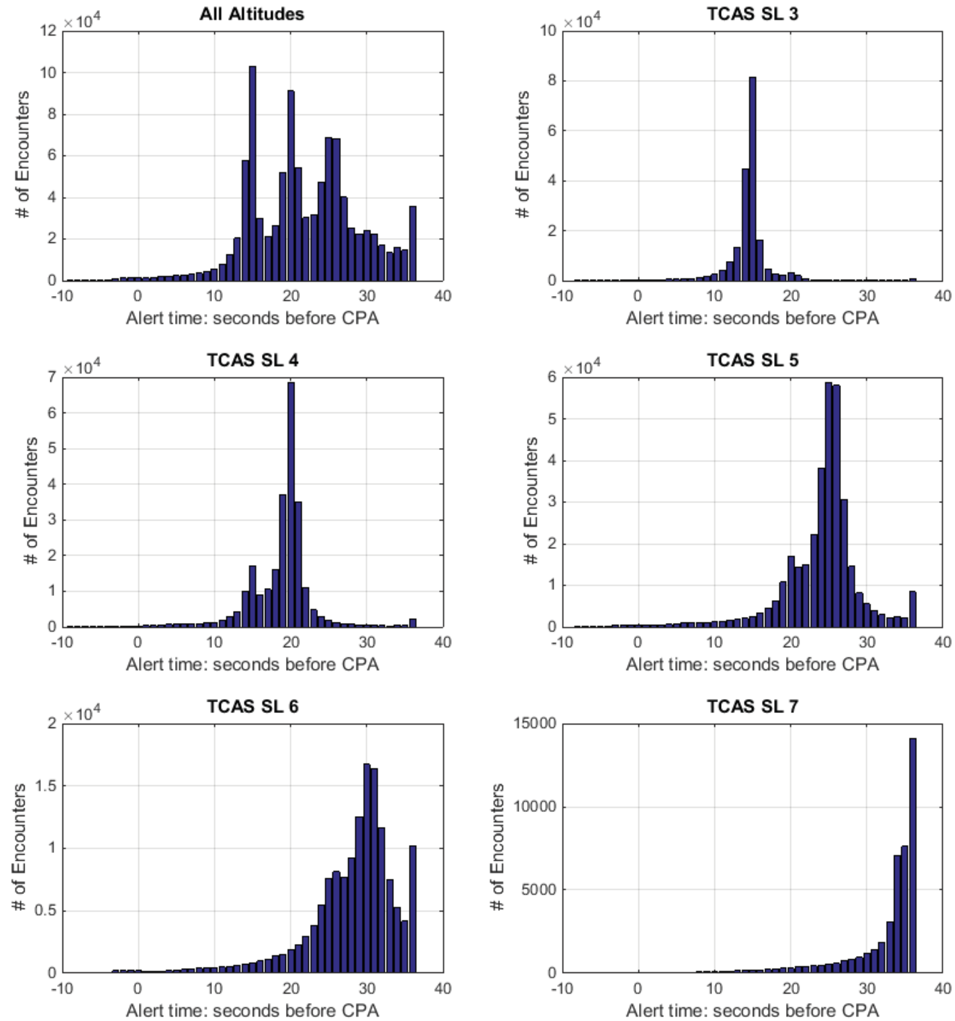


Figure M-5 **TCAS Alerting Time by TCAS Sensitivity Level**

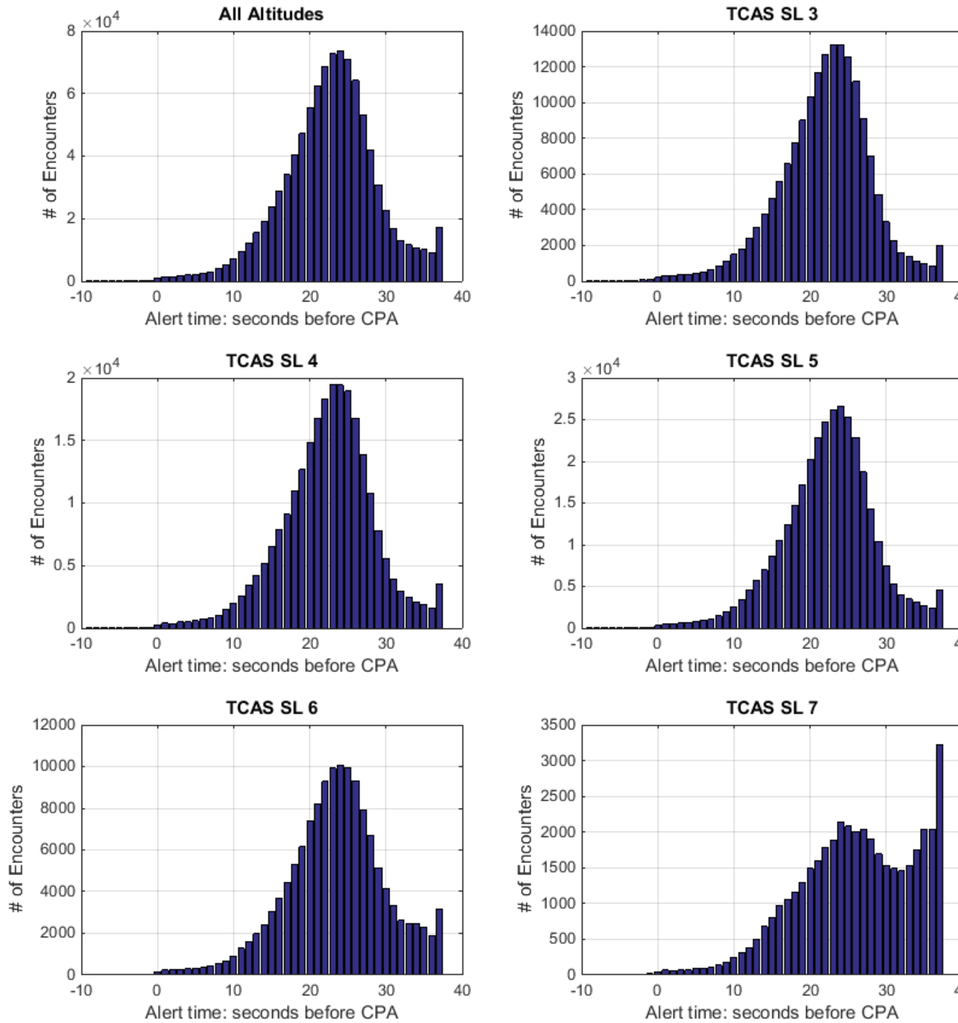


Figure M-6 **ACAS X Alerting Time by TCAS Sensitivity Level**

M.14 DAA MOPS Requirements Compliance Cross Reference

Table M.13.6 provides a requirements compliance cross-reference between the DAA MOPS and this appendix. The table identifies the DAA MOPS subdivision that complies with the corresponding requirement in this appendix. DAA Equipment Class 2 coordination capability is based on the performance provided by a TCAS II since those requirements apply for these MOPS.

Table M-5 Requirements Cross Reference

Appendix M Section	Appendix M Requirement #	DAA MOPS Section	Notes
M.2.1	RM.2.1	2.2.3.1	
M.2.1.1	RM.2.2	2.2.3.1, 2.2.4.5	
M.2.1.1	RM.2.3	2.2.3.1	
M.2.1.1	RM.2.4	N/A	1
M.2.1.1	RM.2.5	N/A	1
M.2.1.1	RM.2.6	2.2.4.5	2
M.2.1.1	RM.2.7	2.2.3.1	2
M.2.1.2	RM.2.8	2.2.3.1	3
M.2.1.2	RM.2.9	2.2.3.1	3
M.2.1.2	RM.2.10	2.2.3.1	3
M.3	RM.3.1	2.2.3.1	3
M.3	RM.3.2	2.2.3.1	3
M.3.1	RM.3.3	2.2.3.1	3
M.3.1.1	RM.3.4	2.2.3.1	3
M.3.1.1	RM.3.5-RM.3.8	2.2.3.1	3
M.3.1.1	RM.3.9	2.2.3.1	3
M.3.1.1	RM.3.10	2.2.3.1	3
M.3.1.1	RM.3.11-RM.3.14	2.2.3.1	3
M.3.1.1	RM.3.15-RM.3.16	2.2.3.1	3
M.3.1.1	RM.3.17-RM.3.18	2.2.3.1	3
M.3.1.2	RM.3.19-RM.3.28	N/A	4
M.3.1.3	RM.3.29-RM.3.33	N/A	4
M.4	RM.4.1	2.2.4.5	
M.4.1	RM.4.2-RM.4.3	2.2.4.5	
M.4.2	RM.4.4	2.2.4.5	5
M.4.2	RM.4.5	2.2.4.5	5
M.4.2	RM.4.6	N/A	6
M.4.2	RM.4.7	N/A	6
M.4.3	RM.4.8-RM.4.10	N/A	6
M.4.4	RM.4.11	2.2.4.5	3
M.5.1	RM.5.1	2.2.3.1	3
M.5.1	RM.5.2	2.2.3.1	3
M.5.2	RM.5.3	2.2.3.1	3
M.5.3	RM.5.4	2.2.3.1	3
M.6.2	RM.6.1-RM.6.7	2.2.3.1	3
M.7.1	RM.7.1	N/A	3, 7
M.7.2	RM.7.2	N/A	3, 7
M.7.2.1	RM.7.3-RM.7.7	N/A	3, 7
M.7.2.2	RM.7.8-RM.7.9	N/A	3, 7
M.7.3	RM.7.10-RM.7.11	N/A	3, 7
M.8.1	RM.8.1	2.2.3.1	3
M.8.1	RM.8.2	2.2.3.1	3
M.8.2.1	RM.8.3	2.2.3.1	3
M.8.2.2	RM.8.4-RM.8.5	2.2.3.1	3

Note:

1. *The CA capability provided for DAA (Class 2) is defined by TCAS II DO-185B which does not include non-peer coordination.*
2. *TCAS II systems only support active coordination*
3. *TCAS II performance meets these requirement(s)*
4. *Neither Class 1 nor 2 DAA systems use passive or responsive coordination. However, they can receive ADS-B OCM transmissions from passive and adjust DAA guidance accordingly.*
5. *DAA equipment can receive ACAS III protocol horizontal resolution complements via active surveillance and ADS-B and adjust guidance accordingly.*
6. *Neither Class 1 or 2 DAA systems do horizontal or speed CA.*
7. *Neither Class 1 nor 2 DAA systems introduce a new CA system.*

M.15 Conclusion

Subsections M.10 through M.15 accompanies the MASPS (Subsections M.1 through M.9) and discusses the means by which a DAA system with and without a Class 2 DAA system with RA capability might comply with the interoperability requirements. A different body of work accompanies each option; for DAA systems that include TCAS, the logic interoperability tests must be performed to ensure interoperability with all existing CA systems. DAA systems that do not include TCAS must suppress vertical guidance in the CA region, or they must be aware of intruder TCAS RAs in the CA region. A variety of methods are presented for a DAA system to be aware of TCAS RAs, but all have limitations that may necessitate suppressing vertical guidance in the CA region when they violate the conditions presented here.

M.16 References

[1] "The European contribution to ACAS X_A validation – Part II, Results on TCAS/ACAS interoperability evaluation," Single European Sky ATM Research (SESAR) work briefed by Thierry Arino to the 77th meeting of SC-147 in March 2014.

[2] FAA white paper, "Coordination between Airborne Collision Avoidance Systems," 3 May 2013. Version 1 Revision 0.

[3] RTCA DO-185B. (June 2008). Minimum Operational Performance Standards for Traffic Alert and Collision Avoidance System II (TCAS II).

[4] ICAO. (November 2014). International Standards and Recommended Practices, Annex 10 to the Convention on International Civil Aviation, Aeronautical Telecommunications, Volume IV, Surveillance and Collision Avoidance Systems, Amendment 89. Fifth Edition.

[5] FAA. (March 2014). AC 20-151B. Airworthiness Approval of TCAS Version 7.0 and 7.1 and Associated Mode S Transponder.

[6] Leeper, C., Lorenzo, E., Brush, J. (June 2012). Active Coordination Emulation Safety Study. JHU/APL.

[7] TCAS Program Office. (August 2013). Coordination Concept Description for the Airborne Collision Avoidance System X, Version 2 Revision 0.

[8] Panken, A. (September 2012). Coordination of ACAS Xp vs. TCAS during Multiple Threat Encounters. MIT Lincoln Laboratory.

[9] TCAS Program Office. (September 2014). Hazard and Operability (HAZOP) Process for ACAS X Coordination; Active Coordination and Responsive Coordination.

[10] Kochenderfer, Mykel J., Holland, Jessica E., and Chryssanthacopoulos, James P. "Next Generation Airborne Collision Avoidance System." Lincoln Laboratory Journal 19 (2012): 55-71.

[11] Holland, Jessica E., Kochenderfer, Mykel J., and Olson, Wesley A. "Optimizing the Next Generation Collision Avoidance System for Safe, Suitable, and Acceptable Operational Performance." Tenth USA/Europe Air Traffic Management Research and Development Seminar. 2013.

[12] TCAS Program Office. (February 2014). Plan for ACAS X Coordination Stress Testing.

[13] EUROCAE. (January 2012). ED-12C. Software considerations in airborne systems and equipment certification.

[14] EUROCAE. (March 2014). ED-224. Minimum Aviation System Performance Specification (MASPS) for Flight Guidance System (GS) Coupled to Traffic Alert and Collision Avoidance System (TCAS).

[15] Londner, Edward H. "Interoperability of Horizontal and Vertical Resolution Advisories." Eleventh USA/Europe Air Traffic Management Research and Development Seminar. 2015.

[16] Drumm, A. (June 1987). TCAS II Coordination Validation. MIT Lincoln Laboratory, 42PM-TCAS-0053 Revision 1.

[17] "The European contribution to ACAS XA validation – Part II, Results on TCAS/ACAS interoperability evaluation," Single European Sky Air Traffic Management Research (SESAR) work briefed by Thierry Arino to the 77th meeting of SC-147 in March 2014.

[18] FAA white paper, "Coordination between Airborne Collision Avoidance Systems," 3 May 2013. Version 1 Revision 0.

[19] RTCA DO-185B. (June 2008). Minimum Operational Performance Standards for Traffic Alert and Collision Avoidance System II (TCAS II).

[20] ICAO. (July 2007). International Standards and Recommended Practices, Annex 10 to the Convention on International Civil Aviation, Aeronautical Telecommunications, Volume IV Surveillance and Collision Avoidance Systems, Fourth Edition.

[21] FAA. (Mar 2014). AC 20-151B. Airworthiness approval of TCAS II Version 7.0 and 7.1 and Associated Mode S Transponder.

[22] Leeper, C., Lorenzo, E., Brush, J. (June 2012). Active Coordination Emulation (ACE) Safety Study. Johns Hopkins University Applied Physics Laboratory.

[23] TCAS Program Office. (Aug 2013). Coordination Concept Description for the Airborne Collision Avoidance System X, Version 2 Revision 0.

[24] Panken, A. (Sep 2012). Coordination of Airborne Collision Avoidance System – Passive (ACAS Xp) vs. TCAS II during Multiple Threat Encounters. Massachusetts Institute of Technology Lincoln Laboratory.

[25] TCAS Program Office. (Sep 2014). Hazard and Operability Process for ACAS X Coordination; Active Coordination and Responsive Coordination.

[26] Kochenderfer, Mykel J., Holland, Jessica E., and Chryssanthacopoulos, James P. "Next Generation Airborne Collision Avoidance System." Lincoln Laboratory Journal 19 (2012): 55-71.

[27] Holland, Jessica E., Kochenderfer, Mykel J., and Olson, Wesley A. "Optimizing the Next Generation Collision Avoidance System for Safe, Suitable, and Acceptable Operational Performance." Tenth United States/Europe Air Traffic Management Research and Development Seminar. 2013.

[28] TCAS Program Office. (Feb 2014). Plan for ACAS X Coordination Stress Testing.

[29] EUROCAE. (Jan 2012). EUROCAE Document 12C (ED-12C). Software considerations in airborne systems and equipment certification.

[30] EUROCAE. (March 2014) ED-224. Minimum Aviation System Performance Specification (MASPS) for Flight Guidance System (GS) Coupled to Traffic Alert and Collision Avoidance System (TCAS).

[31] Londner, Edward H. "Interoperability of Horizontal and Vertical Resolution Advisories." Eleventh USA/Europe Air Traffic Management Research and Development Seminar. 2015.

M.17 Glossary Unique to this Appendix

<u>ACAS</u> – Airborne Collision Avoidance System

<u>Advisory</u> – A message given to the pilot containing information relevant to collision avoidance. Includes traffic advisories (TA) and resolution advisories (RA)

<u>Alert</u> – A message given to the pilot containing information relevant to collision avoidance. Synonymous with Advisory

<u>Collision Avoidance (CA)</u> – Last-resort directive actions or advisories intended to prevent a collision between two aircraft in an unsafe flight geometry

<u>Collision Avoidance Horizon</u> – A period of time or geometric region during an encounter in which collision avoidance systems determine the need to issue or alter an alert

<u>Collision Avoidance System (CAS)</u> – Collision avoidance logic subsystem within ACAS

<u>Coordination</u> – The process of ensuring that the collision avoidance systems on any two conflicting aircraft select complementary avoidance RAs

<u>Explicit Coordination</u> – Coordination in which two aircraft select RAs based on a real-time exchange of the sense (e.g., up/down for vertical coordination) of their avoidance action

Implicit Coordination – Coordination in which each individual aircraft in an encounter select RAs based on a common set of rules

Incompatible – An action or alert which is unsuitable for coordination with ACAS or that makes conflicting demands with that of ACAS under existing conditions

Interoperability – The capability of one collision avoidance system to operate in airspace with other collision avoidance systems without negatively impacting the other systems

Junior/senior – A method for differentiating aircraft used in responsive coordination

Maneuver – A change in an aircraft's trajectory or speed (a vertical or horizontal acceleration) due to aircraft dynamics, pilot intervention, or automatic response

Master/Slave – A method for differentiating peer aircraft in active and passive coordination. The master aircraft has the lower ICAO address. The master is given priority in coordination tiebreaking and is allowed to initiate geometric reversals.

Near Mid-air Collision (NMAC) – Two aircraft simultaneously coming within 100' vertically and 500' horizontally

Peer – Aircraft are considered peers when either aircraft is deemed capable of being the master in active or passive coordination.

Resolution Advisory (RA) – A display indication given to the pilot recommending a maneuver to either increase or maintain the existing separation relative to an intruding aircraft. Positive and negative advisories constitute the resolution advisories. A resolution advisory is also classified as corrective or preventive.

Senior – See Junior/Senior

Sense – The direction that a resolution advisory may take (i.e., either up or down for vertical RAs)

Sense Reversal – A change to the sense opposite that of the original Resolution Advisory

Slave – See Master/slave

TA Only Mode – CA mode in which TAs are displayed and RAs are not generated or displayed

TA/RA Mode – CA mode in which both TAs and RAs are issued as specified

Traffic Alert and Collision Avoidance System (TCAS) – An implementation of ACAS that has been mandated in the United States; unless explicitly stated, all references to TCAS refer to any version of RTCA, Inc. Document 185B (RTCA DO-185B), TCAS II Minimum Operational Performance Standards (MOPS)

Traffic Advisory (TA) – Information given to the pilot pertaining to the position of another aircraft in the immediate vicinity. The information contains no suggested maneuver

M.18 Previous Studies Related to TCAS on UAs

1. **Billingsley, Thomas B., ACAS Xu Responsive Coordination with TCAS II, Lincoln Laboratories Tech Memorandum 42PM-TCAS-0091, July 2013**

Category: Transport Category versus UAS Vertical RAs

Purpose:

- This study examined the effect of employed responsive coordination with the Airborne CA System with updated Architecture (ACAS Xa), which served as a proxy for Xu.

Parameters:

- This study examined encounters between TCAS and ACAS Xu, ACAS Xa, or TCAS.
- Parameters included the wait/no wait strategy, Xu robustness to pilot response time, the master/slave relationship of the two aircraft, and the TCAS intruder's response rate (0 – 100%). Vertical rate limitations were not imposed.
- ACAS Xu was the same as Xa except that it employed responsive and not active coordination.

Results

- On the ownship, Xa performed best, followed closely by Xu no wait; then came Xu wait and TCAS.
- There was some robustness to pilot response delay, but the safety results did degrade at the highest delays

2. **Griffith, J.D. and Kuchar, J.K., Evaluation of TCAS on Global Hawk with United States Airspace Encounter Models, Lincoln Laboratory's Air Traffic Control-353, August 2009**

Category: Transport Category versus UAS Vertical RAs

Purpose:

- This study examined the effect of equipping a Global Hawk with TCAS in encounters against TCAS or an unequipped intruder.

Parameters:

- Pilot response time on Global Hawk
- The equipage of the intruder (TCAS or Mode S)
- The Lincoln Laboratory's Correlated Encounter Model was modified to reflect the flight profile of Global Hawk

Results:

- A set of pilot response latencies were outlined under which TCAS on Global Hawk reduced risk (e.g., 12 seconds for TCAS on the Global Hawk vs. TCAS)

3. **Billingsley, Thomas B., Kochenderfer, Mykel J., and Chryssanthacopoulos, James P., Collision Avoidance for General Aviation, 30th Digital Avionics Systems Conference, October 2011**

Categories (with General Aviation (GA) aircraft serving as a proxy for UAS):

a. Transport Category versus UAS Vertical RAs
b. UAS Vertical RAs versus UAS Vertical RAs
c. Transport Category versus Unequipped
d. UAS Vertical RAs versus Unequipped

Purpose:

- This study examined the effect of equipping GA aircraft limited to 500 or 1000 fpm with TCAS, a vertical-rate optimized ACAS X-type logic, and a simple logic that employs descend/climb responsive coordination

Parameters:

- Equipage of the two aircraft
  - GA vs Transport
    - Ownship: GA with TCAS, GA with responsive logic, GA with optimized logic, GA unequipped
    - Intruder: TCAS
  - GA vs GA:
    - Ownship: GA with TCAS, GA with optimized logic
    - Intruder: Unequipped, GA with TCAS, GA with optimized logic
- Vertical rate limits of GA aircraft (500, 1000 fpm)

Results:

- The optimized GA logic out-performed TCAS and the GA descend/climb responsive logic

4. **Griffith, J.D., and Olson, W., Coordinating General Aviation Maneuvers with TCAS Resolution Advisories, Lincoln Laboratory's Air Traffic Control-374, February 2011**

Categories:

a. Transport Category versus UAS Vertical RAs
b. Transport Category versus Unequipped

Purpose:

- This study examined the effect of equipping GA aircraft with TCAS with and without active coordination and compares this scenario against a set of responsive coordination strategies.

Parameters:

- Vertical rate of the GA aircraft
- Altitude encoding on the GA aircraft
- The equipage and coordination strategy of the GA aircraft
- Response rate of the GA aircraft

Results:

- This study demonstrated the importance of coordination between aircraft equipped with Collision Avoidance Systems (CAS)
- The Descend/Climb (D/C) responsive coordination strategy demonstrated the lowest risk; the Do Not Descend/Do Not Climb (DND/DNC) strategy (tested in the horizontal vs. vertical study) was also present and performed well
- 25' encoding makes for safer encounters with equipped intruders than 100'encoding
- Equipping the GA aircraft with TCAS and coordinating was safer for higher GA aircraft vertical rate limits
- Equipping the GA aircraft with TCAS and not coordinating was riskier for higher GA aircraft vertical rate limits

5. **Londner, Ted. Horizontal vs. Vertical Study, as yet unpublished**

Category: UAS Horizontal RAs versus Transport Category

Purpose:

- This study examined encounters between a UA equipped with horizontal CA and transport category aircraft equipped with vertical collision avoidance.

Parameters:

- UAS response to horizontal RAs
- Change to vertical rate, turning or not turning
- UAS vertical rate limits
- CAS on transport aircraft (ACAS X or TCAS)

Results:

- This study showed that in the worst case scenario where the UA maneuvers vertically towards the intruder when it receives a horizontal RA and does not turn:
    - So long as the UA changes its vertical rate by 500 fpm or less, the performance of the transport aircraft CAS does not degrade (with one exception)
    - Above 500 fpm, DND/DNC rate-responsive coordination prevents degradation to the transport aircraft CAS
    - When the UA turned and levelled off in response to horizontal RAs, the performance of the transport aircraft does not degrade.

N APPENDIX N ADS-B POSITION VALIDATION CRITERIA USING TCAS OR RADAR FOR UAS DAA

This appendix justifies the proposed position validation criteria to enable the use of ADS-B position data for UAS Detect and Avoid (DAA). Position validation can be performed with active TCAS data or with the DAA onboard radar.

N.1 Background

A considerable number of legacy ADS-B Out installations are already fielded that do not adequately address position accuracy. Additionally, ADS-B data can potentially be spoofed causing false and misleading tracking information to be sent to the UAS DAA alerting and guidance functions. Therefore, DAA will require additional validation of ADS-B traffic position. There are two possible sources of data to perform ADS-B position validation: active TCAS data and an onboard DAA radar.

N.2 Experience with ADS-B Position Validation Using Active TCAS Position

At the time these Minimum Operational Performance Standards (MOPS) were published, ADS-B position validation using active TCAS position was used for some ADS-B In surveillance applications. It was used to qualify ADS-B Link Version 0 and Link Version 1 traffic that might not otherwise meet the position accuracy and integrity requirements. It was also used as an additional integrity check on all ADS-B traffic for specific ADS-B In applications.

RTCA DO-317B, Minimum Operational Performance Standards (MOPS) for Aircraft Surveillance Applications (ASA) Systems, describes the general ADS-B position validation requirements in Subparagraph 2.2.3.1.3.5. Specific validation requirements for In-Trail Procedures (ITP) are described in Subparagraph 2.2.4.4.2.1; specific validation requirements for Cockpit Display of Traffic Information (CDTI)-Assisted Visual Separation (CAVS) are described in Subparagraph 2.2.4.6.2.1. Appendix V includes supporting analysis for the CAVS ADS-B position validation requirements. The analysis approach to set the ADS-B position validation requirements for DAA builds directly on the analysis and experience with ITP and CAVS.

N.3 Slant Range within which ADS-B Position Validation is Required

There is a slant range within which ADS-B position validation is required, which will be referred to as the *position validation range* in this appendix. Outside the position validation range, position validation is required if the alternate position source (TCAS or radar) is available. Inside the position validation range, TCAS or radar position must be available as track data or the validation automatically fails. The ADS-B In applications differ from DAA in one respect. For DAA, the function continues even if validation fails, since there is an alternate position source available. For ADS-B In applications, a validation failure means that the ADS-B In application cannot be initiated or can no longer be performed.

ITP uses a position validation range of 30 NM. This range was chosen as a range where a TCAS track was likely to be established in the oceanic environment where ITP operations are performed. A separate analysis showed the ITP was safe for traffic outside 30 NM that were not validated for the aircraft geometries and speeds in the oceanic track environment.

CAVS uses a position validation range of 5 NM. TCAS manufacturers suggested a TCAS track was highly likely to be established even in a high density terminal area environment at a range of 5 NM to 7 NM. A separate analysis showed that for the aircraft geometries and relative speeds for aircraft performing CAVS, CAVS is safe as long as validation is performed for traffic within 5 NM. Thus, 5 NM was chosen as the position validation range since it provides the highest likelihood that a TCAS track will be available.

The position validation range for DAA can be determined considering the range at which validated ADS-B data is needed for separation assurance given the maximum expected closing rates for the unmanned aircraft and traffic and the time at which the system needs to alert for separation assurance. Multiplying the maximum closing rate by the buffered time to closest approach for separation assurance yields the position validation range (Table N-1).

Assume that the maximum speed of the UAS is 200 kts. Assume that traffic above 10,000’ altitude has a maximum speed of 600 kts; traffic below 10,000’ altitude has a maximum speed of 250 kts. This means that the maximum closing rates for traffic in front of the ownship are 800 kts for traffic above 10,000’ and 450 kts for traffic below 10,000’.

Assume that the minimum speed of the UAS is 40 kts. Then the maximum closing rates for traffic from the rear are 560 kts for traffic above 10,000’ and 210 kts for traffic below 10,000’. For traffic perpendicular to the UAS, the maximum closing rates are 600 kts for traffic above 10,000’ and 250 kts for traffic below 10,000’.

Assume that the DAA system needs to alert when the time to the point of closest approach at tau = 60 seconds (sec) and that a 1-second buffer is added so that the position validation is completed before an alert is required. The 60 second tau is calculated from the 35-second well clear tau added to the 25-second UAS maneuver time for the head-on scenario.

The position validation range is then 14 NM or 7.9 NM for traffic in front of the UAS, depending on the altitude of the traffic. The position validation range is 10.5 NM or 4.4 NM for traffic to the side of the unmanned aircraft and 9.8 NM or 3.7 NM for traffic to the rear of the unmanned aircraft.

Table N-1 Position Validation Range

Traffic Altitude	Minimum Speed	Maximum Speed		Maximum Closing Rate			Separation Assurance Tau	Tau Buffer	Position Validation Range		
	Unmanned Aircraft	Unmanned Aircraft	Traffic	Traffic Front	Traffic Side	Traffic Rear			Traffic Front	Traffic Side	Traffic Rear
> 10,000’	40 kts	200 kts	600 kts	800 kts	600 kts	560 kts	60 sec	3 sec	14.0 NM	10.5 NM	9.8 NM
≤ 10,000’	40 kts	200 kts	250 kts	450 kts	250 kts	210 kts	60 sec	3 sec	7.9 NM	4.4 NM	3.7 NM

Table N-2 shows the surveillance range for Mode S and ATCRBS traffic for different levels of interference limiting. These apply when the UA is below 18,000' Note that the Mode S range is sufficient to meet the position validation ranges in Table N-1, for all interference limiting levels. The ATCRBS range is sufficient to meet the position validation ranges if the UA and traffic are below 10,000' for all interference limiting levels. The ATCRBS range is sufficient to meet the position validation ranges if the UA and traffic are above 10,000' except for traffic to the side at maximum interference levels and traffic to the rear for high and maximum interference levels.

Table N-2 Surveillance Range for Different Levels of Interference Limiting (IL)

IL Level	Mode S	ATCRBS Front	ATCRBS Sides	ATCRBS Rear
None	30 NM	25.7 NM	22.3 NM	14.6 NM
Moderate	24.9 NM	23.4 NM	19.3 NM	11.3 NM
High	20.4 NM	20.6 NM	14.3 NM	8.0 NM
Max	15.1 NM	14.6 NM	9.3 NM	5.3 NM

It is proposed that the position validation range be set as a function of slant range, altitude and bearing to the traffic to maximize the availability of ATCRBS traffic for ADS-B position data validation.

The DAA system **shall** perform ADS-B position data validation for DAA traffic at slant ranges less than:

1. 14 NM from the ownship for traffic at an altitude greater than 10,000' and at bearings within ±45 deg
2. 10.5 NM from the ownship for traffic at an altitude greater than 10,000' and at bearings greater than 45 deg and less than or equal to 135 deg or bearings less than -45 deg and greater than or equal to -135 deg
3. 9.8 NM from the ownship for traffic at an altitude greater than 10,000' and at bearings greater than 135 deg and less than or equal to 180 deg or bearings less than -135 deg and greater than -180 deg
4. 7.9 NM from the ownship for traffic at an altitude less than or equal to 10,000' and at bearings within ±45 deg and
5. 4.4 NM from the ownship for traffic at an altitude less than or equal to 10,000' and at bearings greater than 45 deg and less than or equal to 135 deg or bearings less than -45 deg and greater than or equal to -135 deg
6. 3.7 NM from the ownship for traffic at an altitude less than or equal to 10,000' and at bearings greater than 135 deg and less than or equal to 180 deg or bearings less than -135 deg and greater than -180 deg.

Position validation is only required at slant ranges greater than or equal to the values in conditions a through f above if TCAS or radar measurements are available.

An alternative to the range-based requirement is to add a requirement restricting the use of unvalidated ADS-B data for warning alerts.

N.4 Rng, Brng and Alt Criteria for ADS-B Position Validation Using Active TCAS Position

The thresholds within which the range, bearing and altitude calculated from ownship position and the ADS-B position reported from traffic need to match the TCAS range, bearing and altitude are a function of the accuracy of the position sources, uncompensated latency and other processing errors. The following discussion justifies the thresholds selected in the proposed DAA requirements.

ADS-B data from traffic meeting the extended hybrid surveillance criteria in RTCA DO-300A shall pass the validation test. For all other ADS-B traffic, the DAA system shall pass the validation test with TCAS data if:

|slant range difference| < 0.25 NM; and

|bearing difference| ≤ 45 degrees and range > 1 NM; and

|altitude difference| < 200’.

The absolute difference in Time of Applicability between the ADS-B position data with the TCAS data, when used for validation, shall be no more than 250 ms.

N.4.1 TCAS Range Validation Threshold

The range validation threshold is the threshold within which the TCAS range and ADS-B range must match for position validation. ADS-B range is used here as the range calculated using the ownship absolute position source and the ADS-B position from traffic. The range validation threshold is chosen in consideration of the accuracy of the position sources, uncompensated latency and other processing errors.

For ITP, the range validation threshold is the root sum square of the required horizontal position accuracy for the ownship and traffic. The TCAS range error is ignored, since it is much smaller than the 0.5-NM accuracy requirement for traffic and the ownship for ITP. The TCAS range error for Mode S traffic is a 125’ bias with a 50’ rms error, which is a 225’(69 Meters (m)) 95% probability error (per RTCA DO-185B, Subparagraph 2.2.2.2.3). The TCAS range error for Mode C traffic is a 250’ bias with a 50’ rms error, which is 350’ (107 m). Uncompensated latency (timing uncertainty) errors are also ignored, since they too are much smaller than the 0.5-NM accuracy requirement.

For CAVS, more error sources were considered to determine the range validation threshold (see Table N-3, TCAS Mode S column). The ownship and ADS-B 95% position accuracy requirement for CAVS is 0.1 NM (185 m). The TCAS range error, errors due to uncompensated latency in ownship position and traffic position and other data processing errors are taken from RTCA DO-300A Minimum Operational Performance Specification for TCAS II Hybrid Surveillance, Table B-1. The analysis did not consider errors due to compensated latency, such as errors when extrapolating position during a turn. The compensated latency errors are significantly smaller than the 185-meter position errors.

Root-sum-squaring the errors gives a crosscheck range threshold of 367 m or 0.20 NM. The range validation threshold selected per RTCA DO-317B was 0.25 NM. Increasing the threshold reduces the likelihood of failing the validation, and the 0.25 NM value was supported by a separate integrity analysis (RTCA DO-317B, Appendix V).

The revalidation range tolerance for hybrid surveillance is 0.184 NM (see RTCA DO-300A, Table B-1). Thus a hybrid track that has been established on the traffic meets the revalidation range tolerance requirement for CAVS.

Table N-3 Range Validation Error Budget for ADS-B Position Using TCAS or Radar

Error Source	Position Validation Source		
	TCAS Mode S	TCAS Mode C	Radar
Ownship horizontal position error, 95%	185 m	185 m	185 m
Traffic horizontal position error, 95%	185 m	185 m	185 m
Horizontal range error for validation position source, 95% (bias plus 2 sigma)	69 m	107 m	46 m
Uncompensated latency in ownship position (600 kts for 250 ms)	77 m	77 m	77 m
Uncompensated latency in ADS-B traffic (600 kts for 600 ms)	185 m	185 m	185 m
Other data processing errors (including differences in the time of applicability of position sources)	145 m	145 m	145 m
Total, Assuming Errors Root Sum Square	**367 m (0.20 NM)**	**376 m (0.20 NM)**	**363 m (~0.20 NM)**

If DAA has the same ownship and traffic position accuracy requirements as CAVS, 0.25 NM is an appropriate range validation threshold. It is slightly larger than the 95% error budget to reduce the likelihood of falsely failing the validation. If DAA has different position accuracy requirements, the analysis in Table N-2 can be adjusted accordingly. Use of a hybrid track as a means of meeting the range validation requirement will still hold as long as the range validation threshold is no smaller than 0.184 NM.

In RTCA DO-317B, the 250 ms requirement for the absolute difference in Time of Applicability between the ADS-B position data, and the TCAS data comes from hybrid surveillance and the 145-meter allocation for other data processing errors. The same requirement should apply for DAA if hybrid traffic is a potential means of complying with the position validation requirements.

N.4.2 TCAS Altitude Validation Threshold

ADS-B data and TCAS data use the same pressure altitude source. However, the reported altitude from ADS-B data and TCAS data can differ based on how the Mode S or Mode C altitude is encoded. CAVS and ITP use a 200’ altitude threshold. The ensures that position validation does not fail due to encoding differences, but it still catches true altitude mismatches.

N.4.3 TCAS Bearing Validation Threshold

The minimum requirements for TCAS bearing accuracy are given in RTCA DO-185B, Minimum Operational Performance Standards for Traffic Alerting and Collision Avoidance System II (TCAS II), Subparagraph 2.2.4.6.4.2. For elevation angles from 10 deg to 20 deg, the bearing error shall not exceed 15 degrees RMS or 45 degrees peak. Based on this requirement, the bearing difference for CAVS and ITP position validation in RTCA DO-317B was set to 45 degrees.

The RTCA DO-317B analysis for bearing error ignored bearing errors due to errors in the ownship and ADS-B position. For the ranges at which ITP and CAVS traffic are expected, these errors are not significant with respect to the 45-deg TCAS bearing error. However, once the range is within 1 NM, the ADS-B bearing error becomes large enough that the 45-degree bearing validation thresholds need to be adjusted (Table N-4). For example, the 14-deg bearing error at 1 NM root sum squared with the 45-deg TCAS bearing error is 47 degrees.

If DAA traffic is expected at ranges closer than 1 NM, the RTCA DO-317B bearing validation criterion should be modified. It can by modified by either increasing the allowable bearing difference or by not requiring validation at close ranges. Since DAA traffic will be validated at ranges starting at either 8 NM or 14 NM and the bearing error calculation becomes less accurate as range approaches the position error, the most straightforward approach is to keep the constant 45-degree bearing threshold and add a requirement stating that bearing validation should only be done at ranges greater than 1 NM.

Table N-4 Bearing Error for a 0.1 NM 95% Position Error for Ownship and Traffic

Range	Bearing Error
14 NM	0.8 deg
8 NM	1.5 deg
5 NM	2.4 deg
2 NM	6.3 deg
1 NM	14 deg
0.5 NM	42 deg
0.2 NM	90 deg

The bearing errors in Table N-4 were calculated as follows. The bearing error from ownship position and traffic ADS-B position is approximated as the arctangent of the combined position error divided by the range adjusted by the combined position error. The combined position error is the error budget from Table N-3, which is 0.2 NM.

Bearing error = arctan(combined position error/(range- combined position error)) =

arctan (0.2/(R-0.2)) where R is in units of NM.

The approximation breaks down when the range approaches the size of the position error. At this point, the bearing calculation is no longer valid.

N.5 Range, Bearing and Altitude Criteria for ADS-B Position Validation Using Radar

The thresholds within which the range, bearing and altitude calculated from the ownship position and the ADS-B position reported from traffic need to match the radar range, bearing and altitude are a function of the accuracy of the position sources, uncompensated latency and other processing errors. The following discussion justifies the thresholds selected in the proposed DAA requirements.

The DAA system shall pass the validation test with radar data if:

|slant range difference| < 0.25 NM; and

|bearing difference| ≤ 15 degrees and range > 1 NM; and

|altitude difference| < sqrt (178*178 + 265*265 R^2) feet, where sqrt is the square root and R is the slant range in units of NM.

The absolute difference in Time of Applicability between the ADS-B position data with the radar data, when used for validation, shall be no more than 250 ms.

N.5.1 Radar Range Validation Threshold

The 95% range error for the radar system is assumed to be 150' (46 m), which is calculated from a 50' bias error added to a 100' two-sigma error. The error contributions for ownship position error, traffic position error, uncompensated latency in the ownship's position and uncompensated latency in ADS-B traffic are the same as what was used for position validation using TCAS (Paragraph N.4.1, Table N-3). It is also reasonable to use the same error budget for other data processing errors. This error budget assumes a difference in the time of applicability of the radar position data and ADS-B position data of no more than 250 ms.

Paragraph N.4.1, Table N-3 summarizes the error budget using a 46 m radar error. The total is 0.20 NM. If DAA has the same ownship and traffic position accuracy requirements as CAVS, 0.25 NM is an appropriate range validation threshold. It is slightly larger than the 95% error budget to reduce the likelihood of falsely failing the validation threshold. If DAA has different position accuracy requirements, the analysis in Table N-3 can be adjusted accordingly.

N.5.2 Altitude Validation Threshold

There are three altitude measurement sources to consider when selecting the altitude validation threshold for validating ADS-B position with radar altitude. These are:

- Pressure altitude error for traffic. ADS-B reports pressure altitude.
- Pressure altitude error for the ownship. Since ADS-B reports pressure altitude, the reference altitude for the ownship should also be pressure altitude.
- Radar relative altitude measurement error.

The radar relative altitude measurement error is an error in the radar elevation measurement. The radar elevation error is assumed to be a 0.5-deg mean with a 1.0-degree standard deviation, for a 2.5 deg 95% error. Since the radar error is an elevation error, the relative altitude error Δh_{radar} is a function of slant range R.

$$\Delta h_{radar} = R * \sin(2.5 \text{ deg})$$

or

$$\Delta h_{radar} = 265.04 R$$

where R is input in units of NM and Δh_{radar} is units of feet.

The 95% pressure altitude errors are assumed to be 125’ This is consistent with the requirements described in SAE AS8003, “Minimum Performance Standard for Automatic Pressure Altitude Reporting Code Generating Equipment,” and 14 CFR 91.217, “Data correspondence between automatically reported pressure altitude data and the pilot's altitude reference.”

Each altitude measurement source has errors associated with uncompensated latency or differences in the time of applicability of the altitude measurements. The error analysis assumes that the maximum climb or descent rate is 2,000 fpm (33.3 feet per second (fps)).

Table N-5 summarizes the error budget. For ranges less than 0.5 NM, the pressure altitude error dominates. For ranges greater than 2.0 NM, the radar relative altitude error dominates. The errors due to uncompensated latency are significantly smaller than the other error sources.

The altitude validation threshold in units of feet can be calculated using the following equation, where sqrt is the square root and R is the range to the traffic in units of NM.

Altitude validation threshold RSS = sqrt $(178*178 + 265*265 R^2)$ = sqrt $(31684 + 70246 R^2) \approx$ sqrt $(32000 + 70300 R^2)$.

Table N-5 **Altitude Validation Error Budget for ADS-B Position Using Radar**

Error Source	Altitude Error (feet)			
Ownship Pressure Altitude Error, 95%	125			
Traffic Pressure Altitude Error, 95%	125			
Uncompensated Latency in the Ownship's Position (33.3 fps for 250 ms)	8			
Uncompensated Latency in ADS-B Traffic (33.3 fps for 600 ms)	20			
Uncompensated Latency in Radar Relative Altitude Measurements (33.3 fps for 250 ms)	8			
Total Without Radar Relative Altitude Error, Assuming Errors Root Sum Square	**178**			
Radar Relative Altitude Error	**Range**			
	1 NM	5 NM	8 NM	14 NM
	265'	1325'	2120'	3711'
Total, Assuming Errors Root Sum Square	**319'**	**1336'**	**2127'**	**3715'**

N.5.3 Bearing Validation Threshold

There are two bearing error measurement sources to consider when selecting the altitude validation threshold for validating ADS-B position with radar altitude. These are:

- Radar azimuth measurement error
- Bearing error from ownship position error and traffic ADS-B position error.

The radar azimuth error is assumed to be a 0.5-deg mean with a 1.0-degree standard deviation, for a 2.5-deg 95% error. For the purposes of this analysis, the azimuth error and bearing error are considered the same thing. Thus the radar bearing error is 2.5 deg, 95%. The calculation of the bearing error from ownship position and traffic ADS-B position was described in Paragraph N.4.3. Table N-6 summarizes the bearing error for various ranges.

The bearing threshold could be expressed as a function of range, as the altitude threshold was in Subsection 5.2. However, bearing is difficult to spoof, so it is probably not necessary to set such tight thresholds. The bearing threshold when TCAS is used for position validation is 45 deg. To simplify the requirements, the bearing threshold could be set at 15 deg for ranges greater than 1 NM. Within 1 NM, bearing validation is not done.

Table N-6 **Bearing Validation Error Budget for ADS-B Position Using Radar**

<table>
<tr><th>Error Source</th><th colspan="6">Bearing Error</th></tr>
<tr><td>Radar Bearing Error, 95%</td><td colspan="6">2.5 deg</td></tr>
<tr><td rowspan="3">ADS-B/Ownship Bearing Error, Based on a Combined Position Error of 0.2 NM, 95%</td><td colspan="6">Range</td></tr>
<tr><td>0.2 NM</td><td>0.5 NM</td><td>1 NM</td><td>5 NM</td><td>8 NM</td><td>14 NM</td></tr>
<tr><td>90 deg</td><td>42 deg</td><td>14 deg</td><td>2.4 deg</td><td>1.5 deg</td><td>0.8 deg</td></tr>
<tr><td>Total, Assuming Errors Root Sum Square</td><td>90 deg</td><td>42 deg</td><td>14 deg</td><td>3.5 deg</td><td>2.9 deg</td><td>2.6 deg</td></tr>
</table>

N.6 Position Validation Interval

The position validation interval for ADS-B In applications per RTCA DO-317B is:

- Once every 10 seconds for systems performing position validation based on TCAS output track data
- At validation intervals used for hybrid surveillance per RTCA DO-300, Subparagraph 2.2.7.4, or RTCA DO-300A Subparagraph 2.2.7.5.

ADS-B position validation needs to be performed often enough that problems with the traffic position can be detected before there is a safety issue. Table N-7 shows the distance closed during the interval between revalidation for a 10-second, 20-second, 30-second and 60-second revalidation interval for closing rates of 450 kts and 800 kts.

Table N-7 **Distance Closed During Interval between Revalidations**

Revalidation Interval (sec)	Closing Rate (kts)	
	450 kts	800 kts
10	1.25 NM	2.22 NM
20	2.50 NM	4.44 NM
30	3.75 NM	6.67 NM
60	7.50 NM	13.33 NM

The validation intervals for hybrid surveillance range from 10 to 60 seconds and are summarized as a function of range and range rate in Table N-8. The notation “A” is the point at which ADS-B data is no longer used so a revalidation interval is not applicable. For a 450 kts closing rate, the validation interval is 10 sec at 8 NM (the maximum proposed position validation range for traffic under 10,000’). For an 800-kt closing rate, the validation interval is 10 sec at 14 NM (the maximum proposed position validation range for traffic above 10,000’). Thus, a hybrid track should meet the validation interval requirements for DAA.

Table N-8 Hybrid Surveillance Validation Interval

(per RTCA DO-300A, Subparagraph 2.2.7.5, Table 2)

	Range (NM)																											
Range Rate (kt)	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	≥30
≥300	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
200	30	40	40	40	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
100	10	20	30	30	40	40	40	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
0	10	10	10	20	20	30	40	40	40	40	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
-100	10	10	10	10	10	20	20	30	30	40	40	40	40	40	60	60	60	60	60	60	60	60	60	60	60	60	60	60
-200	A	10	10	10	10	10	10	20	20	20	30	30	40	40	40	40	40	60	60	60	60	60	60	60	60	60	60	60
-300	A	A	A	10	10	10	10	10	10	10	20	20	30	30	30	40	40	40	40	40	60	60	60	60	60	60	60	60
-400	A	A	A	A	A	10	10	10	10	10	10	10	20	20	20	30	30	40	40	40	40	40	40	40	60	60	60	60
-500	A	A	A	A	A	A	10	10	10	10	10	10	10	10	20	20	20	30	30	30	40	40	40	40	40	40	40	60
-600	A	A	A	A	A	A	A	A	10	10	10	10	10	10	10	10	20	20	20	20	30	30	30	40	40	40	40	40
-700	A	A	A	A	A	A	A	A	A	A	10	10	10	10	10	10	10	10	10	20	20	20	30	30	30	30	40	40
-800	A	A	A	A	A	A	A	A	A	A	A	10	10	10	10	10	10	10	10	10	10	20	20	20	20	30	30	30
-900	A	A	A	A	A	A	A	A	A	A	A	A	A	10	10	10	10	10	10	10	10	10	10	20	20	20	20	30
-1000	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	10	10	10	10	10	10	10	10	10	10	20	20	20
-1100	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	10	10	10	10	10	10	10	10	10	10	10	20
-1200	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	10	10	10	10	10	10	10	10	10	20

O APPENDIX O EQUIPMENT CLASS TO REQUIREMENT CROSS-REFERENCES

This appendix contains information for manufacturers intending to build part of the Detect and Avoid (DAA) system.

Manufacturers can choose to build one article, a few articles, airborne articles only, or control station articles only of the DAA system. The manufacturer should adequately document in the installation drawing and/or installation manual, detailed instructions and limitations for the installation and use of the incomplete article. For example, if the manufacturer chooses to develop the Unmanned Aircraft (UA) DAA processor without DAA alerting, then the article will need to be clearly identified (markings) that the article does not contain any alerting and will need to have a compatible system that has alerting logic on the ground.

Table O-1 provides guidance on the Minimum Operational Performance Standards (MOPS) for MOPS paragraphs associated with each article, grouped by Basic DAA (Class 1), and Class 2, which includes Traffic Alert and Collision Avoidance System Model 2 (TCAS II). For the purposes of defining MOPS paragraphs for each article, the table is based on Figure 2-1. It assumes the DAA alerting is an airborne function. In addition, Class 2 equipment has additional performance requirements that are underlined in the table to ensure proper integration with the DAA alerting, guidance and display functions.

Table O-1 Article Matrix for Partial Standard Compliances

Class	Equipment	Article Designation	Equipment Article Name	DAA MOPS Paragraph Compliance
1	DA – Basic	A	Active Surveillance	§§2.1, 2.2.1.1, 2.2.1.4, 2.2.3.1, 2.2.8, 2.3, 2.4.2.1.4, 2.4.3, 2.4.6, 2.4.8
		B	UA DAA Processor	§§2.1, 2.2.1.1, 2.2.2.1, 2.2.2.2, 2.2.3.2,2.2.4.1 (Alerting), 2.2.4.2, 2.2.4.3 (Alerting), 2.2.8, 2.2.9, 2.3, 2.4.2.2.1, 2.4.2.2.2, 2.4.3.2, 2.4.4, (Alerting),2.4.6, 2.4.8, 2.4.9, 2.4.11
		C	Control Station (CS) DAA Processor	§§2.1, 2.2.1.1, 2.2.2.3, 2.2.2.4, 2.2.4.1, (Guidance), 2.2.4.4 (Guidance), 2.2.4.5.2 (DAA Only), 2.2.4.5.3, 2.2.8, 2.2.9, 2.3, 2.4.2.2.3, 2.4.2.2.4, 2.4.4.4, 2.4.6, 2.4.8, 2.4.9, 2.4.12
		D	CS DAA Control Panel	§§2.1, 2.2.2.5, 2.2.2.6, 2.2.5.10, 2.2.6, 2.2.8, 2.2.9, 2.3, 2.4.2.2.5, 2.4.2.2.6, 2.4.8, 2.4.9, 2.4.13
		E	CS DAA Traffic Display	§§2.1, 2.2.1.1, 2.2.2.7, 2.2.5.1, 2.2.5.2, 2.2.5.3, 2.2.5.4 2.2.5.5, 2.2.5.6,2.2.5.7, 2.2.5.8, 2.2.5.9, 2.2.5.10, 2.2.8, 2.2.9, 2.3, 2.4.2.2.7, 2.4.5, 2.4.6, 2.4.8, 2.4.9, 2.4.15

Class	Equipment	Article Designation	Equipment Article Name	DAA MOPS Paragraph Compliance
2	**DAA with TCAS II**	A	TCAS II Version 7.1	§§2.1, 2.2.1.1. 2.2.1.6, 2.2.3.1, 2.2.3.1.2, 2.2.4.5, 2.3, 2.4.2.1.6, 2.4.11
		B	UA DAA Processor	§§2.1, 2.2.1.1, 2.2.2.1, 2.2.2.1.4.4, 2.2.2.1.5, 2.2.2.2, 2.2.2.2.3, 2.2.3.1.2, 2.2.3.2, 2.2.4.1 (Alerting), 2.2.4.2, 2.2.4.3(Alerting), 2.2.8, 2.2.9, 2.3, 2.4.2.2.1, 2.4.2.2.2, 2.4.3, 2.4.4, (Alerting), 2.4.6, 2.4.8, 2.4.9, 2.4.11
		C	CS DAA Processor	§§2.1, 2.2.1.1, 2.2.2.3, 2.2.2.4, 2.2.4.1 (Guidance), 2.2.4.2, 2.2.4.4, (Guidance), 2.2.4.5.1, 2.2.4.5.2 (with RA Mode), 2.2.4.5.3, 2.2.8, 2.2.9, 2.3, 2.4.2.2.3, 2.4.2.2.4, 2.4.4.4, 2.4.6, 2.4.8, 2.4.9, 2.4.12
		D	CS DAA Control Panel	§§2.1, 2.2.2.5, 2.2.2.6, 2.2.5.8, 2.2.5.10, 2.2.6.1, 2.2.8, 2.2.9, 2.3, 2.4.2.2.5,2.4.2.2.6, 2.4.8, 2.4.9, 2.4.13
		E	CS DAA Traffic Display	§§2.1, 2.2.1.1, 2.2.2.7, 2.2.5.1, 2.2.5.2, 2.2.5.3, 2.2.5.4, 2.2.5.5, 2.2.5.6, 2.2.5.7, 2.2.5.8, 2.2.5.9, 2.2.8, 2.2.9, 2.3, 2.4.2.2.7, 2.4.5, 2.4.6, 2.4.8, 2.4.9, 2.4.15,

P APPENDIX P TEST VECTORS

P.1 Summary and Assumptions

This appendix describes specific aircraft tracks ("test vectors") used to verify that a DAA system designed to these MOPS operates as required. The state files for each test vector are available via separate media. The test vectors are binned into the categories shown in Table P-1.

Table P-1 Categories and Numbers of DAA Test Vectors

Category Prefix	Category Description	Number of Alerted Tracks	Number of Non-Alerted Tracks	Total
H	Head-On Encounter	15	7	22
C	Convergence at Fix	20	12	32
S	Convergence with Fast-Moving Jet	4	4	8
O	Overtake Encounter	16	7	23
M	Encounter With Maneuvering Target	15	12	27
D	Designer Cases	0	17	17
LL	Representative Sample from LL Data Sets	176	0	176
	Total	**246**	**59**	**305**

Each track is either alerted or non-alerted. Alerted tracks test the alerting capabilities of a DAA system for a range of aircraft encounters that have either occurred historically in the enroute environment, or have been identified through flight test or the design of prototype DAA systems to stress the performance of a DAA system. Non-alerted tracks are similar but the separation between the ownship and the intruder(s) remains such that no alert is desired.

P.1.1 Sources Used for Test Vector Derivation

The tracks were derived from multiple sources, including:

1. A review of mid-air collisions that occurred between 2000 and 2010[69]
2. 95 Stressing Cases used by the SaRP for the derivation of the DAA Well Clear boundaries
3. Flight Test 4 conducted by NASA in support of DAA MOPS development[70]

In aggregate, the test vectors described in this appendix include cases representative of encounters observed during routine operations (H, C, O M, LL), encounters considered to be "corner cases" that stress the performance of the system (S, D), as well as synthetic

[69] Kunzi, Fabrice and Hangman, R. John. "ADS-B Benefits to General Aviation and Barriers to Implementation." MIT ICAT Report. http://hdl.handle.net/1721.1/63174
[70] NASA, Flight Test Series 4 Flight Test Report-TN# 36020, September 2016.

test vectors that are not always representative of actual operational dynamics but are designed to elicit a specific behavior of the system (D).

P.1.2 Intruder and Ownship Assumptions

During the development of the H, S, C, O, M and D test vectors the maximum maneuver capability of the ownship was limited to turns at 3 deg/sec and vertical velocities of ±2500 ft/min. Intruder maneuvering assumptions were limited to ±3000 ft/min and 6 deg/sec turns.

Similarly, the maximum forward velocity (ground speed) of the ownship was limited to 200 kts and the maximum intruder velocity was limited to 600 kts. If the intruder operates faster than 250 kts, the altitude at which the encounter occurs is selected to be above 10,000'.

The performance of ownship and intruder dynamics for the LL encounters are defined by the Lincoln Laboratory Encounter Model and were not modified as part of the test vector generation.

As mentioned in Appendix Q, the minimum sensor capability assumptions were implemented and applied to the degraded intruder tracks for all test vectors. For example, a degraded radar track would not contain any data if the intruder is outside of the minimum required radar field of view of ± 110 degrees horizontally (similarly for radar and active surveillance range limitations).

P.1.3 Verification of Achievability

The CPAs for all alerted tracks were selected such that they reside inside Hazard Zones defined in Subparagraph 2.2.4.3 for the respective alerts. For non-alerted tracks, the CPA was selected to reside inside Non-Hazard Zones for all alerts.

Each test vector was also evaluated using the sample tracker and alerting algorithms provided in these MOPS. Appendix Q provides a detailed overview of this simulation implementation, including any wrappers and additional functionalities that were included beyond the basic alerting and tracking algorithms. Additionally, an alternate alerting algorithm was also used to verify that test vectors are not too narrowly defined such that only the MOPS sample algorithms can pass them. Doing so ensures independence of the test tracks from specific alerting and tracking algorithms and system implementations. Lastly, the errors used to degrade the test vectors were verified to not be rare cases such as very large altitude biases or horizontal position errors.

It should be noted that the version of DAIDALUS described in Appendix G – which is the version that was used for the verification of the test vectors – did not contain logic to identify alerting special cases. Work on Daidalus, however, is continuing and will likely result in updates that introduce additional functionality, including alerting during special cases.

P.2 Description of Individual Test Vector Sets

Each set of test vectors listed in Table P-1 is described in detail here. A table highlighting the details of individual test vectors within a given set is also provided at the end of this appendix.

P.2.1 Head-on Encounters

For all head-on encounters the ownship and the intruder track intersect at an angle of 180 degrees (exactly head-on), but with various HMD and VMD offsets. In test vectors H1-H10 the ownship and the intruder fly level at speeds ranging from 40 kts – 200 kts for the ownship and 150 kts – 600 kts for the intruder. For test vectors H11 – H22 either the ownship, the intruder, or both climb or descend throughout the encounter. Ownship vertical rates are limited to ±1000 ft/min and intruder vertical rates are limited to ±1500 ft/min. A CPA altitude of 17,000' is used for test vectors with high operational velocities, and 8,000' is used for test vectors with lower operational velocities.

provides a more detailed description of the head-on test vectors.

P.2.2 Convergence at Fix

Test vectors simulating two aircraft converging at a fix are representative of a common type of encounter when operating in the enroute environment. The ownship and the intruder can encounter each other at any angle, velocity and vertical rate. For all test vectors, ownship operates at speeds ranging from 40 kts – 200 kts; intruders operate at speeds ranging from 150 kts – 600 kts. Vertical velocities are limited to ±1000 ft/min for the ownship and ±1500 ft/min for the intruder.

Test vectors C1 – C20 verify alerting for intersect angles of 5, 60 120 and 175 degrees, with encounter geometries ranging from the ownship being above, below, ahead or behind the intruder at the CPA. Similarly, test vectors C20 – C32 verify that no alerts are issued for the same intersect angles.

Note that these test vectors are not intended to test the scenario where either the ownship or the intruder are cruising level while the other is descending through the same altitude at high velocity. That scenario is covered in Paragraph P.2.3. Table P-15 provides more detailed descriptions of convergence at fix test vectors.

P.2.3 Convergence with Fast-Moving Jet

This set of test vectors verifies alerting performance in an encounter with a fast-moving business jet climbing or descending through the airspace where ownship is operating. Ownship horizontal velocities are set to either 150 kts or 200 kts, and vertical velocities are ±2500 ft/min. Intruder horizontal velocities are 150 kts, 250 kts or 600 kts, and vertical velocities are set to ±3000 ft/min.

Test vectors S1 and S2 verify alerting in a head-on encounter where the ownship and the intruder encounter each other at maximum horizontal and vertical velocities.

Test vectors S3 and S6 verify alerting for an intersect angle of 0 degrees where the ownship and the intruder operate at the same velocity, resulting in an encounter with only vertical closure.

Test vectors S4, S5, S7 and S8 verify alerting for intersect angles of 90 and 180 degrees where either the ownship or the intruder is not climbing while the other is transitioning vertically through co-altitude.

Table P-16 provides a more detailed description of high-speed encounter test vectors.

P.2.4 Overtake Encounter

The overtake test vector set verifies alerting behavior for an ownship being chased or overtaken by an intruder. Both the ownship and the intruder can be cruising, ascending or descending. All test vectors have an intersect angle of 0 degrees, but are offset at various HMD and VMD combinations to elicit specific alerting behaviors. Ownship velocities range from 40 kts to 150 kts, and intruder velocities range from 100 kts to 600 kts. Ownship vertical rates are limited to ±1000 ft/min and intruder vertical rates are limited to ±1500 ft/min.

Test vectors O1-O10 verify alerting where both aircraft are cruising in level flight, and test vectors O11-O22 verify alerting where one or both aircraft are maneuvering vertically. O23 verifies alerting for a slow-closure rate encounter. Table P-17 provides additional detail on individual overtake test vectors.

P.2.5 Encounter with Maneuvering Intruder or During Ownship Maneuver

The maneuvering test vector set verifies the alerting behavior for encounters where either the ownship or the intruder is maneuvering. Ownship velocities range from 150 kts to 200 kts and intruder velocities range from 150 kts to 600 kts. Ownship vertical rates are limited to ±2500 ft/min and intruder vertical rates are limited to ±1500 ft/min.

Test vectors are designed to combine where the intruder crosses with respect to the ownship (behind, ahead, above, below), who is maneuvering (ownship or intruder), as well as the intersect angle at the beginning and end of the encounter. Table P-18 provides more detailed information for the design of individual test vectors.

P.2.6 Designer Cases

The designer test vector set consist of unique encounters that were identified as stressing the system, or were designed to verify a system behavior that is difficult to tie to a routine encounter.

P.2.7 Dynamic Set

The set of dynamic test vectors serves as the basis for requirements that require the calculation of statistical metrics for verification. This data set was generated by sampling encounters from the Lincoln Laboratory Encounter generator with requirements that the intruder must be initialized in the non-hazard zone for all alerts, and that a loss of well clear occurs 90 seconds or later into the encounter.

All metrics as required by the MOPS have been verified to be achievable with the reference implementation for the tracker and alerting algorithm provided in a separate appendix.

P.3 Track File Description

Each test vector is made up the following files:

1. Truth Track – Ownship and Intruder
2. Degraded Ownship Track
3. Degraded Intruder Track – ADS-B
4. Degraded Intruder Track – Mode C Active Surveillance

5. Degraded Intruder Track – Mode S Active Surveillance
6. Degraded Intruder Track – Radar Surveillance
7. Tracker Output – ADS-B/R
8. Tracker Output – Mode C/S Active Surveillance
9. Tracker Output – Radar
10. Encounter Characterization and Required Alerting and Guidance Performance

P.3.1 Truth Track Format and Contents

The truth tracks for the ownship and the intruder provide the reference against which the performance of the guidance and alerting systems are evaluated. The required performance files discussed in Paragraph P.3.7 are generated based on these truth tracks.

The truth tracks contain the following data fields:

Table P-2 Data Fields in Test Vector Truth Tracks

Field (Header)	Format and Units
Time of Applicability (ToA)	Seconds Since Midnight
24-bit Address (ICAO)	Hexadecimal Address
Latitude (Lat)	Degrees, 8 Decimal Places
Longitude (Lon)	Degrees, 8 Decimal Places
Altitude (Alt)	Feet above MSL
East/West (E/W) Velocity (EWV)	Knots
North/South (N/S) Velocity (NSV)	Knots
Vertical Rate (VR)	Feet per minute (fpm)
Heading (HDG)	0 = North, Increasing to 359 Clockwise

P.3.2 Format and Contents of Degraded Ownship Track

The degraded ownship track represents the data that would be received by the DAA system from the ownship position. Note that Time of Report refers to when the data is made available to DAA and Time of Applicability refers to when the states were measured. The difference between the two times represents the latency between the measurement of the states and when they become available to the DAA system.

Table P-3 Data Fields in Ownship Test Vector Tracks

Field (Header)	Format and Units
Time of Report (ToR)	Seconds Since Midnight
24-bit Address (ICAO)	Hexadecimal address
Time of Applicability (ToA)	Seconds Since Midnight
Latitude (Lat)	Degrees, 8 decimal places
Longitude (Lon)	Degrees, 8 decimal places
Altitude (Alt)	Feet above MSL
E/W Velocity (EWV)	Knots

Field (Header)	Format and Units
N/S Velocity (NSV)	Knots
Horizontal Position Accuracy (HPA)	R95 value, Feet
Horizontal Velocity Accuracy (HVA)	R95 Value, knots
Vertical Rate (VR)	Feet per minute (fpm)
Heading (HDG)	0 = North, increasing to 359 clockwise

Sensor model parameters used to introduce representative surveillance errors into the ownship tracks are described in Appendix Q

P.3.3 Format and Contents of Degraded Intruder Track – ADS-B

To model the effects of automatic dependent surveillance, intruder tracks are degraded using sensor models that inject representative surveillance errors and transmission effects typical for ADS-B intruders. ADS-B intruder tracks contain the following data elements:

Table P-4 Data Fields in ADS-B Test Vector Tracks

Field (Header)	Format
Time of Report (ToR)	Seconds Since Midnight
24-bit Address (ICAO)	Hexadecimal address
Time of Applicability (ToA)	Seconds Since Midnight
Latitude (Lat)	Degrees, 8 decimal places
Longitude (Lon)	Degrees, 8 decimal places
Altitude (Alt)	Feet above MSL
E/W Velocity (EWV)	Knots
N/S Velocity (NSV)	Knots
NAC_P (NACP)	Integer, 0-11
NIC (NIC)	Integer, 0-11
NAC_V (NACV)	Integer, 0-4
Vertical Rate (VR)	Feet per minute (fpm)

Sensor model parameters used to introduce representative ADS-B surveillance errors into the intruder tracks are described in Appendix Q.

P.3.4 Format of Degraded Intruder Track – Mode C and Mode S Active Surveillance

To model the effects of active surveillance, intruder tracks are degraded using sensor models that inject representative surveillance errors and sensor effects typical for Mode C and Mode S intruders. Mode C and Mode S intruder tracks contain the following data elements:

Table P-5 Data Fields in Mode C and Mode S Test Vector Tracks

Field (Header)	Format
Time of Report (ToR)	Seconds Since Midnight
Time of Applicability (ToA)	Seconds Since Midnight
Track ID (TID)	Unique ID
24-bit ICAO address (ICAO)	Hexadecimal Address
Slant Range (RNG)	Nautical Miles (NM)
Relative Bearing (BRG)	Degrees, 1 Decimal Point, increasing to 180 degrees clockwise, or decreasing to -180 counter clockwise
Pressure Altitude – Intruder (ALT)	Feet above MSL
Altitude Quantization (QUANT)	25'or 100'
Range Validity Flag (RVF)	0 = Invalid, 1 = Valid
Altitude Validity Flag (AVF)	0 = Invalid, 1 = Valid
Bearing Validity Flag (BVF)	0 = Invalid, 1 = Valid
Passive/Active Flag (P/A)	0 = Passive Surveillance 1 = Active Surveillance
Intruder TCAS Equipage (EQ)	0 = No TCAS 1 = TCAS in TA Mode 2 = TCAS in TA/RA Mode

Sensor model parameters used to introduce representative Mode C and Mode S surveillance errors into the intruder tracks are described in Appendix Q. For some test vectors, the intruder remains outside of the field of view for most or the entire duration of the test vector. In those cases, no radar track is provided for evaluation, and can be skipped.

P.3.5 Format of Degraded Intruder Track – Radar Surveillance

To model the effects of radar surveillance, intruder tracks are degraded using sensor models that inject representative surveillance errors and sensor effects typical for intruders tracked by radar. Radar intruder tracks contain the following data elements:

Table P-6 Data Fields in Radar Test Vector Tracks

Field (Header)	Format
Time of Report (ToR)	Seconds Since Midnight
Time of Applicability (ToA)	Seconds Since Midnight
Track ID (TID)	Unique ID
Slant Range (RNG)	Nautical Miles
Range Rate (RR)	Knots
Relative Bearing (BRG)	Degrees, 1 decimal, increasing to 180 degrees clockwise, or decreasing to -180 counter clockwise
Relative Elevation Angle (REA)	Degrees, 1 decimal, increasing to 180 degrees upward, or decreasing to -180 downward

Field (Header)	Format
Slant Range Accuracy (SRA)	Nautical Miles
Range Rate Accuracy (RRA)	Knots
Relative Bearing Accuracy (RBA)	Degrees
Elevation Angle Accuracy (EAA)	Degrees

Sensor model parameters used to introduce representative radar surveillance errors into the intruder tracks are described in Appendix Q. For some test vectors, the intruder remains outside of the field of view for most or the entire duration of the test vector. In those cases, no radar track is provided for evaluation, and can be skipped.

Table P-7 **Test Vectors Without a Degraded Radar Track**

C1	H15	M22	O15
C3	H20	O1	O16
C5	M4	O11	O19
C15	M5	O12	O20
S3	M9	O13	
H1	M13	O14	

P.3.6 Format of Tracker Output

The output of the sample tracker described in Appendix F depends on which sensors are providing information about a particular intruder. The sample tracker determines which surveillance source provides the best information, and then smoothes and extrapolates the data from that sensor. As a result, the test vectors contain multiple tracker outputs that depend on which sensor is used in the particular test procedure.

The test vector files in these MOPS were generated by passing the tracker described in Appendix F the degraded intruder tracks and recording the output from the tracker. The MOPS allows the tracker's output to be in absolute states as well as in ownship-relative states. Thus, both types of states are included in the tracker output files, and are described below:

Table P-8 **Data Fields in Tracker Output Test Vector Tracks**

Field (Header)	Format
Time of Applicability (ToA)	Seconds Since Midnight
Traffic ID (TID)	Unique ID (0 = ownship, 1 = Intruder 1, 2 = Intruder 2, …)
24-bit ICAO (ICAO)	Hexadecimal Address
Source Data Type (SRC)	1 = ADS-B, 2 = ADS-R, 3 = Mode C, 4 = Mode S, 5 = Radar
Latitude (LAT)	Degrees, 8 decimal places
Longitude (LON)	Degrees, 8 decimal places
Pressure Altitude (Alt)	Feet Above MSL
Heading (HDG)	0 = North, increasing to 359 clockwise

Field (Header)	Format
Absolute Ground Speed (GS)	Absolute value, not vectorized
Absolute Position Accuracy (APA)	R95 value, Nautical Miles
Pressure Altitude Accuracy (PAA)	R95 value, Feet
Ground Speed Accuracy (GSA)	R95 value, Knots
Heading/Track Accuracy (HDGA)	R95 value, Degrees
Absolute Vertical Velocity	Feet per Minute, Climb = positive, descent = negative
Absolute Vertical Velocity Accuracy	R95 value, Feet per Minute
Slant Range (RNG)	Nautical Miles
Range Rate (RR)	Knots
Relative Altitude (RA)	Feet, above = positive, below = negative
Intruder Bearing (BRG)	Relative to Heading, increasing to 180 degrees clockwise, or decreasing to -180 counter clockwise
Relative Elevation Angle (REA)	Degrees, 1 decimal, increasing to 180 degrees upward, or decreasing to -180 downward
Relative Altitude Accuracy (RAA)	R95 value, Feet
Relative Bearing Accuracy (RBA)	R95 value, Degrees
Elevation Angle Accuracy (EAA)	R95 value, Degrees
Slant Range Accuracy (SRA)	R95 value, Nautical Miles
Range Rate Accuracy (RRA)	R95 value, Knots
Radar/Act. Surv. Validation Flag	0 = Not Validated 1 = Validated
Horizontal Position Valid	0 = Not Valid 1 = Valid (i.e., meets requirements in Table 2-20)
Vertical Position Valid	
Horizontal Velocity Valid	
Vertical Velocity Valid	

Additional details on how the tracker generates its output can be found in Appendix F.

P.3.7 Encounter Characterization and Required Performance Files

The encounter characterization file provides a reference for the expected behavior of the DAA system under test. The required alerting and guidance performance for each test vector was determined based on the truth tracks for each test vector using the parameters and formulas for the Hazard Zone (HZ) and Non-Hazard Zone (NHZ) described in Subparagraph 2.2.4.3. Table P-9 is a notional visualization of the contents for a fictional test vector.

Table P-9 Notional Contents of an Encounter Characterization File: Horizontal Only

			Minimum Required Alert Level and Horizontal Guidance							Maximum Allowed Alert Level and Horizontal Guidance						
T	**HZ**	**NHZ**	**A**	**0**	**1**	**2**	**…**	**358**	**359**	**A**	**0**	**1**	**2**	**…**	**358**	**359**
1	N	P	N	N	N	N	…	N	N	N	N	N	N	…	N	N
2	N	P	N	N	N	N	…	N	N	N	N	N	N	…	N	N
3	N	C	N	N	N	N	…	N	N	P	P	P	P	…	N	N
4	N	W	N	N	N	N	…	N	N	C	C	C	C		C	C
5	P	N	C	C	C	C	…	P	P	W	W	W	W		W	W
6	C	N	C	C	P	P	…	C	C	W	W	W	W		W	W
7	C	N	C	C	C	P	…	C	C	W	W	W	W		W	W
8	W	N	W	W	C	P	…	C	W	W	W	W	W		W	W
…																

For each time step along the test vector, the encounter characterization file provides the following information:

1. **HZ:** Identifies whether the intruder has violated any of the Hazard Zones. Due to the nested nature of the zones, a higher alert level implies that the Hazard Zone of the lower alert levels have also been violated. For example, a “W” or a “3”in the HZ column implies that the Hazard Zone for the Warning, Corrective and Preventive Alerts have been violated. See Table P-10 for the meaning of potential entries in these columns. For details on how to calculate the Hazard Zone refer to Subparagraph 2.2.4.3.2 and Appendix L.
2. **NHZ:** Identifies whether the intruder is in any of the Non-Hazard Zones. However as opposed to the HZ column, if the intruder is in a particular the Non-Hazard Zone it implies that the intruder has left the lower level Non-Hazard zones as well. For example, a “W” in the NHZ column implies that the intruder has departed all but the Warning Non-Hazard Zone. For details on how to calculate the Non-Hazard Zone refer to Subparagraph 2.2.4.3.3 and Appendix L.
3. **Minimum Required Alert Level and Horizontal Guidance:** Identifies the lowest required alert level and guidance for the system under test at a given time step along the test vector. Column A lists the required level of aural alert. It is determined based on the intruder’s current location with respect to the hazard and non-hazard zones requirements as well as the alerting requirements defined in Subparagraph 2.2.4.3. A supplement in the digital media identifies which test vectors use the alternative late and early thresholds. Columns 0-359 list the minimum required level of visual guidance for each degree around a compass rose. The compass rose is referenced to North. For example, a C in any of the Minimum Required Guidance columns indicates that that segment must at least display corrective guidance. The required guidance is calculated based on the requirements outlined in Subparagraph 2.2.4.4 (Guidance) and Appendix L.

4. **Maximum Allowed Alert Level and Horizontal Guidance:** Identifies the highest allowed alert level and guidance for the system under test at a given time step along the test vector. Column A lists the required level of aural alert. It is determined based on the intruder's current location with respect to the hazard and non-hazard zones requirements as well as the alerting requirements defined in Subparagraph 2.2.4.3 (Alerting) and Appendix L. Columns 0-359 list the maximum allowed level of visual guidance for each degree around a compass rose. The compass rose is referenced to North. For example, a C indicates that that segment must at most show corrective guidance (i.e., cannot display warning guidance). The required guidance is calculated based on the requirements outlined in in Subparagraph 2.2.4.4 (Guidance) and Appendix L.
5. **Minimum Required Altitude Guidance:** Identifies the minimum altitude guidance required for the system under test at a given time step along the test vector. Similar to the angular columns for horizontal guidance, the vertical guidance uses 100' increments for altitude starting at 100' to 50,000'. The key for cell contents is the same as for horizontal guidance.
6. **Maximum Allowed Altitude Guidance:** Identifies the maximum altitude guidance allowed for the system under test at a given time step along the test vector. The altitude range is the same as described under the minimum required altitude guidance and the key for cell contents is the same as for horizontal guidance.
7. **Regain Well Clear Region:** Identifies a region into which regain well clear guidance should point. Other implementations may be possible, and a manufacturer would need to provide a method for its evaluation if the data provided here is insufficient. The regain well clear guidance region here is derived using a minimum heading change edge defined by the heading that would result in ownship to miss HMD, and a maximum heading change edge 90 degrees from the minimum edge in the direction that increases distance to HMD and CPA.

Table P-10 Key for Interpreting the HZ and the NHZ Columns in Table P-9

Hazard Zone Key	
P/1	The intruder violated the Preventive HZ
C/1	The intruder violated the Preventive and Corrective HZ
W/3	The intruder violated the Preventive, Corrective and Warning HZ
N/4	The intruder has not violated any HZ

Non-Hazard Zone Key	
P/1	The intruder is in the Preventive, Corrective and Warning NHZ
C/1	The intruder is in the Corrective and Warning NHZ
W/3	The intruder is in the Warning NHZ
N/4	The intruder has left all NHZs

It should be noted that while preventive alerting and guidance is included in the encounter characterization files, preventive alerts and guidance are optional as discussed in the main body of this MOPS.

Additionally, the encounter characterization files provides as part of the test vectors assume a climb rate of 500' for the encoding of the minimum required and maximum allowed guidance information. If the manufacturer uses a different climb or descend rate assumption in the design of the vertical guidance processing sub-function, the altitude data in the encounter characterization files will need to be adjusted accordingly.

P.3.8 Encounter Characterization and Required Performance File

Depending on encounter dynamics, some test vectors require the use of the alternate alerting thresholds for early and late alerts. Table P-11 and Table P-12 list the test vectors that use the alternate early and late thresholds, respectively.

Table P-11 Test Vectors that Require Use of Alternate Early Threshold

C1	LL132	LL162
C2	LL139	LL169
O2	LL141	LL173
O4	LL143	LL175
O6	LL147	LL177
LL89	LL158	LL179
LL125	LL160	
LL131	LL161	

Table P-12 Test Vectors that Require Use of Alternate Late Threshold

M1	LL9	LL128
M5	LL27	LL133
M9	LL40	LL134
M12	LL46	LL137
M13	LL56	LL154
M16	LL57	LL155
M17	LL62	LL156
M19	LL67	LL158
M21	LL68	LL161
M22	LL92	LL171
M23	LL95	LL174
M27	LL99	LL175
LL3	LL122	LL180

P.4 Detailed Test Vector Descriptions

Where applicable, individual tracks list parameters for the ownship and the intruders(s), as well as the conditions at the CPA. The columns in the following tables are labeled as follows:

Table P-13 Legend for Tables Describing Individual Test Vectors

Test Vector Column Headers	
ID	ID of the test vector
GS	Ground Speed, knots
VR	Vertical Rate, fpm
Alt	Altitude, Feet
IA	Intersect Angle, degrees, 0 = Overtake, 180 = Head-On

Test Vector Column Headers	
HMD	Horizontal Miss Distance at the CPA, Nautical Miles
VMD	Vertical Miss Distance at VMD, Feet
Alert	Y = Alerted Encounter N = Non-Alerted Encounter N/A = Any alerts issued are not used for analysis

Table P-14 Detailed Description of Head-On Test Vectors

ID	Ownship			Intruder			IA	HMD	VMD	Alert	Notes
	GS	VR	Alt	GS	VR	Alt					
H1	200	0	17000	600	0	17000	180	0	0	Y	Verify corrective and warning alerts are issued for high horizontal velocity convergence and 0 vertical offset. Altitude is set to be just below Class A, allowing the fastest combination of ownship/intruder velocity.
H2	40	0	8000	150	0	8000	180	0	0	Y	Verify corrective and warning alerts are issued for low horizontal velocity convergence and 0 vertical offset.
H3	200	0	17000	600	0	16550	180	0	450	Y	Verify corrective and warning alerts are issued for high horizontal velocity convergence and 450’ vertical offset (which is the edge of the corrective and warning HAZ). Altitude is set to be in Class A, fastest ownship/intruder velocity. The ownship is above the intruder.
H4	40	0	6550	150	0	8000	180	0	450	Y	Verify corrective and warning alerts are issued for low horizontal velocity convergence and 450’ vertical offset (which is the edge of the corrective and warning HAZ). The ownship is below the intruder
H5	200	0	17000	600	0	16300	180	0	700	Y	Verify preventive alert is issued for high horizontal velocity convergence and 700’ vertical offset (which is the edge of the preventive HAZ). Altitude is set to be in Class A, fastest ownship/intruder velocity. The ownship is above the intruder.
H6	40	0	7300	150	0	8000	180	0	700	Y	Verify preventive alert is issued for low horizontal velocity convergence and 700’ vertical offset (which is the edge of the preventive HAZ). The ownship is below the intruder. This vector can also be used to test non-alerting of warning/corrective alerts.
H7	200	0	17000	600	0	17000	180	> 1.5	0	N	Verify no alerts are issued for high horizontal velocity encounters separated more than 1.5 NM at the CPA and 0’ vertical offset.
H8	200	0	17000	600	0	17000	180	> 1.2, but < 1.5	0	Y	Verify no warning alerts are issued for high horizontal velocity convergence and more than 1.2 NM but less than 1.5 NM horizontal offset at the CPA and 0’ vertical offset. Corrective Alerts are allowed.

ID	Ownship			Intruder			IA	HMD	VMD	Alert	Notes
	GS	VR	Alt	GS	VR	Alt					
H9	200	0	17000	600	0	16150	180	0	> 800	N	Verify no alert is issued for high horizontal velocity convergence and 800' vertical offset (which is the edge of the preventive Non-HAZ). Altitude is set to be in Class A, fastest ownship/intruder velocity. The ownship is above the intruder.
H10	40	0	16150	150	0	17000	180	> 1.5	> 800	N	Verify no corrective or warning alert is issued for low horizontal velocity convergence while in the Non-Hazard Zone in both dimensions. The ownship is below the intruder.
H11	150	0	14000	400	1500	14000	180	< 4000'	0	Y	Verify preventive, corrective and warning alerts are issued when the ownship is level and the intruder is ascending to the fix. The intruder passes through the forward section of the HMD radius.
H12	150	0	14000	400	-1500	14000	180	< 4000'	0	Y	Verify preventive, corrective and warning alerts are issued when the ownship is level and the intruder is descending to the fix. The intruder passes through the aft section of the HMD radius.
H13	150	1000	14000	400	0	14000	180	< 4000'	0	Y	Verify preventive, corrective and warning alerts are issued when the ownship is level and the intruder is ascending to the fix. The intruder passes through the aft section of the HMD radius.
H14	150	-1000	14000	400	0	14000	180	< 4000'	0	Y	Verify preventive, corrective and warning alerts are issued when the ownship is level and the intruder is ascending to the fix. The intruder passes through the forward section of the HMD radius.
H15	150	1000	14000	400	1500	14000	180	< 4000'	0	Y	Verify preventive, corrective and warning alerts are issued when the ownship and the intruder are ascending to the fix. The intruder passes through the forward section of the HMD radius
H16	150	1000	14000	400	-1500	14000	180	< 4000'	0	Y	Verify preventive, corrective and warning alerts are issued when the ownship is ascending and the intruder is descending to fix. The intruder passes through the aft section of the HMD radius
H17	150	1000	14000	400	1500	14000	180	> 1.5	As neces-sary (nec.)	N	Verify no alerts are issued for regular horizontal closure rates with vertical convergence. The intruder passes to the right and ahead of the ownship.
H18	150	1000	14000	400	-1500	14000	180	as nec.	> 800	N	Verify no alerts are issued for regular horizontal closure rates with vertical convergence. The intruder passes above and ahead of the ownship.
H19	150	-1000	14000	400	1500	14000	180	< 4000'	0	Y	Verify that preventive, corrective and warning alerts are issued for regular horizontal closure rates with vertical convergence. The intruder passes through the forward section of the HMD radius. Necessary

ID	Ownship			Intruder			IA	HMD	VMD	Alert	Notes
	GS	VR	Alt	GS	VR	Alt					
H20	150	-1000	14000	400	-1500	14000	180	< 4000’	0	Y	Verify that preventive, corrective and warning alerts are issued for regular horizontal closure rates with vertical convergence. The intruder passes through the aft section of the HMD radius.
H21	150	-1000	14000	400	1500	14000	180	> 1.5	as nec.	N	Verify no alerts are issued for regular horizontal closure rates with vertical convergence. The intruder passes to the left and behind the ownship.
H22	150	-1000	14000	400	-1500	14000	180	as nec.	> 800	N	Verify no alerts are issued for regular horizontal closure rates with vertical convergence. The intruder passes behind and below the ownship.

Table P-15 Detailed Description of Convergence at Fix Test Vectors

ID	Ownship			Intruder			IA	HMD	VMD	Alert	Notes
	GS	VR	Alt	GS	VR	Alt					
C1	150	0	10000	200	0	10000	5	> 4000’	0	Y	Verify alerting for low horizontal and no vertical velocity convergence with small intersect angle. The intruder passes in front of the ownship.
C2	150	1000	10000	150	1500	10000	-5	see desc.	see description (desc.)	Y	Verify alerting for very low horizontal and low vertical closure convergence at a small intersect angle. The intruder passes behind and above the ownship.
C3	150	1000	10000	100	-1500	10000	5	see desc.	see desc.	Y	Verify alerting for low horizontal and high vertical closure convergence at a small intersect angle. The intruder passes behind and below the ownship.
C4	200	-1000	10000	100	1500	10000	-5	see desc.	see desc.	Y	Verify alerting for low horizontal and high vertical closure convergence at small intersect angle. The intruder passes ahead and above the ownship.
C5	200	-1000	14000	400	-1500	14000	5	see desc.	see desc.	Y	Verify alerting for high horizontal and low vertical closure convergence at a small intersect angle. The intruder passes ahead and below the ownship.
C6	150	0	10000	150	0	10000	-60	0	0	Y	Verify alerting for low horizontal velocity convergence with no vertical closure at high but less than 90-degree relative intersect angle. The intruder remains stationary with respect to the ownship, ending in 0/0 separation.
C7	150	1000	10000	100	1500	10000	60	see desc.	> 450, > 700	Y	Verify preventive alerting for low horizontal and vertical closure rate with the ownship overtaking the intruder at high but less than 90-degree relative intersect angle. The ownship passes behind and above the intruder.
C8	150	1000	10000	150	-1500	10000	-60	see desc.	see desc.	Y	Verify alerting for low horizontal and high vertical closure rate at a high but less than 90-degree intersect angle. The ownship passes behind and below the intruder.
C9	200	-1000	14000	400	1500	14000	60	see desc.	see desc.	Y	Verify alerting for high horizontal and low vertical closure rate at high but less than 90-degree intersect angle. The ownship passes ahead and above the intruder.

ID	Ownship			Intruder			IA	HMD	VMD	Alert	Notes
	GS	VR	Alt	GS	VR	Alt					
C10	200	-1000	10000	100	-1500	10000	-60	see desc.	see desc.	Y	Verify alerting for high horizontal and low vertical closure rate at high but less than 90-degree intersect angle. The ownship passes ahead and below the intruder.
C11	150	0	10000	100	0	10000	120	0	0	Y	Verify alerting for low horizontal velocity convergence with no vertical closure at an intersect angle greater than 90 degrees. The intruder passes in front of the ownship
C12	150	1000	10000	150	1500	10000	-120	see desc.	see desc.	Y	Verify alerting for low horizontal and vertical closure rate with the ownship overtaking the intruder at an intersect angle greater than 90 degrees. The intruder passes behind and above the ownship.
C13	150	1000	10000	100	-1500	10000	120	see desc.	see desc.	Y	Verify alerting for low horizontal and high vertical closure rate at an intersect angle greater than 90 degrees. The intruder passes behind and below the ownship.
C14	200	-1000	10000	100	1500	10000	-120	see desc.	see desc.	Y	Verify alerting for high horizontal and high vertical closure rate an intersect angle greater than 90 degrees. The intruder passes ahead and above the ownship
C15	200	-1000	14000	400	-1500	14000	120	see desc.	> 450, > 700	Y	Verify alerting for high horizontal and low vertical closure rate an intersect angle greater than 90 degrees. The intruder passes ahead and below the ownship.
C16	200	0	10000	150	0	10000	-175	0	0	Y	Verify alerting for low horizontal velocity convergence with no vertical closure an intersect angle greater than 90 degrees.
C17	150	1000	10000	100	1500	10000	175	see desc.	see desc.	Y	Verify alerting for low horizontal and vertical closure rate with the ownship overtaking the intruder an intersect angle greater than 90 degrees. The ownship passes behind and above the intruder.
C18	150	1000	10000	150	-1500	10000	-175	see desc.	see desc.	Y	Verify alerting for low horizontal and high vertical closure rate an intersect angle greater than 90 degrees. The ownship passes behind and below the intruder.
C19	200	-1000	14000	400	1500	14000	175	see desc.	see desc.	Y	Verify alerting for high horizontal and high vertical closure rate an intersect angle greater than 90 degrees. The ownship passes ahead and above the intruder.
C20	200	-1000	10000	100	-1500	10000	-175	see desc.	see desc.	Y	Verify alerting for low horizontal and low vertical closure rate an intersect angle greater than 90 degrees. The ownship passes ahead and below the intruder.
C21	150	0	10000	200	0	10000	5	> 1.5	0	N	Verify non-alert for low horizontal and no vertical velocity convergence with small intersect angle. The intruder passes in front of the ownship.

ID	Ownship			Intruder			IA	HMD	VMD	Alert	Notes
	GS	VR	Alt	GS	VR	Alt					
C22	150	1000	10000	150	1500	10000	-5	see desc.	see desc.	N	Verify non-alert for very low horizontal and low vertical closure convergence at a small intersect angle. The intruder passes behind and above the ownship.
C23	150	1000	10000	100	-1500	10000	5	see desc.	see desc.	N	Verify non-alert for low horizontal and high vertical closure convergence at a small intersect angle. The intruder passes behind and below the ownship.
C24	150	0	10000	150	0	10000	-60	0	> 800’	N	Verify non-alert for low horizontal velocity convergence with no vertical closure at high but less than 90-degree relative intersect angle. The intruder remains stationary with respect to the ownship, ending in 0/0 separation.
C25	150	1000	10000	100	1500	10000	60	see desc.	see desc.	N	Verify non-alert for low horizontal and vertical closure rate with the ownship overtaking the intruder at high but less than 90-degree relative intersect angle. The ownship passes behind and above the intruder.
C26	200	-1000	14000	400	1500	14000	60	see desc.	see desc.	N	Verify non-alert for high horizontal and low vertical closure rate at high but less than 90-degree intersect angle. The ownship passes ahead and above the intruder.
C27	150	0	10000	100	0	10000	120	> 1.5	> 800’	N	Verify non-alert for low horizontal velocity convergence with no vertical closure at an intersect angle greater than 90 degrees. The intruder passes in front of the ownship
C28	200	-1000	10000	100	1500	10000	-120	see desc.	see desc.	N	Verify non-alert for high horizontal and high vertical closure rate an intersect angle greater than 90 degrees. The intruder passes ahead and above the ownship
C29	200	-1000	14000	400	-1500	14000	120	see desc.	see desc.	N	Verify non-alert for high horizontal and low vertical closure rate an intersect angle greater than 90 degrees. The intruder passes ahead and below the ownship.
C30	200	0	10000	150	0	10000	-175	> 1.5	> 800’	N	Verify non-alert for low horizontal velocity convergence with no vertical closure an intersect angle greater than 90 degrees.
C31	150	1000	10000	150	-1500	10000	-175	see desc.	see desc.	N	Verify non-alert for low horizontal and high vertical closure rate an intersect angle greater than 90 degrees. The ownship passes behind and below the intruder.
C32	200	-1000	10000	100	-1500	10000	-175	see desc.	see desc.	N	Verify non-alert for low horizontal and low vertical closure rate an intersect angle greater than 90 degrees. The ownship passes ahead and below the intruder.

Table P-16 Detailed Description of High Speed Encounter Test Vectors

ID	Ownship			Intruder			IA	HMD	VMD	Alert	Notes
	GS	VR	Alt	GS	VR	Alt					
S1	200	2500	FL190	600	-3000	FL190	180	< 4000’	0	Y	Verify corrective and warning alerts are issued in encounters with high horizontal and vertical convergence. The ownship is climbing and the intruder is descending when they encounter head-on.
S2	200	-2500	FL190	600	3000	FL190	180	> 1.5	0	N	Verify no alerts are issued in cases of high vertical and horizontal velocity convergence if separated by more than 1.5 NM. The ownship is descending and the intruder is ascending when they encounter head-on
S3	150	-2500	10000	150	3000	10000	0	< 4000’	0	Y	Verify alerting for high relative vertical velocity and no horizontal relative speed. The ownship is descending and the intruder is ascending.
S4	150	0	10000	250	-3000	10000	90	< 4000’	0	Y	Verify alert for crossing encounter with high vertical rate. The ownship is in level cruise.
S5	150	2500	10000	250	0	1000	180	< 4000’	0	Y	Verify Alert for head on encounter with high vertical rate. Target is in level cruise.
S6	150	-2500	10000	150	3000	10000	0	as nec.	as nec.	N	Verify no alert is issued if the intruder remains in the non-hazard zone in a high vertical closure rate scenario. VMD set to be in Non-Hazard Zone
S7	150	0	10000	250	-3000	10000	90	as nec.	as nec.	N	Verify no alert is issued if the intruder remains in the non-hazard zone in a high vertical closure rate scenario. VMD set to be in Non-Hazard Zone
S8	150	2500	10000	250	0	1000	180	as nec.	as nec.	N	Verify no alert is issued if the intruder remains in the non-hazard zone in a high vertical closure rate scenario. VMD set to be in Non-Hazard Zone

Table P-17 Detailed Descriptions of Overtake Test Vectors

ID	Ownship			Intruder			IA	HMD	VMD	Alert	Notes
	GS	VR	Alt	GS	VR	Alt					
O1	40	0	17000	600	0	17000	0	0	0	Y	Verify corrective and warning alerts are issued for high horizontal velocity convergence and 0 vertical offset. The intruder is overtaking the ownship. Altitude is set to be in Class A, fastest ownship/intruder velocity.
O2	150	0	8000	100	0	8000	0	0	0	Y	Verify corrective and warning alerts are issued for low horizontal velocity convergence and 0 vertical offset. The ownship is overtaking the intruder.
O3	40	0	17000	600	0	16550	0	0	450	Y	Verify corrective and warning alerts are issued for high horizontal velocity convergence and 450’ vertical offset (which is the edge of the corrective and warning HAZ). Altitude is set to be in Class A, fastest ownship/intruder velocity. The intruder is below and overtaking the ownship.

ID	Ownship			Intruder			IA	HMD	VMD	Alert	Notes
	GS	VR	Alt	GS	VR	Alt					
O4	150	0	6550	100	0	8000	0	0	450	Y	Verify corrective and warning alerts are issued for low horizontal velocity convergence and 450' vertical offset (which is the edge of the corrective and warning HAZ). The ownship is below and overtaking the intruder.
O5	40	0	17000	600	0	16300	0	0	700	Y	Verify preventive alert is issued for high horizontal velocity convergence and 700' vertical offset (which is the edge of the preventive HAZ). Altitude is set to be in Class A, fastest ownship/intruder velocity. The intruder is above and overtaking the ownship.
O6	150	0	7300	100	0	8000	0	0	700	Y	Verify preventive alert is issued for low horizontal velocity convergence and 700' vertical offset (which is the edge of the preventive HAZ). The ownship is above and overtaking. This vector can also be used to test non-alerting of warning/corrective alerts.
O7	40	0	17000	600	0	17000	0	> 1.5	0	N	Verify no alerts are issued for high horizontal velocity encounters separated more than 1.5 NM at the CPA and 0' vertical offset. The intruder is overtaking the ownship
O8	40	0	17000	600	0	17000	0	> 1.2, but < 1.5	0	Y	Verify no warning alerts are issued for high horizontal velocity convergence and more than 1.2 NM but less than 1.5 NM horizontal offset at the CPA and 0' vertical offset. Corrective Alerts are allowed. The intruder is overtaking the ownship.
O9	40	0	17000	600	0	16150	0	0	> 800	N	Verify no alert is issued for high horizontal velocity convergence and greater than 800' vertical offset (which is the edge of the preventive Non-HAZ). Altitude is set to be in Class A, fastest ownship/intruder velocity. The intruder is overtaking the ownship.
O10	120	0	16150	150	0	17000	0	> 1.5	> 800	N	Verify no corrective or warning alert is issued for low horizontal velocity convergence while in the Non-Hazard Zone in both dimensions. The ownship is overtaking the intruder.
O11	150	0	14000	400	1500	14000	0	< 4000'	0	Y	Verify preventive, corrective and warning alerts are issued when the ownship is level and the intruder is ascending to the fix. The intruder passes through the forward section of the HMD radius.
O12	150	0	14000	400	-1500	14000	0	< 4000'	0	Y	Verify preventive, corrective and warning alerts are issued when the ownship is level and the intruder is descending to the fix. The intruder passes through the aft section of the HMD radius.
O13	150	1000	14000	400	0	14000	0	< 4000'	0	Y	Verify preventive, corrective and warning alerts are issued when the intruder is level and the ownship is ascending to the fix. The intruder passes through the aft section of the HMD radius.

ID	Ownship			Intruder			IA	HMD	VMD	Alert	Notes
	GS	VR	Alt	GS	VR	Alt					
O14	150	-1000	14000	400	0	14000	0	< 4000’	0	Y	Verify preventive, corrective and warning alerts are issued when the ownship is level and the intruder is descending to the fix. The intruder passes through the forward section of the HMD radius.
O15	150	1000	14000	400	1500	14000	0	< 4000’	0	Y	Verify preventive, corrective and warning alerts are issued when the ownship and the intruder are ascending to the fix. The intruder passes through the forward section of the HMD radius
O16	150	1000	14000	400	-1500	14000	0	< 4000’	0	Y	Verify preventive, corrective and warning alerts are issued when the ownship is ascending and the intruder is descending to fix. The intruder passes through the aft section of the HMD radius
O17	150	1000	14000	400	1500	14000	0	> 1.5	as nec.	N	Verify no alerts are issued for regular horizontal closure rates with vertical convergence. The intruder passes to the right and ahead of the ownship.
O18	150	1000	14000	400	-1500	14000	0	as nec.	> 800	N	Verify no alerts are issued for regular horizontal closure rates with vertical convergence. The intruder passes above and ahead of the ownship.
O19	150	-1000	14000	400	1500	14000	0	< 4000’	0	Y	Verify that preventive, corrective and warning alerts are issued for regular horizontal closure rates with vertical convergence. The intruder passes through the forward section of the HMD radius.
O20	150	-1000	14000	400	-1500	14000	0	< 4000’	0	Y	Verify that preventive, corrective and warning alerts are issued for regular horizontal closure rates with vertical convergence. The intruder passes through the aft section of the HMD radius.
O21	150	-1000	14000	400	1500	14000	0	> 1.5	as nec.	N	Verify no alerts are issued for regular horizontal closure rates with vertical convergence. The intruder passes to the left and behind the ownship.
O22	150	-1000	14000	400	-1500	14000	0	as nec.	> 800	N	Verify no alerts are issued for regular horizontal closure rates with vertical convergence. The intruder passes behind and below the ownship.
O23	150	0	6000	140	0	6000		0.25	0	Y	Verify corrective and warning alerts are issued for very slow horizontal closure rate.

Table P-18 Detailed Descriptions of Maneuvering Test Vectors

ID	Ownship			Intruder			IA	HMD	VMD	Alert	Notes
	GS	VR	Alt	GS	VR	Alt					
M1	200	0	8000	200	0	8000	var.	as nec.	as nec.	Y	The ownship and the intruder initially fly parallel with IA = 0, but horizontally offset with the intruder in the Preventive May Alert Zone, causing peripheral guidance. The intruder maneuvers left to cross behind the ownship, causing peripheral guidance to escalate through all levels of alert.
M2	200	0	8000	200	0	8000	var.	as nec.	as nec.	N	The ownship and the intruder initially fly parallel with IA = 0, but horizontally offset with the intruder in the Non-Hazard Zone. The intruder maneuvers right to cross ahead of the ownship, but never causing an alert.
M3	200	0	17000	600	0	17000	var.	as nec.	as nec.	N	The ownship and the intruder initially fly head-on (IA = 180), but horizontally offset with the intruder in Non-Hazard Zone. The intruder maneuvers left to cross behind the ownship, but never causing an alert.
M4	200	0	17000	600	0	17000	var.	as nec.	as nec.	Y	The ownship and the intruder initially fly head-on (IA = 180), but horizontally offset with the intruder in the Non-Hazard Zone. The intruder maneuvers right to cross ahead of the ownship, causing alerts and guidance to escalate through all levels of alert.
M5	200	0	17000	600	0	17000	var.	as nec.	as nec.	Y	The ownship and the intruder initially fly parallel with IA = 0, but horizontally offset with the intruder in the Non-Hazard Zone. The ownship maneuvers left to cross ahead of intruder, causing peripheral guidance to escalate through all three levels of alert.
M6	200	0	17000	600	0	17000	var.	as nec.	as nec.	N	The ownship and the intruder initially fly parallel with IA = 0, but horizontally offset with the intruder in the Non-Hazard Zone. The ownship maneuvers right to cross behind of the intruder, but never causing an alert.
M7	200	0	8000	200	0	8000	var.	as nec.	as nec.	N	The ownship and the intruder initially fly head-on (IA = 180), but horizontally offset with the intruder in Non-Hazard Zone. The ownship maneuvers left to cross in front of the intruder, but never causing an alert.
M8	200	0	8000	200	0	8000	var.	as nec.	as nec.	Y	The ownship and the intruder initially fly head-on (IA = 180), but horizontally offset with the intruder in the Preventive May-Alert Zone, causing peripheral guidance. The intruder maneuvers right to cross behind of the ownship, causing peripheral guidance to escalate through all three levels of alert.
M9	200	var.	17000	600	var.	17000	0	as nec.	as nec.	Y	The ownship and the intruder initially fly parallel with IA = 0, but vertically offset with the intruder below the ownship in the preventive may alert zone, causing a preventive alert. The intruder begins climb to cross behind the ownship, causing preventive alert to increase through corrective and warning alerts.

ID	Ownship			Intruder			IA	HMD	VMD	Alert	Notes
	GS	VR	Alt	GS	VR	Alt					
M10	200	var.	17000	600	var.	17000	0	as nec.	as nec.	N	The ownship and the intruder initially fly parallel with IA = 0, but vertically offset with the intruder above the ownship in the non-hazard zone. The intruder begins a descent to cross ahead of the ownship, never causing an alert.
M11	200	var.	8000	200	var.	8000	180	as nec.	as nec.	N	The ownship and the intruder initially fly head-on (IA=180), but vertically offset with the intruder above the ownship in the non-hazard zone. The intruder begins descent to cross behind the ownship, never causing an alert.
M12	200	var.	8000	200	var.	8000	180	as nec.	as nec.	Y	The ownship and the intruder initially fly head-on (IA= 180), but vertically offset with the intruder below the ownship in the non-hazard zone. The intruder begins a climb to cross ahead of the ownship, causing all three levels of alerts.
M13	200	var.	8000	200	var.	8000	0	as nec.	as nec.	Y	The ownship and the intruder initially fly parallel with IA = 0, but vertically offset with the intruder below the ownship in the non-hazard zone. The intruder begins climb to cross ahead of the ownship, causing all three levels of alerts.
M14	200	var.	8000	200	var.	8000	0	as nec.	as nec.	N	The ownship and the intruder initially fly parallel with IA = 0, but vertically offset with the intruder above the ownship in the non-hazard zone. The intruder begins a descent to cross behind of the ownship, never causing an alert.
M15	200	var.	17000	600	var.	17000	180	as nec.	as nec.	N	The ownship and the intruder initially fly head-on (IA=180), but vertically offset with the intruder above the ownship in the non-hazard zone. The intruder begins descent to cross ahead of the ownship, never causing an alert.
M16	200	var.	17000	600	var.	17000	180	as nec.	as nec.	Y	The ownship and the intruder initially fly head-on (IA= 180), but vertically offset with the intruder above the ownship in the corrective may alert zone. The intruder begins a climb to cross behind of the ownship, causing all three levels of alerts.
M17	200	var.	8000	150	var.	8000	0	as nec.	as nec.	Y	The ownship and the intruder initially fly parallel with IA = 0, but vertically and horizontally offset with the intruder below and to the right the ownship in the non-hazard zone. The intruder begins climb and turn toward the ownship, crossing behind and causing all three levels of alerts.
M18	200	var.	8000	150	var.	8000	180	as nec.	as nec.	N	The ownship and the intruder initially fly head-on with IA = 180, but vertically and horizontally offset with the intruder below and to the right of the ownship in the non-hazard zone. The intruder begins climb and turn toward the ownship, crossing ahead and never causing an alert.
M19	200	var.	8000	300	var.	8000	0	as nec.	as nec.	Y	The ownship and the intruder initially fly parallel with IA = 0, but vertically and horizontally offset with the intruder above and to the left of the ownship in the preventive may alert zone. The intruder begins descent and turn toward the ownship, crossing ahead and causing preventive guidance to escalate through three levels of alert.

ID	Ownship			Intruder			IA	HMD	VMD	Alert	Notes
	GS	VR	Alt	GS	VR	Alt					
M20	200	var.	8000	300	var.	8000	180	as nec.	as nec.	N	The ownship and the intruder initially fly head-on with IA = 180, but vertically and horizontally offset with the intruder above and to the left of the ownship in the non-hazard zone. The intruder begins climb and turn toward the ownship, crossing behind and never causing an alert.
M21	200	1500	6000	250	0	6000	var.	as nec.	as nec.	Y	The ownship and the intruder initially fly parallel with IA = 0, but vertically and horizontally offset with the intruder above and to the right of the ownship in the non-hazard zone. The ownship is climbing throughout entire encounter, and the intruder begins a level turn toward the ownship, causing corrective guidance. Same as M_11 from stressing cases
M22	200	0	6000	250	1500	6000	var.	as nec.	as nec.	Y	The ownship and the intruder initially fly parallel with IA = 0, but vertically and horizontally offset with the intruder below and to the left of the ownship in the non-hazard zone. The intruder is climbing throughout entire encounter, and the ownship begins a level turn toward the ownship, causing warning guidance. Same as M_12 from stressing cases, with OS and TAR reversed.
M23	150	2500	6000	150	0	6000	var.	as nec.	as nec.	Y	The ownship descends through airspace where the intruder is circling at constant turn rate. Corrective guidance is generated. Similar to Alerted TSAA 15-3.
M24	150	2500	6000	150	0	6000	var.	as nec.	as nec.	Y	Verify an alert in an ownship descending through airspace where the intruder is performing a stall maneuver. Similar to Alerted TSAA 15-6
M25	150	2500	6000	150	0	6000	var.	as nec.	as nec.	N	The ownship ascends through airspace where the intruder is circling at constant turn rate. Corrective guidance is generated. Similar to Non-Alerted TSAA 16-2
M26	150	2500	6000	150	0	6000	var.	as nec.	as nec.	N	Verify an alert in an ownship ascending through airspace where the intruder is performing a stall maneuver. Similar to Non-Alerted TSAA 16-5
M27	150	1000	6000	173	0	8000	var.	as nec.	as nec.	Y	Verify a corrective alert on an ownship climbing and turning into a level intruder. Same as #277 from FT4

Table P-19 Detailed Description of Designer Test Vectors

Scenario	Alert	Notes
D1	N/A	Provides basis for correct reception and rejection of ownship data.
D2	N/A	Reserved
D3	N/A	Provides basis for verification that the tracker properly validates ADS-B using active surveillance and/or radar.
D4	N/A	Provides basis for verification of the non-display prioritization order.
D5	N/A	Provides basis for verification of data association performance for the various sensor combinations.
D6	N/A	Provides basis for verification of some requirements related to radar-only alerting special case. Same as H5 but with the ownship and the intruder separated by 4100’.
D7	N/A	Provides basis for verification of track management by tracker. OS at 600 kts, intruder at 600 kts, head on, vertically converging at 10,000 ft/min

D8	N/A	Provides basis for verification of track management by tracker. OS at 200 kts, intruder at 170 kts, head on, vertically converging at 10,000 ft/min
D9	N/A	Provides basis for verification of prioritization of intruders according to the display priority/alert state. Contains multiple intruders that are in a given alert state for the entire track. Intruder 1: TCAS II RA Intruder 2: DAA Warning Alert Intruder 3: DAA Corrective Alert Intruder 4: DAA Preventive Alert Intruder 5: DAA Guidance Traffic Intruder 6-36: Remaining Traffic, increasing distance and time of first appearance.
D10	N/A	Provides basis for verification of some requirements related to radar-only alerting special case.
D11	N/A	Provides basis for verification of some requirements related to the generation of regain well clear guidance in multi-threat scenarios.
D12	N/A	Provides basis for verification of some requirements related to the generation of regain well clear guidance in multi-threat scenarios.
D13	N/A	Provides basis for verification of some requirements related to the generation of regain well clear guidance in multi-threat scenarios.
D14	N/A	Provides basis for verification of some requirements related to the generation of regain well clear guidance in multi-threat scenarios.
D15	N/A	Provides basis for verification of some requirements related to modification of DAA well clear guidance in the presence of a TCAS II RA and a non-cooperative intruder.
D16	N/A	Provides basis for verification of some requirements related to modification of DAA well clear guidance in the presence of a TCAS II RA and a non-cooperative intruder.
D17	N/A	Provides basis for verification of requirement that preventive alerts cannot occur prior to corrective guidance in level-level encounters.

Q APPENDIX Q SENSOR, TRACKING, AND ALERTING ASSESSMENT

Q.1 Introduction

Appendix Q contains modeling and simulation work that was used to validate the DAA tracker performance, alerting algorithms, and sensor performance assumptions. Specifically, this appendix outlines the assessment performed to determine the ability of the representative open-loop DAA MOPS Phase 1 system to meet alerting performance requirements specified in DAA MOPS Paragraph 2.2.4. Additional alerting metrics found in Appendix P were also evaluated, as they provided additional insight into a system's alerting performance. The representative system on which this assessment was performed encompasses:

- Representative surveillance sensor models for ADS-B, active surveillance, and radar
- FAA's ASDP tracking algorithm (discussed in Appendix F) as the representative DAA tracker
- NASA's DAIDLAUS algorithm (discussed in Appendix G) as the representative DAA alerting/guidance algorithm
- Several alerting/guidance algorithm "wrappers," including NASA's Sensor Uncertainty Mitigation (SUM) algorithm (discussed in Appendix G) as a means to mitigate sensor uncertainty and its effect on alerting and guidance performance

Each aspect of the representative system listed above will be discussed in this appendix, with particular focus being placed on the process used to determine minimum surveillance and tracking performance requirements by evaluating the effect that surveillance and tracking error has on alerting performance.

Q.2 Analysis Approach Overview

Figure Q-1 provides a block diagram of the process used to evaluate alerting performance in the presence of multiple levels of surveillance and tracker error, on a per encounter basis.

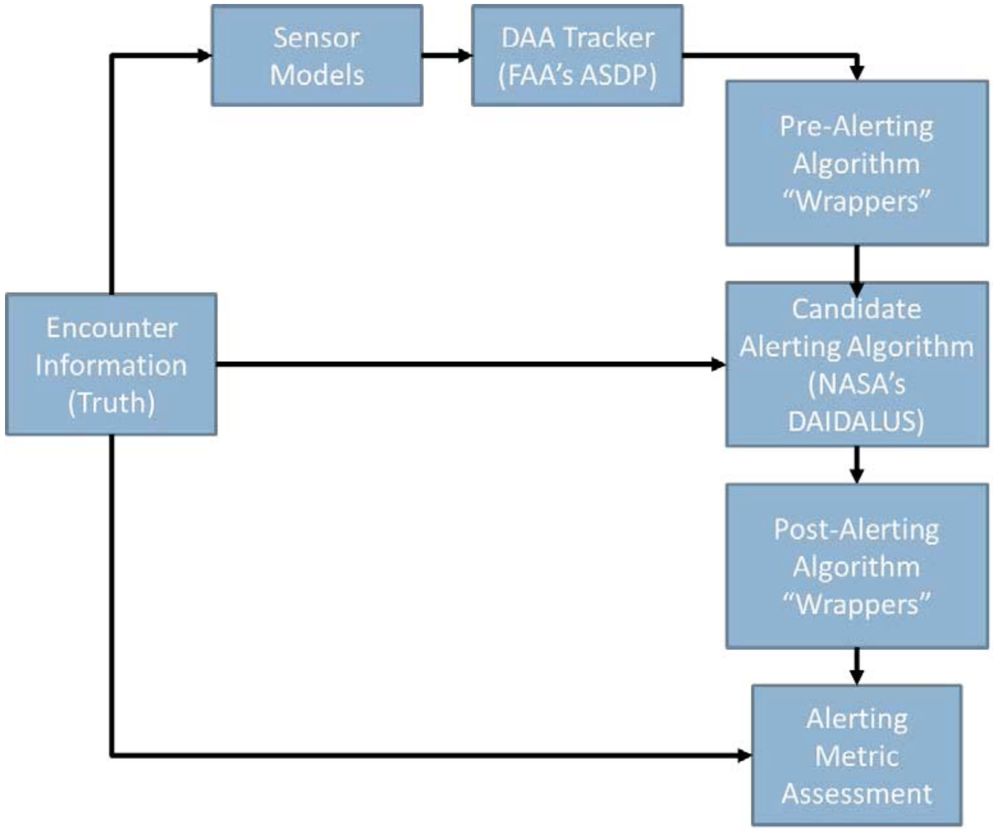


Figure Q-1 **Analysis Process Flow Chart**

Truth data (used to represent perfect surveillance) was obtained from an encounter model created by Massachusetts Institute of Technology Lincoln Laboratory (MIT LL). It is important to note that these encounters are unmitigated in the sense that they do not take into consideration a pilot's or a system's response to alerts. One million encounters were provided for each of the following aircraft-like platforms: High Altitude Long Endurance-Like (HALE-like), Medium-Altitude Long Endurance-Like (MALE-like), and Low-End Performance Representative-Like (LEPR-like). For analysis purposes, these encounters were down-sampled to a smaller subset of encounters, which was then used for initial, truth-based alerting performance assessment. In addition, this encounter set was used as input into sensor models created for the purposes of introducing representative surveillance errors for several of the currently proposed required surveillance sensors (ADS-B, active surveillance, and radar). The output of each sensor model was used as input to the FAA ASDP DAA tracker, which is responsible for processing all of the onboard sensor inputs and forming surveillance tracks. The tracker output was then used as input to the candidate alerting algorithm – the National Aeronautics and Space Administration's (NASA) Detect and AvoID Alerting Logic for Unmanned Systems (DAIDALUS) algorithm. In particular, the alerting logic portion of DAIDALUS, which issues alerts based on linear projections of both the ownship and the intruder in a given encounter. As illustrated by the block diagram in Figure Q-1, several "wrappers" were put in place to account for specific alerting effects introduced by surveillance and tracker noise, which the DAIDALUS algorithm does not specifically address. For example, the large amount of vertical uncertainty that may be present in radar-only encounters was addressed pre-DAIDALUS by treating encounters with a certain range of uncertainty as co-altitude. Additionally, NASA's SUM algorithm was inserted pre-DAIDALUS to assist in the mitigation of sensor uncertainty for all sensors, by creating a cloud of perturbed intruder states. Post-DAIDALUS, an M of N filter was implemented to reduce the amount of alerting jitter, or transitioning, introduced by sensor and/or tracker error which may be undesirable from a pilot-in-command's (PIC) perspective. This process allowed for an open-loop alerting assessment, on a per encounter basis, used to determine minimum surveillance and tracking performance requirements by evaluating the effect that surveillance and tracking error has on alerting performance.

Q.3 Encounter Trajectories

For analysis purposes, two overarching types of encounters were used. The first was "extended – backwards linearly propagated" correlated and the second was simply uncorrelated. Correlated indicates that "the trajectories of each aircraft may involve maneuvers that are correlated to some degree due to prior intervention."[71] The correlated encounter model was originally designed for the shorter time-line of Collision Avoidance systems, therefore had to be extended backwards to account for the longer DAA alerting times. The linear approach to this extension is less than ideal and should be addressed in future iterations. The uncorrelated encounters "involve at least one non-cooperative aircraft (i.e., not using a transponder) or two aircraft flying under Visual Flight Rules (VFR) without fight following (i.e., using a transponder Mode A code of 1200)."[72]

These encounter sets were processed through a screening and rejection process to satisfy the following criteria, for the purpose of assessing/informing statistical-based alerting and tracker requirements, such as average alerting time:

1. Align with assumed UAS dynamics (HALE-Like, MALE-Like, LEPR-Like)
2. Loss of Well Clear (LoWC) 90 seconds or greater into the encounter
3. Encounters must begin within the non-hazard zone (for all alert types), as described in these DAA MOPS, Subparagraph 2.2.4.3.3

Item 2 was implemented to ensure that all encounters contained a LoWC and also violated the alerting hazard zones, as described DAA MOPS Subparagraph 2.2.4.3 and its subdivisions. Item 3 was implemented to ensure that encounters did not begin in an alerting zone, allowing for an alerting progression more representative of that likely to be witnessed with in the NAS.

Once sampled based on the criteria provided above, a single encounter set containing 176 encounters was created. The assumptions used to create this collective data set include:

1. An equal distribution across aircraft platforms (HALE-Like, MALE-Like, and LEPR-Like)
2. 2/3 of the encounters to be correlated
3. 1/3 of the encounters to be uncorrelated

---

[71] Kochenderfer, M.J, et. al, MIT Lincoln Laboratory, Correlated Encounter Model for Cooperative Aircraft in the National Airspace System Version 1.0, 24 October 2008.
[72] Kochenderfer, M.J, et. al, MIT Lincoln Laboratory, Uncorrelated Encounter Model of the National Airspace System Version 1.0, 14 November 2008.

Q.4 Sensor Model Descriptions

In addition to perfect surveillance, alerting and tracking performance was also evaluated in the presence of the following levels of surveillance error/uncertainty:

- Automatic Dependent Surveillance – Broadcast (ADS-B)
- Airborne DAA Radar
- Active Surveillance (TCAS Mode C and TCAS Mode S)
- Ownship Navigation

Q.4.1 ADS-B

Automatic Dependent Surveillance–Broadcast (ADS-B) is a precise satellite-based surveillance system. ADS-B Out uses GPS technology to determine an aircraft's location, airspeed and other data, and broadcasts that information to a network of users, including other airborne aircraft. Although ADS-B has a variety of performance levels, the following assumptions were used to model ADS-B equipped intruder aircraft.

Table Q-1 ADS-B Model Parameters

	State	Absolute Error (per AC) 1-sig	Bias	Time Correlation	Notes
NACp = 7	Horizontal Position	75.6m	0	300 sec	NACp = 185.2m (95%) / 2.45 = 75.6m
	Baro Altitude	0	Per TSAA model		ICAO 10 Annex Bias model used in Traffic Situation Awareness with Alerts (TSAA). Quantization 25ft / 100 ft. Can apply the jitter if you models do not have aerodynamic "noise" turbulence/atmospheric effects. Pending information on whether this effect is implemented in encounter models.
NACv = 2	Horizontal Velocity	1.22m/s	0	300 sec	NACv = 2 (3 m/s 95% / 2.45 = 1.22) horizontal
	Vertical Velocity	1.707m/s (95%)			Per TSAA model. Laplacian distribution. 95_bound = 5.6ft/s Equivalent to 95% bound of 336ft/min, as determined empirically by analysis of installed Version 2 ADS-B avionics.

	State	Notes
Update Rate	dt = 1 second	
Latency Effects (Uncompensated)	<.4sec	Bias transport delay with uniform distribution up to 400msec. This does not address the ADS-R latency effects/contributions.
Detection Range	DR = <20NM	Will be based on Active Surveillance DR. This is due to validation requirement for ADS-B. Per SC228 meeting 14Dec2015, where it was decided we can use ADS-B w/o validation, but there is a cross-over point at which point would be required.
Probability of Reception / Detection	PD: 0.95	Over any 3secs <= 10NM (Based on the reception of both a position and velocity) Over any 7secs > 10NM

Q.4.2 Radar

The radar model embodies the error among readings of range, range rate, azimuth, and elevation. The directional nature of the radar sensor necessitates the modeling of both a detection range and a field of regard. The table below holds values per state describing the modeled amount of error per sigma and the bias associated with each distribution as well as the update rate, detection range, and field of regard state restrictions

Table Q-2 Radar Model Parameters

State	Relative Error 1-sig	Bias	Notes
Range	21.34m (70 ft)	15.24m (50 ft)	White noise model, with bias drawn from a [+/- bias] uniform distribution for each encounter.
Range Rate	3.0m/s (10ft/sec)	2.4m/s (8ft/sec)	White noise model, with bias drawn from a [+/- bias] uniform distribution for each encounter.
Angle (Az/EL)	1 deg	0.5 deg	White noise model, with bias drawn from a [+/- bias] uniform distribution for each encounter.

	State		Notes
Update Rate	dt = 1 second		
Tracking Range / Detection Range (DR)	DR = 5.4NM (<100kts intruder) DR = 6.0NM (100-130kts intruder) DR = 6.7NM (>130kts intruder)	DR Scale Factor Az: [0 30], 1.0, 1.0, 1.0 Az: (30,60], 0.67, 0.78, 0.84 Az: (60, 90], 0.45, 0.52, 0.6 Az: (90, 110], 0.35, 0.43, 0.55	Assumption is intruder size is loosely correlated to speed, hence DR is determined by max speed in across the entire encounter. For additional detail, see the Radar MOPS. Once the track is established, do not perform the scale factor correction. DR scale factors should be linearly interpolated between levels, where the max value in each bin is given.
Field of Regard (FOR)	+/-15 Elevation (Stabilized w/ respect to velocity vector) +/-110 Azimuth		
Probability of Track	Pr(Track) = 1		Will assume perfect detection when inside the DR and FOR

Q.4.3 Active Surveillance

Active surveillance uses the standard TCAS transponder interrogation that provides range, bearing and altitude to the intruder. The following table provides the assumed model performance for both Mode S and Mode C active surveillance.

Table Q-3 Active Surveillance Model Parameters

State	Relative Error 1-sig	Bias	Quant	Notes
Range	15.24m (50 ft)	38.1m (125 ft)		250ft bias for Mode-C
Bearing	[-10, 10deg]: 9deg RMS, 27deg max [-15, -10] or [10, 20deg]: 15deg RMS, 45 deg max			Will assume RMS value = sigma in white noise model
Altitude	0	Per TSAA model	Quantization 25ft / 100 ft (Intruder) / 1ft (Ownship)	Can apply the jitter if you models do not have aerodynamic "noise" turbulence/atmospheric effects. Pending information on whether this effect is implemented.

	State	Notes
Update Rate	1 Hz / 0.2 Hz (Tau > 60)	
Detection Range (DR)	DR = < [20.6, 14.3, 8.0] NM (Mode C) DR = <15.6NM (Mode S)	Front: [0, +/-45deg], Side: [0, +/-45deg], Rear: [0, +/-45deg]
Probability of Detection (PD)	PD: 0.90 (Mode C) PD: 0.95 (Mode S)	Per 1 second epoch
Field of Regard (FOR)	360 deg Azimuth [-15, +20 deg] Elevation Angle	

Q.4.4 Ownship Navigation (NAV) Model

The ownship navigation system is based on Inertial Navigation System/Global Positioning System (INS-GPS) performance, and provides the ownship's position, velocity, and attitude information. The following table provides the assumed performance of the ownship navigation system, which in large part is based on expected ADS-B performance.

Table Q-4 Ownship Navigation (NAV) Model Parameters

	State	Absolute Error (per AC) 1-sig	Bias	Time Correlation	Notes
NACp = 8	Horizontal Position	37.8m	0	300 sec	NACp = 92.6m (95%) / 2.45 = 37.8m
	Baro Altitude	0	Per TSAA model		ICAO 10 Annex Bias model. Quantization 1ft. Can apply the jitter if you models do not have aerodynamic "noise" turbulence/atmospheric effects. Pending information on whether this effect is implemented in encounter models.
NACv = 2	Horizontal Velocity	1.22m/s	0	300 sec	NACv = 2 (3 m/s 95% / 2.45 = 1.22) horizontal
	Vertical Velocity	1.707m/s (95%)			Per TSAA model. Laplacian distribution. 95_bound = 5.6ft/s Equivalent to 95% bound of 336ft/min, as determined empirically by analysis of installed Version 2 ADS-B avionics.
	Attitude	[0.2, 0.2, 0.4] degs			[Roll, Pitch, Yaw/Heading]. Note the heading error is with respect to true north. Per AHRS guidance. White Noise Model, no bias.

Q.5 Tracking Assessment

The DAA track processing function or tracker, such as the Federal Aviation Administration's ASDP tracking algorithm used for this analysis, is responsible for integrating the various surveillance sensor sources into a single integrated track for each unique intruder aircraft within the DAA service volume.

The tracking system must overcome various noise, latency, intermittent missed detections and other surveillance sensor characteristics in order to provide reliable and accurate intruder aircraft state information for the DAA system. Although, many options are available for designing a tracker system for the intended DAA use, the assumed minimum performance assumption is best source selection. Meaning, the DAA system must work independently for each of the surveillance sources under consideration. However, this does not imply that the performance under each of these intruder equipage assumptions will be identical, and it is accepted that the system will behave differently.

The following results illustrate the resulting tracking performance using the assumed sensor performances. This assessment was performed using a collection of test vectors outlined in Appendix P, including the encounter set described in Subsection Q.3.

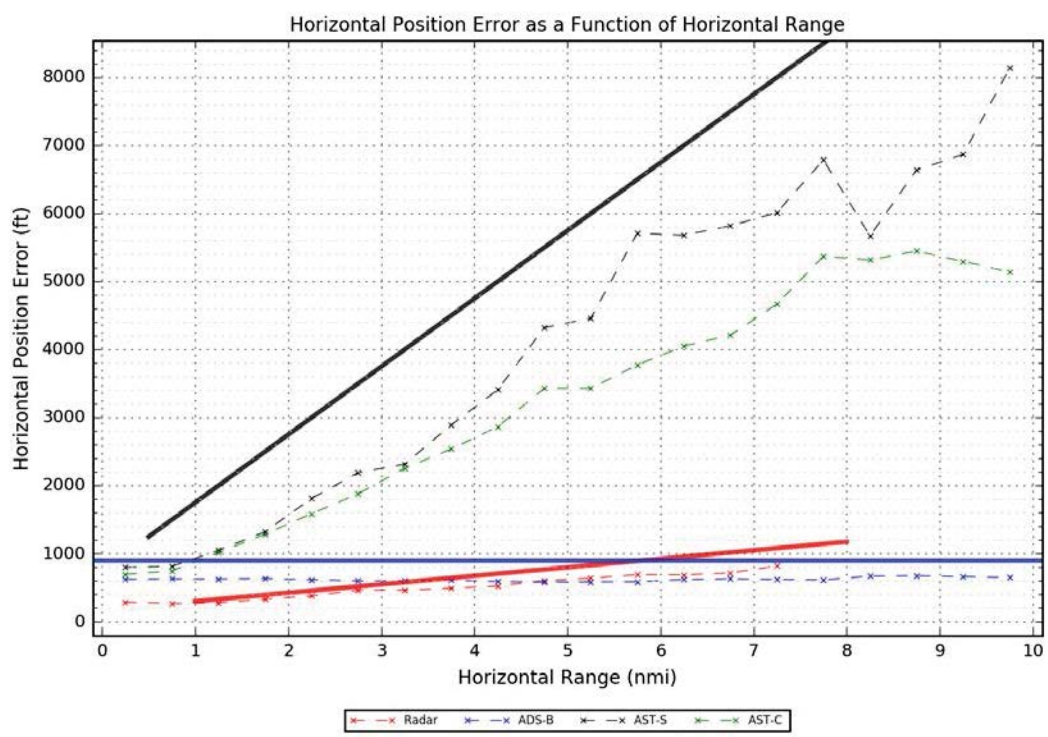


Figure Q-2 **Horizontal Position Tracking Error as a Function of Horizontal Range**

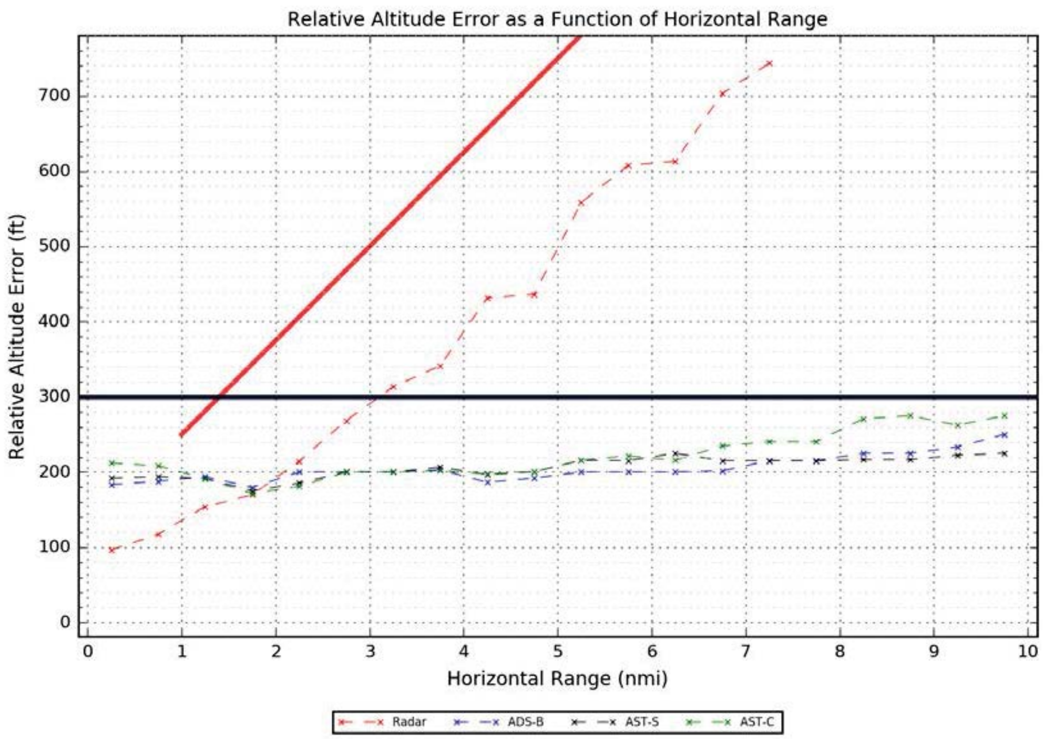


Figure Q-3 **Relative Altitude Tracking Error as a Function of Horizontal Range**

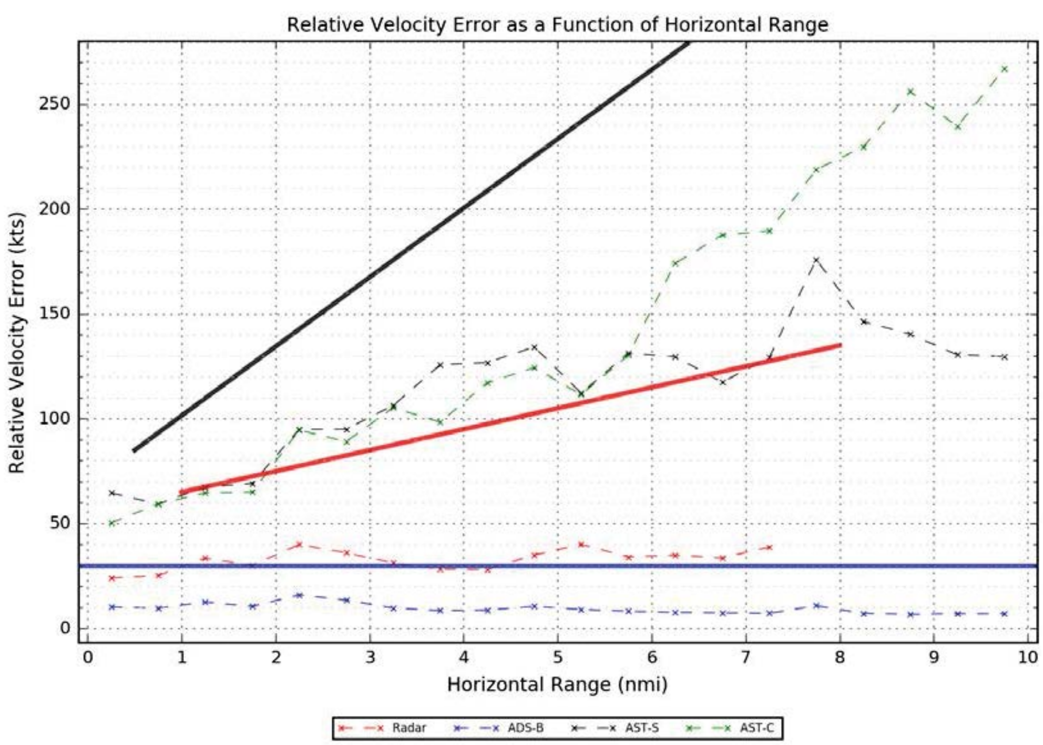


Figure Q-4 **Relative Velocity Tracking Error as a Function of Horizontal Range**

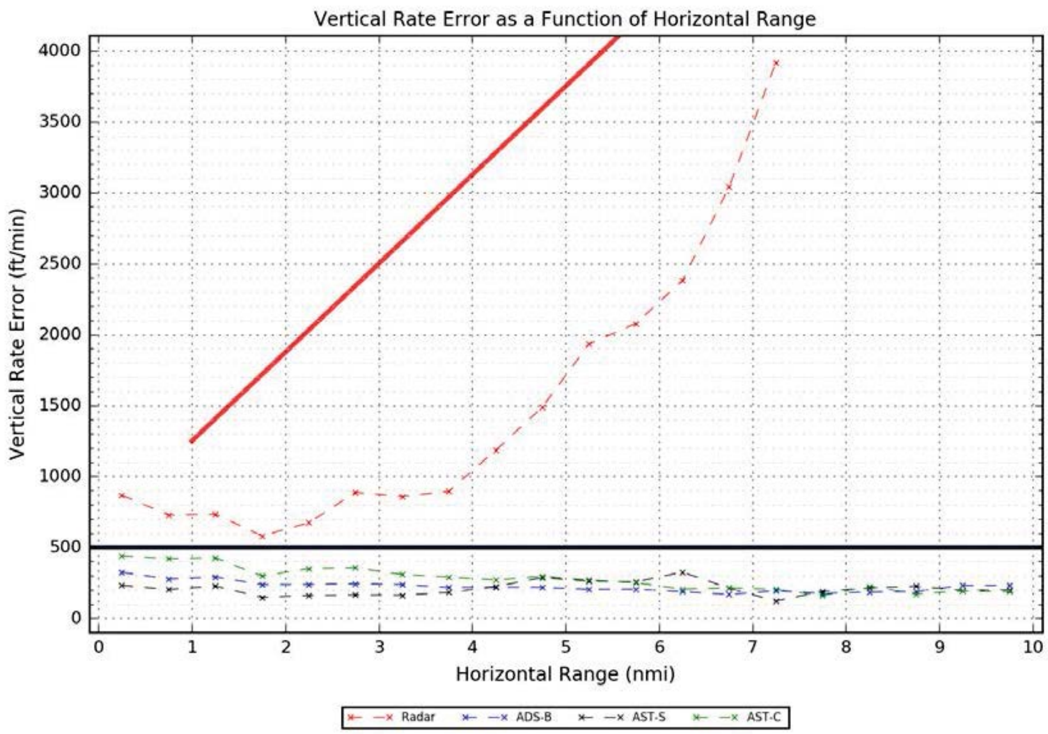


Figure Q-5 **Vertical Rate Tracking Error as a Function of Horizontal Range**

Based on the above results, notional tracking requirements were derived on a per source/sensor basis (solid lines in each figure), which are reflected in DAA MOPS Subparagraph 2.2.3.2.3, namely Table 2-20.

For analysis purposes and understanding the effect that these assumed performances have on DAA alerting, tracker output was only provided by the FAA's ASDP tracker to the alerting/guidance algorithm (DAIDALUS) when a track was deemed valid. Validity was assessed as a track which met all notional horizontal and vertical position and velocity requirements within DAA MOPS Table 2-20 as specified in DAA MOPS Paragraph 2.2.3 for a particular source. The track was deemed no longer valid once all horizontal and vertical position and velocity information no longer met the requirements, for 8 consecutive seconds.

Q.6 DAIDALUS and SUM Algorithm Implementations

Q.6.1 Overview

The purpose of this paragraph is not to provide a detailed description of the NASA algorithms, as both the DAIDALUS and SUM algorithms are described in detail within Appendix G, but rather to outline implementation specifics pertaining to this analysis.

Q.6.2 DAIDALUS

The Detect and Avoid Alerting Logic for Unmanned Aircraft Systems (DAIDALUS) software library is released under the National Aeronautics and Space Administration (NASA)'s Open Source Agreement and is available in Java and C++ http://www.github.com/nasa/wellclear. For the purposes of this analysis however, the

Java version (v1.a2) of the DAIDALUS software was integrated into a MATLAB-based environment and the following configurations were implemented:

```
# V-1.0
# Conflict Bands Parameters
lookahead_time = 180.000000 [s]
left_trk = 180.000000 [deg]
right_trk = 180.000000 [deg]
min_gs = 10.000000 [knot]
max_gs = 700.000000 [knot]
min_vs = -6000.000000 [fpm]
max_vs = 6000.000000 [fpm]
min_alt = 100.000000 [ft]
max_alt = 50000.000000 [ft]
# Kinematic Bands Parameters
trk_step = 1.000000 [deg]
gs_step = 5.000000 [knot]
vs_step = 100.000000 [fpm]
alt_step = 100.000000 [ft]
horizontal_accel = 2.000000 [m/s^2]
vertical_accel = 2.451662 [m/s^2]
turn_rate = 3.000000 [deg/s]
bank_angle = 0.000000 [deg]
vertical_rate = 500.000000 [fpm]
horizontal_nmac = 500.000000 [ft]
vertical_nmac = 100.000000 [ft]
# Recovery Bands Parameters
recovery_stability_time = 2.000000 [s]
# If min_horizontal_recovery is set to 0, TCAS RA HMD is used instead
min_horizontal_recovery = 1.000000 [nmi]
# If min_vertical_recovery is set to 0, TCAS RA ZTHR is used instead
min_vertical_recovery = 450.000000 [ft]
conflict_crit = false
recovery_crit = false
recovery_trk = true
recovery_gs = true
recovery_vs = true
recovery_alt = true
# if ca_bands is true, keep computing recovery bands by reducing min
horizontal/vertical recovery until NMAC
ca_bands = true
# ca_factor is the reduction factor, when computing CA bands
ca_factor = 0.2000
# Contours Parameters
# If contour_thr is set to 0, only conflict contours are computed. Max value
is 180 [deg]
contour_thr = 180.000000 [deg]
# Alert Levels
alert_1_alerting_time = 60.000000 [s]
alert_1_detector = det_1
alert_1_early_alerting_time = 75.000000 [s]
```

alert_1_region = NONE
alert_1_spread_alt = 0.000000 [ft]
alert_1_spread_gs = 0.000000 [knot]
alert_1_spread_trk = 0.000000 [deg]
alert_1_spread_vs = 0.000000 [fpm]
alert_2_alerting_time = 60.000000 [s]
alert_2_detector = det_2
alert_2_early_alerting_time = 75.000000 [s]
alert_2_region = MID
alert_2_spread_alt = 0.000000 [ft]
alert_2_spread_gs = 0.000000 [knot]
alert_2_spread_trk = 0.000000 [deg]
alert_2_spread_vs = 0.000000 [fpm]
alert_3_alerting_time = 30.000000 [s]
alert_3_detector = det_3
alert_3_early_alerting_time = 55.000000 [s]
alert_3_region = NEAR
alert_3_spread_alt = 0.000000 [ft]
alert_3_spread_gs = 0.000000 [knot]
alert_3_spread_trk = 0.000000 [deg]
alert_3_spread_vs = 0.000000 [fpm]
conflict_level = 2
det_1_WCV_DTHR = 1.0000 [nmi]
det_1_WCV_TCOA = 20.0000 [s]
det_1_WCV_TTHR = 35.0000 [s]
det_1_WCV_ZTHR = 750.0000 [ft]
det_2_WCV_DTHR = 1.0000 [nmi]
det_2_WCV_TCOA = 20.0000 [s]
det_2_WCV_TTHR = 35.0000 [s]
det_2_WCV_ZTHR = 450.0000 [ft]
det_3_WCV_DTHR = 1.0000 [nmi]
det_3_WCV_TCOA = 20.0000 [s]
det_3_WCV_TTHR = 35.0000 [s]
det_3_WCV_ZTHR = 450.0000 [ft]
load_core_detection_det_1 = gov.nasa.larcfm.ACCoRD.WCV_TAUMOD
load_core_detection_det_2 = gov.nasa.larcfm.ACCoRD.WCV_TAUMOD
load_core_detection_det_3 = gov.nasa.larcfm.ACCoRD.WCV_TAUMOD

It should be noted that, as the above parameters outline, the DAIDALUS configuration used for this analysis implemented buffered well clear thresholds, meaning that the thresholds associated within issuing an alert were made larger than that of the DAA well clear volume, in horizontal, vertical, and temporal aspects. These larger parameters assist in accounting for dynamic uncertainty, caused by ownship/intruder maneuvering. Extensive analysis was performed to arrive at these values, which is described in "Analysis of Alerting Performance for Detect and Avoid of Unmanned Aircraft Systems."[73]

[73] Smearcheck, Samantha, Calhoun, Sean, Adams, William, Kresge, Jared, Kunzi, Fabrice, "Analysis of Alerting Performance for Detect and Avoid of Unmanned Aircraft Systems," Proceedings of IEEE/ION PLANS 2016, Savannah, GA, April 2016, pp. 710-730.

For the purposes of this analysis, absolute position and velocity information output by the FAA's ASDP tracker, and perturbed by SUM, is provided to DAIDALUS. The DAIDALUS algorithm uses this information to generate alerting and guidance information, which is then adjusted based on the alerting/guidance "wrappers" described in the following paragraphs, and evaluated against the requirements within DAA MOPS Subparagraph 2.2.4.3.4 and its subdivisions, as well as the alerting metrics within Appendix L. This alerting evaluation is described in a subsequent paragraph.

Q.6.3 SUM

NASA's Sensor Uncertainty Mitigation algorithm was incorporated as part of the representative system for the purposes of reducing the effect that sensor-related uncertainty may have on alerting and guidance. SUM uses the position and velocity standard deviations provided by the tracker to augment the sensed position of each intruder with additional "phantom" intruders. SUM uses North, East, and Down sigma values for its perturbations, in addition to several cross-covariance terms, such as East-North position and velocity. It should be noted that for the purposes of this analysis, these cross-covariance terms were assumed to be zero. Additionally, the vertical sigma values associated with cooperative targets were also assumed to be zero. This block of intruders spans possible intruder positions and velocities, based on the provided covariance information, around the sensed intruder position and velocity. The entire block, sensed and "phantom', of intruders is provided to DAIDALUS.

The below scaling parameters were used when implementing SUM, along with a look ahead time of 75 seconds.

Table Q-5 Sensor Uncertainty Mitigation Scaling Factors

Scaling Factor	Value
Horizontal Position	1.5
Horizontal Velocity	0.5
Vertical Position	1.0
Vertical Velocity	1.0

Q.7 Alerting and Guidance "Wrappers"

As mentioned previously, there are some undesirable alerting and guidance characteristics that can be introduced by sensor and/or tracking error, which the DAIDALUS algorithm does not currently take into consideration. To mitigate these effects, several "wrappers" were implemented, either preceding or after DAIDALUS, in the analysis environment, as illustrated in Figure Q-1

Prior to DAIDALUS, all tracks involving radar data were evaluated based on their level of sensor uncertainty at each time epoch, for each encounter. If either an altitude uncertainty of greater than 175' (95%) or a vertical velocity uncertainty of greater than 400 fpm (95%) was observed while the intruder was believed to be within 3000' of the ownship, then that intruder, for that time epoch, was treated as if it were at the same altitude as the ownship, or co-altitude. This was done in attempts to mitigate the large amount of vertical uncertainty that can be present for radar-only cases and also in attempts to align with the alerting and guidance requirements outlined in DAA MOPS Subparagraph 2.2.4.3.5.1 and Subparagraph 2.2.4.4.4 of these MOPS, respectively.

Additionally, NASA's SUM algorithm was implemented prior to DAIDALUS to assist in the mitigation of sensor uncertainty by perturbing the intruder aircraft based on its associated uncertainty. Each actual and perturbed aircraft was then provided to the DAIDALUS algorithm for alerting and guidance evaluation. At each time epoch, for each encounter, the worst-case alert level across all actual and perturbed states was selected and the associated level of guidance was evaluated.

An approach was implemented post-DAIDALUS to account for alerting jitter, or transitions, which can be an undesirable behavior from both an alerting metric and PIC perspective. The approach chosen to mitigate this effect was an M of N filter. This M of N filter required that at least 2 (M) out of 4 (N) time epochs met the associated alerting criteria prior to the issuance of an alert. While several combination of M and N values were evaluated, an M of 2 and an N of 4 were chosen for their ability to provide a significant reduction in alerting jitter, while not increasing undesirable alerting behavior (i.e., late alerts) to a large degree. The same M of N approach and values were used across all sensor sources.

Lastly, an alerting hysteresis filter, with a duration of 4 seconds, was implemented to fulfill the persist alerting requirements outlined in DAA MOPS Subparagraph 2.2.4.3.4. This filter ensured that, once an alert was issued, it remained present for a minimum duration of 4 seconds.

Q.8 ALERTING ASSESSMENT

The alerting performance of the representative DAA open-loop system will be assessed based on each level of surveillance error/uncertainty discussed in Subsection Q.4 and the notional tracker performance discussed in Subsection Q.5. The alerting metrics that will be used for this assessment can be found in Appendix L, with an overview flowchart being provided below. These metrics will be used to validate whether or not the alerting requirements within the MOPS are achievable, and also verify that the representative DAA open-loop system is able to meet the MOPS alerting requirements. Appendix P provides more detail regarding the verification process and the specific test vectors used. Particular focus will be placed on the system's ability to achieve the requirements associated with early alerts, late alerts, and the average alerting time, as found in the DAA MOPS Subparagraph 2.2.4.3.4 and its subdivisions.

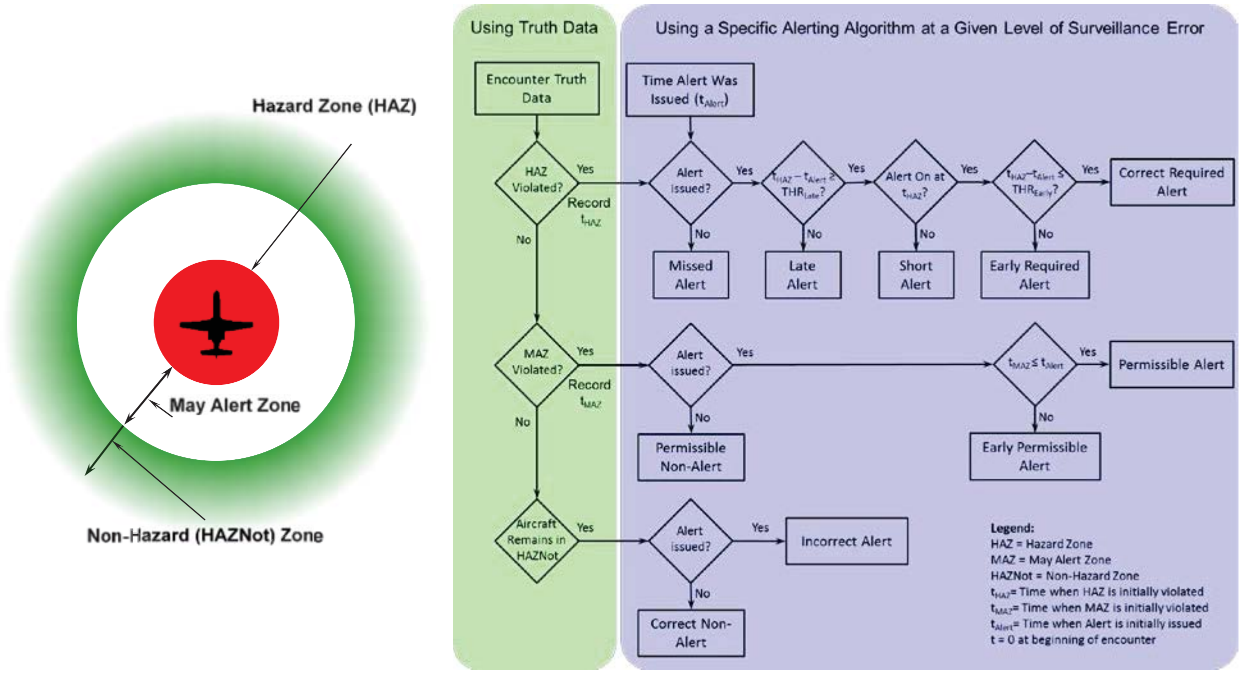


Figure Q-6 **Alerting Metrics Definitions**

The intent of this analysis is to understand the ability of the system to alert to a particular hazard, under various levels of surveillance error and tracker performance. Thus, the encounter set(s) that will be used contain(s) only alerted encounters and this assessment focuses on the metrics outlined within the first row of the flowchart provided in Figure Q-6, which include metrics associated with violating a hazard zone (missed, late, short, early required, and correct required alerts). In addition, average alerting time and alerting jitter will also be evaluated. Alerting jitter refers to the average number of increasing alerting transitions that occur within an encounter set, where an increasing alert transition is considered to be a transition between no alert to any other alert level (preventive, corrective, or warning), as well as from a lower alert level (i.e., preventive) to a more severe alert level (i.e., corrective).

In addition to evaluation against the Validation and Verification (V&V) criteria, this analysis approach and assumptions will also be used to inform the FAA Safety Risk Management (SRM) process, to ensure the system can be safely integrated into the National Airspace System (NAS). However, for the SRM process, it is likely that many additional encounters will be used in order to generate sufficient statistics for the SRM safety case.

Table Q-6 **Alerting Metric Results Given Representative DAA Open-Loop System**

	Surveillance Type	P(Missed Alert)	P(Late Alert)	P(Short Alert)	P(Early Required Alert)	P(Correct Required Alert)	Average Alert Time (s)
Preventive	Truth	0	0	0	0	100 %	57.1
	ADS-B	0	0	1.1 %	1.1 %	97.8 %	60.4
	Radar (Co-Altitude)	6.1 %	9.4 %	3.9 %	3.9 %	76.7 %	58.5
	TCAS (Mode C)	2.8 %	1.1 %	2.8 %	9.4 %	83.9 %	63.3
	TCAS (Mode S)	2.8 %	0.6 %	1.7 %	6.1 %	88.9 %	54.4
Corrective	Truth	0	0	0	0	100 %	58.0
	ADS-B	1.1 %	0	2.8 %	3.4 %	92.7 %	63.9
	Radar (Co-Altitude)	5.1 %	7.9 %	7.9 %	9.6 %	69.5 %	65.4
	TCAS (Mode C)	4.0 %	1.7 %	6.2 %	10.2 %	77.9 %	66.8
	TCAS (Mode S)	3.4 %	0.6 %	4.5 %	6.8 %	84.7 %	58.6
Warning	Truth	0	0	0	0	100 %	34.5
	ADS-B	1.1 %	0	3.4 %	1.7 %	93.8 %	43.7
	Radar (Co-Altitude)	5.1 %	7.9 %	7.9 %	9.0 %	70.1 %	45.1
	TCAS (Mode C)	4.0 %	1.1 %	6.8 %	14.7 %	73.4 %	50.9
	TCAS (Mode S)	3.4 %	0.6 %	5.1 %	10.2 %	80.7 %	48.7

Table Q-7 **Alerting Jitter Results Given Representative DAA Open-Loop System**

Surveillance Type	Average Number of Increasing Alert Transitions
Truth	2.5
ADS-B	3.8
Radar (Co-Altitude)	1.6
TCAS (Mode C)	4.0
TCAS (Mode S)	3.2

This Page Intentionally Left Blank