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Minimum Operational Performance Standards (MOPS) for Traffic Alert and Collision Avoidance System II (TCASII) Hybrid Surveillance

RTCA DO-300A
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Prepared by: SC-147

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FOREWORD

This report was prepared by Special Committee 147 (SC-147) and approved by the RTCA Technical Management Committee on March 20, 2013. It provides modifications to RTCA/DO-185B, *Minimum Operational Performance Standards for Traffic Alert and Collision Avoidance System II (TCAS II) Airborne Equipment* that are required to implement hybrid surveillance techniques in conjunction with the other functions of that equipment.

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- 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.

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1 PURPOSE AND SCOPE

1.1 Introduction

This document contains Minimum Operational Performance Standards for Traffic Alert and Collision Avoidance System II (TCAS II) equipment that uses hybrid surveillance. Hybrid surveillance includes both passive surveillance using the Mode S extended squitter as well as the active interrogations used in TCAS II systems built in compliance with RTCA/DO-185B. These standards specify system characteristics that should be useful to designers, manufacturers, installers and users of the equipment.

Compliance with these standards is recommended as one means of assuring that the equipment will perform its intended function satisfactorily under all conditions normally encountered in routine aeronautical operation. Any regulatory application of this document is the sole responsibility of appropriate governmental agencies.

Section 1 of this document provides information needed to understand the rationale for equipment characteristics and requirements stated in the remaining sections. It describes typical equipment operations and operation goals, as envisioned by the members of RTCA Special Committee 147 (SC-147) and EUROCAE Working Group 75 and establishes the basis for the standards stated in Sections 2 and 3. Definitions and assumptions essential to proper understanding of this document are also provided in this section.

Section 2 contains the minimum operational performance standards for the equipment. These standards specify the required performance under standard environmental conditions. Also included are recommended bench tests 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.

This document considers an equipment configuration as specified in Ref. A with the following additions:

- The TCAS Processor Unit is implemented with the ability to decode the extended squitter. This was identified as an optional feature in Ref. A, §1.3.2.1. The TCAS Processor Unit must meet the additional requirements (defined in Ref. C) of a receiver that is shared between TCAS and a 1090 MHz Automatic Dependent Surveillance-Broadcast (ADS-B) receiver.

- The TCAS Processor Unit is provided own position latitude and longitude information from the aircraft and associated quality parameters.

- The TCAS Processor Unit is provided own aircraft ground speed from the aircraft.

This document considers an equipment configuration identified in the System Overview, §1.2. Operational performance standards for functions or components that refer to equipment capabilities that exceed the stated minimum requirements are identified as optional features.

"TCAS equipment" as used herein includes all components or units necessary (as determined by the manufacturer or installer) for the equipment to perform its function properly with the exception of the Mode S transponder. It should not be inferred that each TCAS equipment design will necessarily have all components or units in separate packages. This will depend on the specific design chosen by the manufacturer.

If the equipment implementation includes a computer software package, the guidelines contained in RTCA Document No. DO-178B, *Software Consideration in Airborne Systems and Equipment Certification*, should be considered.

1.2 System Overview

TCAS with hybrid surveillance is used as a means to decrease Mode S interrogations. Hybrid surveillance allows TCAS to use passive surveillance instead of active surveillance to track intruders that meet certain criteria and are not projected to be near-term collision threats. Passive surveillance is surveillance performed using data broadcast from other aircraft. Passive surveillance data is provided by an on-board navigation source that is typically based on GPS. For the TCAS hybrid surveillance defined in this document, the passive surveillance data is broadcast and received through the use of Mode S extended squitter, i.e., 1090 MHz ADS-B, which is described in Ref. C. Active surveillance uses the standard TCAS/transponder interrogations/replies that provide range, bearing and altitude to the intruder.

There are two passive surveillance techniques: the first is called ‘extended hybrid surveillance’ and can be used when an intruder’s ADS-B position data meets certain quality and power requirements. The second technique, called ‘hybrid surveillance’ or ‘standard hybrid surveillance,’ must use TCAS active interrogations to validate the passive surveillance position.

Figure 1 – 1 illustrates how the system transitions from extended hybrid surveillance through hybrid surveillance to active surveillance as a function of collision potential. When the intruder is far from being a threat, it is tracked with passive surveillance. If the intruder meets all conditions for extended hybrid surveillance, the intruder is tracked using ADS-B data exclusively. Otherwise hybrid surveillance is used, and the passive surveillance position is validated every 10 to 60 seconds with a TCAS active interrogation. When the intruder comes close to being a collision threat in altitude and range (referred to in this section as a near threat), it is tracked with active surveillance at a 1 Hz interrogation rate. The conditions that determine that an intruder is a near threat ensure that the system transitions to active surveillance in time to issue a traffic advisory (TA) and a resolution advisory (RA) if needed.

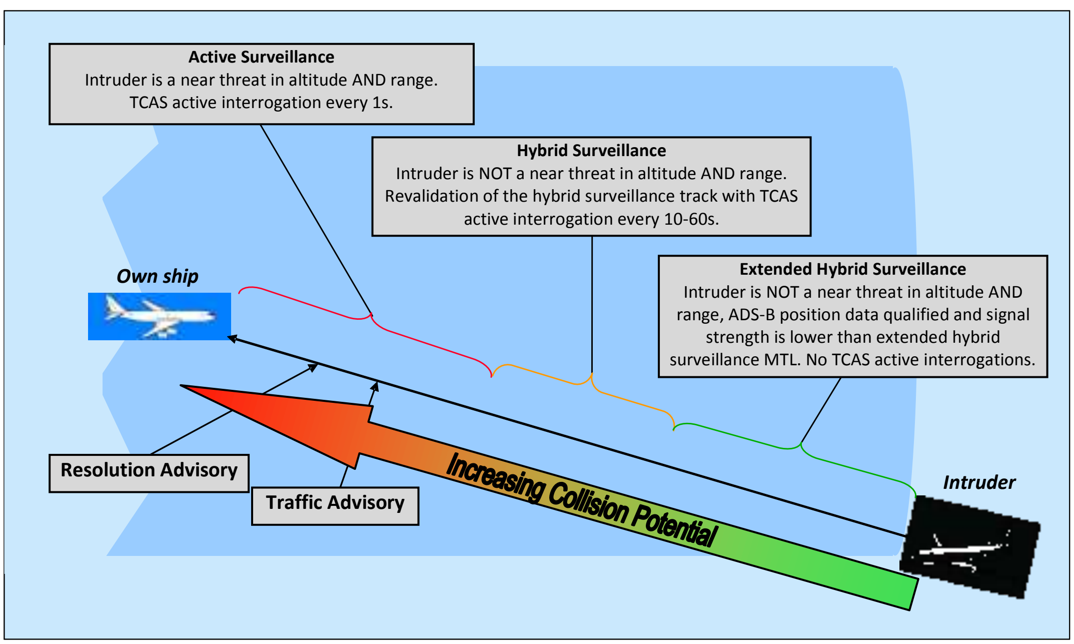

Figure 1 - 1. Transition from Passive to Active Surveillance as a Function of Collision Potential

Figure 1 – 2 and Figure 1 – 3 are flow diagrams illustrating possible transitions between surveillance methods for surface and airborne operation.

Figure 1 – 2 illustrates the transitions between the three surveillance techniques (active, hybrid, and extended hybrid) when own ship is Taking Off/Airborne (§2.2.8). Intruder tracks can be established either exclusively by extended hybrid surveillance or exclusively by active surveillance. The system initiates an intruder track with extended hybrid surveillance (§2.2.5.2) when own and intruder data meet data quality requirements (§2.2.5.2.1) and the intruder's signal strength is lower (weaker) or equal to the extended hybrid surveillance MTL (§2.2.5.2.3, §2.2.5.2.4). In all other cases the system initiates an intruder track using active surveillance.

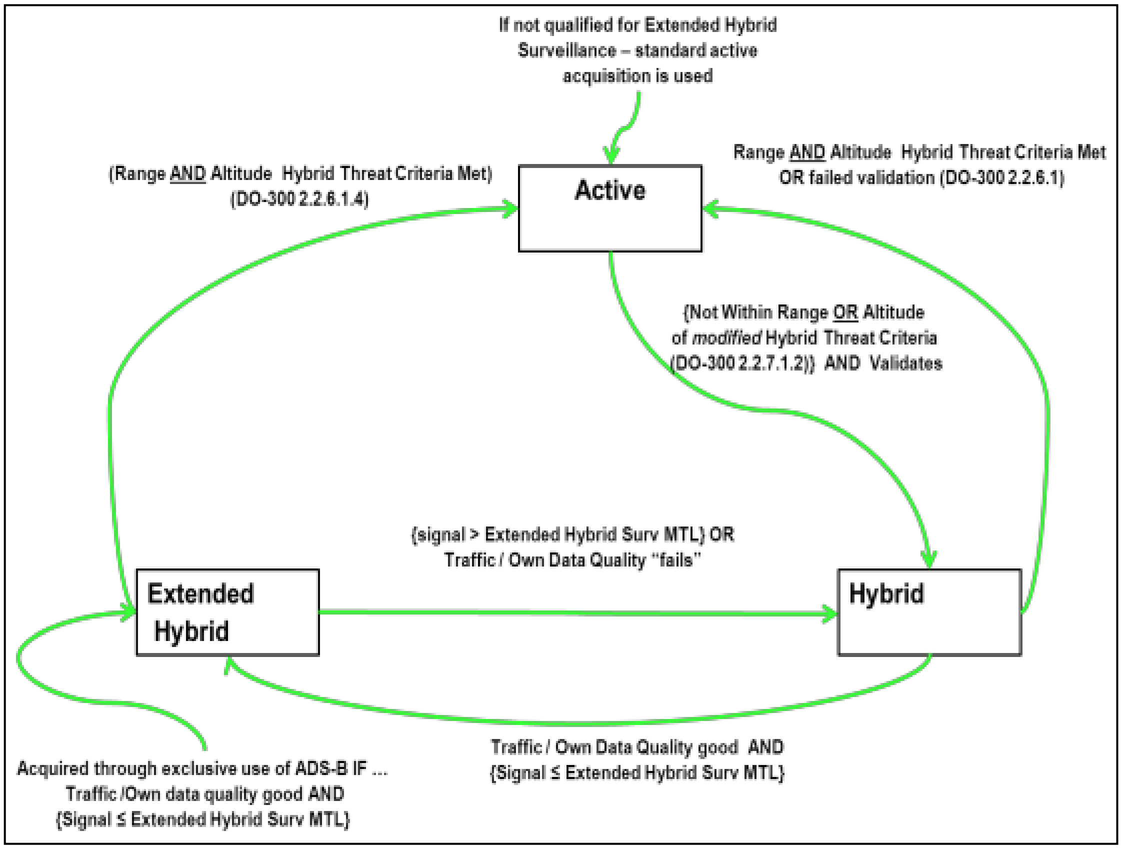

Figure 1 - 2. Extended Hybrid Surveillance State Transition Diagram (Own Ship Taking Off / Airborne)

Once under active surveillance, if an intruder is not a near threat in both altitude and range and its passive position data is successfully validated (§2.2.6.1.2, §2.2.6.3), the intruder can be tracked using hybrid surveillance, and the passive surveillance data is revalidated regularly (§2.2.7.5). If revalidation fails, the intruder transitions to active surveillance. The intruder transitions from hybrid to extended hybrid surveillance (§2.2.7.2.2.2) if own and intruder data meet data quality requirements (§2.2.5.2.1) and the intruder's signal strength is lower or equal to the extended hybrid surveillance MTL (§2.2.5.2.3). Once the intruder is tracked passively (extended hybrid or hybrid surveillance), the hybrid threat status is monitored once per second (§2.2.6.1.4). If an intruder becomes a near threat in range and altitude, it transitions to active surveillance. When the passive data are available but not qualified, or the intruder's signal strength is higher (stronger) than the extended hybrid surveillance MTL (§2.2.5.2.3, §2.2.5.2.4), the intruder transitions from extended hybrid surveillance to hybrid surveillance (§2.2.7.1.3).

A track is maintained under extended hybrid surveillance (§2.2.7.2.1) as long as own and intruder data meet data quality requirements, (§2.2.5.2.1) and the intruder's signal strength is lower or equal to the extended hybrid surveillance MTL and the intruder is not a near threat in range and altitude.

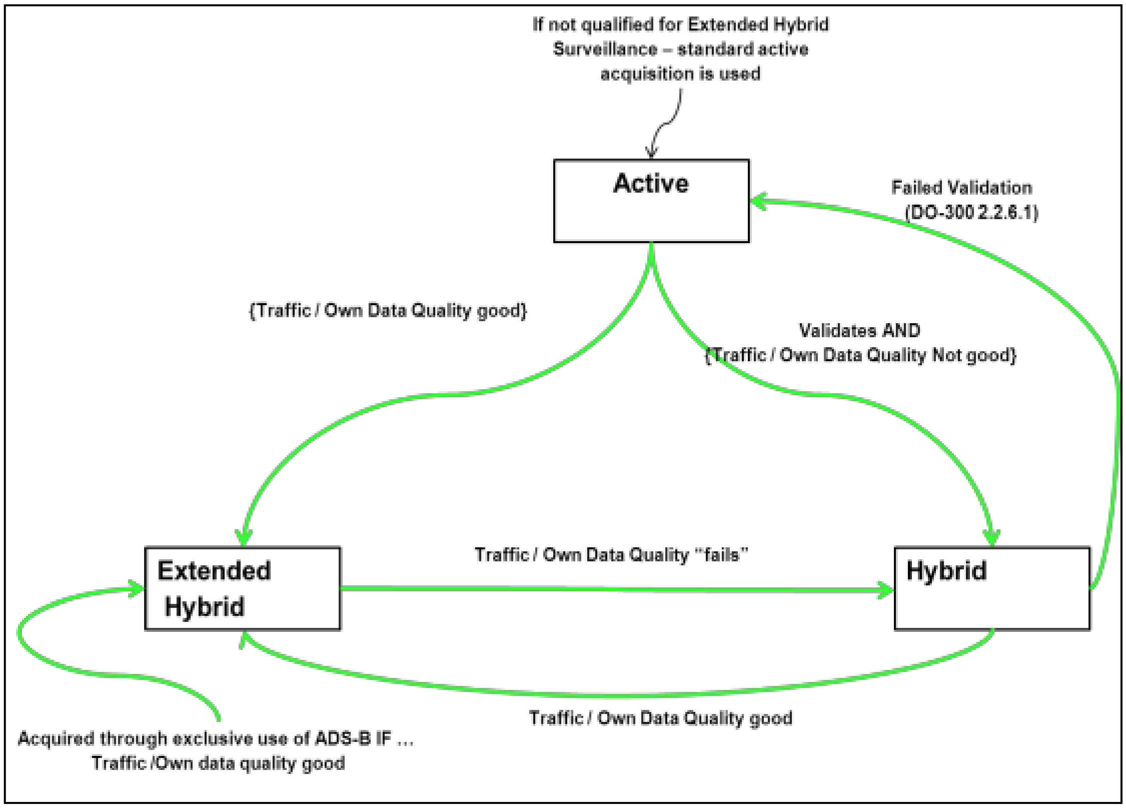

Figure 1 - 3. Extended Hybrid Surveillance State Transition Diagram (Own Ship Operating on Surface)

Figure 1 – 3 illustrates the transitions between the three surveillance techniques when own ship is operating on the surface (§2.2.8). In contrast to airborne operation (Figure 1 – 2), strong signal level does not require active surveillance acquisition (§2.2.5.2), and signal level is not a factor in determining transitions between extended hybrid and hybrid surveillance (§2.2.7.2.2.2, §2.2.7.1.3). Data quality (§2.2.5.2.1) is the only and sufficient condition for transition to extended hybrid surveillance, even directly from active surveillance (§2.2.7.2.2.1). While operating on the surface, the near threat criteria are not required, and therefore the transition between hybrid and active surveillance is based only on (re)validation results (§2.2.6.3, §2.2.7.5). Direct transition from extended hybrid to active is not permitted.

While TCAS is on the ground it only provides traffic information to the pilot. While not an intended function of TCAS when own aircraft is on the ground, it is still desirable to not present inaccurate information. The data quality requirement for entry into extended hybrid surveillance is sufficient guarantee for that purpose. Without that guarantee, intruders under hybrid surveillance require validation/revalidation to ensure that erroneous position reports are not displayed to the pilot.

The system block diagram (Figure 1 - 4) of TCAS with hybrid surveillance highlights the differences (in gray) from a minimum TCAS II defined in Ref. A.

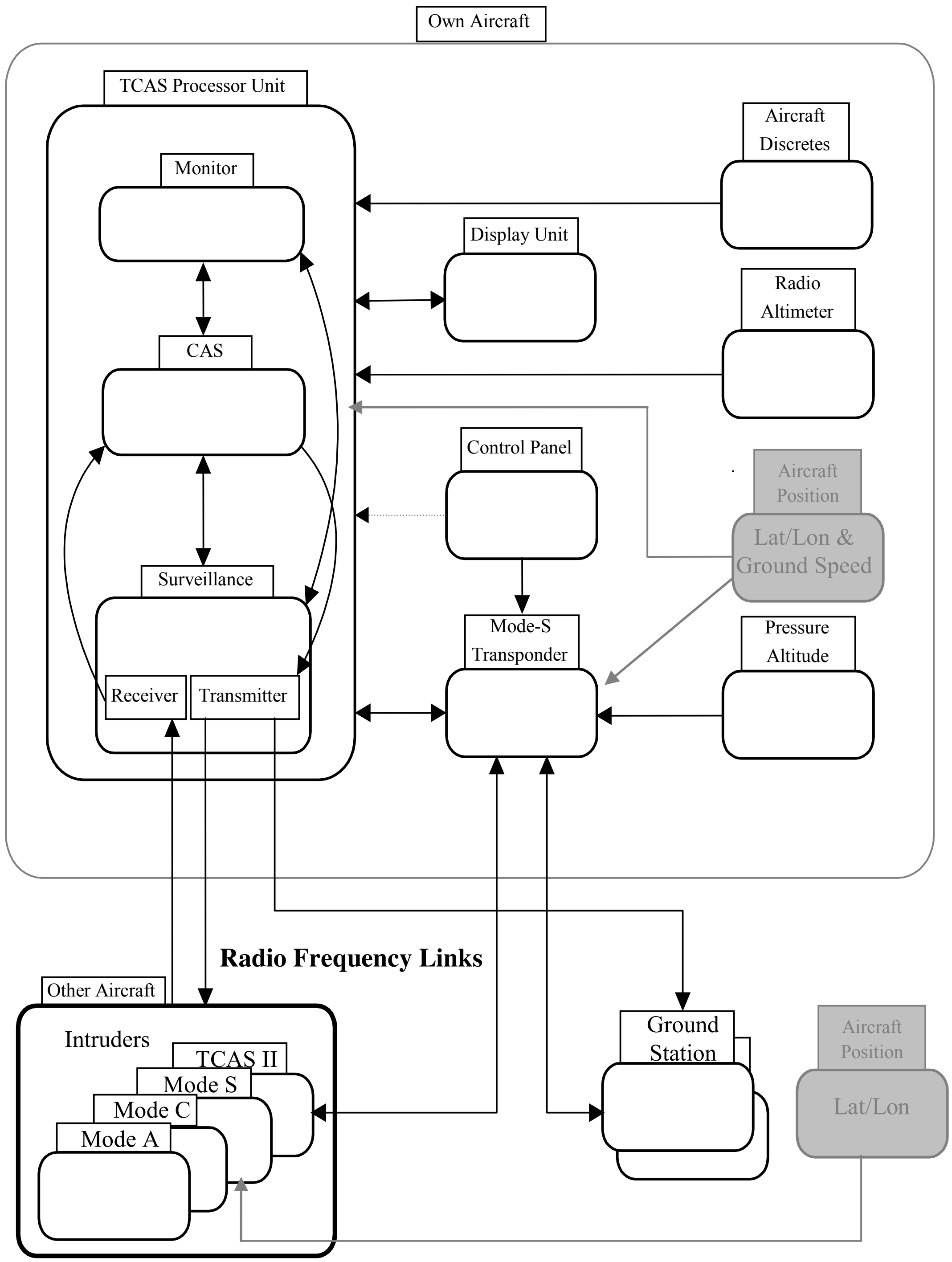

Figure 1 - 4. System Block Diagram

Note: Figure 1 - 4 depicts the functional components of TCAS as well as the ancillary functional components of the TCAS-equipped aircraft and the functional components of other aircraft and the ground Air Traffic Management system that enable full TCAS operation. In Figure 1 - 4, the system components on the TCAS-equipped aircraft are depicted in the box labeled "Own Aircraft". These include:

1. *Aircraft discretes – Discrete inputs such as those which cause TCAS to alter its RA processing when own aircraft is climb inhibited because it is at its ceiling altitude.*

2. *Radio altimeter, pressure altitude, ground speed and latitude / longitude inputs.*

3. *TCAS processor unit – The principal TCAS functional unit which includes the TCAS performance monitor, collision avoidance system (CAS) logic and the surveillance subsystem, including the TCAS receiver and transmitter.*

The "Other Aircraft" box in Figure 1 - 4 depicts the equipage on other aircraft which is necessary for TCAS to track and to issue RAs and/or TAs against them. Finally, Figure 1 - 4 provides an indication that "Ground Stations" (e.g. a Mode S ground sensor or a specially designed ground receiver) may provide commands to or receive information from TCAS.

1.3 Intended Function

The intended function of a TCAS with hybrid surveillance as defined in this minimum performance specification includes all the functionality of TCAS defined in Ref. A with the addition of the hybrid surveillance function.

The intent of hybrid surveillance is to reduce the TCAS interrogation rate through the judicious use of the ADS-B data provided via the Mode S extended squitter without any degradation of the safety and effectiveness of the TCAS.

While TCAS is operating on the airport surface airborne intruders will be displayed as Non-Threat or Proximate traffic, but not as a Traffic Advisory. Previous versions of TCAS do display airborne intruders as Traffic Advisories while own aircraft is on the ground. This MOPS eliminates this feature in order to use passive surveillance more exclusively while on the airport surface, thus reducing the 1090 MHz channel utilization of TCAS operators who enable the TCAS on the ground. Although the operation of TCAS on the airport surface has become common practice, such use was not intended. In particular, Traffic Advisories and the underlying logic were not designed for use while own aircraft is operating on the airport surface.

Loss of the hybrid surveillance function does not degrade the minimum TCAS function defined in Ref. A.

1.4 Operational Goals

The goals of a TCAS with hybrid surveillance are the same as those of a minimum TCAS identified in Ref. A with the following additions:

- No degradation of the existing TCAS collision protection.

- Reduced TCAS interrogation rate along with reduction in associated replies resulting in decreased 1030 MHz and 1090 MHz utilization.

- Maintain tracks that might have been dropped from the display in high density traffic areas due to interference limiting algorithms of Ref. A.

Note: Ref. A states the minimum number of intruder aircraft that must be displayed – no change in this requirement is implied. However, due to the reduction in TCAS interrogations provided by hybrid surveillance, TCAS will be less impacted by interference limiting and therefore be able to maintain more tracks for display.

1.5 Assumptions

The assumptions in Ref. A apply with the additional hybrid surveillance assumption identified below:

It is assumed that the barometric altitude provided in Mode S replies is the same barometric altitude reported in the ADS-B extended squitter.

1.6 Test Procedures

The test procedures specified in this document are intended to be used as one means of demonstrating compliance with the performance requirement. Although specific test procedures are cited, it is recognized that other methods may be preferred. 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.

The order of tests specified suggests that the equipment be subjected to a succession of tests as it moves from design and design qualification to operational use.

a. Environmental Tests

   Environmental test requirements are specified in §2.3. 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 in actual operations.

b. Bench Tests

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

c. Installed Equipment Tests

The installed equipment test procedures and their associated limits 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, installed equipment tests may be used in lieu of bench test simulation of such factors as power supply characteristics and interference from or to other equipment installed on the aircraft. Installed tests are normally performed under two conditions:

- With the aircraft on the ground, using simulated or operational system inputs.

- 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.

1.7 Definition of Terms

Active Surveillance – The use of TCAS interrogations and subsequent replies to update or acquire a TCAS track.

Airborne Position Message – A Mode S extended squitter (DF=17) that contains aircraft position and altitude or an ADS-B report updated for position.

ADS-B Report – A report from a Ref. C compliant ADS-B report generator function which contains ICAO address, latitude, longitude, altitude, NIC, NACp, SIL, and Air/Ground information.

Crosslink Interrogation – A Mode S UF=0 interrogation with RL=1. This interrogation can be used to request the aircraft position data from another aircraft's transponder that would be included if an Airborne Position Message was squittered at that instant.

Established Track – A track that has been acquired as specified in Ref. A, §2.2.4.6.2.2.2 (Acquisition) or per §2.2.5.2 of this document, and subsequently maintained under either active or passive surveillance.

Estimated Signal Strength – The signal strength associated with an aircraft used in determining if an aircraft is above or below the Extended Hybrid Surveillance MTL.

Extended Hybrid Surveillance MTL – A signal threshold used in determining whether an aircraft qualifies for Extended Hybrid Surveillance (see §2.2.5.2.3).

Extended Hybrid Surveillance Track – A track that is being maintained with qualified Airborne Position Messages without validating active interrogations.

Extended Squitter – A long 112-bit unsolicited reply, DF=17 Mode S squitter.

Horizontal Position Integrity Bounds – Describes an integrity containment region about the reported position, within which the true position of the surveillance position reference point is assured to lie at the reported time of applicability.

Horizontal Position Uncertainty – 95% accuracy bound on horizontal position equivalent to Estimated Position Uncertainty (EPU), which is defined as the radius of a circle, centered on the reported position, such that the probability of the actual position being outside the circle is 0.05. When reported by a GPS or GNSS system, EPU is commonly called Horizontal Figure of Merit (HFOM).

Hybrid Surveillance – There are two definitions:

(1) The combined use of active and validated passive surveillance to update a TCAS track. This general definition of the term is used primarily in the introduction section.

(2) A specific surveillance technique that uses validated ADS-B position messages for surveillance. This is a term with specific meaning used in §2 which is differentiated from extended hybrid surveillance.

Passive Surveillance – The use of Airborne Position Messages to update a TCAS track. This is a general term that covers both Hybrid and Extended Hybrid Surveillance.

Qualification – The function of verifying that the quality of the Airborne Position Messages associated with a passive surveillance track is sufficient for use in Extended Hybrid Surveillance.

Surface Position Message – A Mode S extended squitter (DF=17) that contains aircraft surface position or an ADS-B report updated for surface position.

Surveillance Mode – The data field provided as part of each surveillance report provided to the CAS logic. This field has two values: Reduced and Normal. Reduced implies a 5 sec nominal surveillance update rate and Normal implies a 1 sec nominal surveillance update rate for active tracks. *The CAS logic will only generate TAs and RAs for intruders in normal surveillance mode*.

Surveillance Update Interval – Nominally 1 sec per Ref. A.

Standard TCAS MTL – -74 ±2 dBm per Ref. A.

Revalidation - The validation that is performed after a track transitions to passive surveillance.

Validation – The function of comparing range, bearing, and altitude derived from active surveillance with range, bearing, and altitude derived from passive surveillance. Validation in this document refers to this comparison when it is performed after a track is acquired under active surveillance in order to determine whether it can transition to passive surveillance.

1.8 Abbreviations

ADS-B: Automatic Dependent Surveillance – Broadcast.

ADS-R: Automatic Dependent Surveillance – Re-broadcast

AQ: Acquisition.

ARTS: Automated Radar Terminal System.

ATC: Air Traffic Control.

ATCRBS: Air Traffic Control Radar Beacon System.

BDS: B-Definition Subfield.

CAS: Collision Avoidance System.

CC: Crosslink Capable.

CPR: Compact Position Report.

dBm: Decibels (dB) Relative to One Milliwatt.

DEG: Degrees.

DF: Downlink Format.

DoD: Department of Defense.

EADS: European Aeronautic Defense and Space Company.

FPM: Feet Per Minute.

ft: Feet.

g: The standard value of gravitational acceleration at sea level on Earth.

GPS: Global Positioning System.

HAE: Height Above Ellipsoid.

Hz: Hertz.

ICAO: International Civil Aviation Organization.

IFF: Identification Friend or Foe.

INS: Inertial Navigation System.

kt: Knot.

LSB: Least Significant Bit.

m: Meter.

mbar: Millibar.

ME: Extended Squitter Message.

MHz: Megahertz.

MIT: Massachusetts Institute of Technology.

MOPS: Minimum Operational Performance Standards.

msec: Millisecond.

MTL: Minimum Trigger Level.

NAC: Navigation Accuracy Category

NACp: Navigation Accuracy Category - Position

NAVSTAR: Navigation Signal Timing and Ranging.

NIC: Navigation Integrity Category

NM: Nautical Miles.

NMAC: Near Mid-Air Collision.

NTA: Number of TCAS-equipped Aircraft.

Q-bit: Quantization-bit

RA: Resolution Advisory.

Ref: Reference.

RFLG: Range Flag.

RL: Reply Length.

RMS: Root Mean Square.

SDA: System Design Assurance

SIL: Source Integrity Level

sec: Second(s).

SEM: Signal Environment Model.

SSR: Secondary Surveillance Radar.

T: Time.

TA: Traffic Advisory.

TCAS: Traffic Alert and Collision Avoidance System.

TIS-B: Traffic Information System – Broadcast.

UF: Uplink Format.

WGS 84: World Geodetic System 1984.

1.9 References

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

Ref. Title

A. "Minimum Operational Performance Standards for Traffic Alert and Collision Avoidance System II (TCAS II)", RTCA/DO-185B, Volume I, June 19, 2008, and all revisions thereto.

B. "Minimum Operational Performance Standards for Traffic Alert and Collision Avoidance System II (TCAS II)", RTCA/DO-185B, Volume II, June 19, 2008, and all revisions thereto.

C. "Minimum Operational Performance Standards for 1090 MHz Extended Squitter Automatic Dependent Surveillance – Broadcast (ADS-B) and Traffic Information Services – Broadcast (TIS-B)", RTCA/DO-260B, December 2, 2009, and all revisions thereto.

D. "Minimum Operational Performance Standards for Air Traffic Control Radar Beacon System/Mode Select (ATCRBS/Mode S) Airborne Equipment", RTCA/DO-181C, June 12, 2001, and all revisions thereto.

E. Pratap Misra and Per Enge, Global Positioning System: Signals, Measurements, and Performance, Ganga-Jamuna Press, 2001.

F. "Atmospheric pressure," Encyclopedia Britannica, Vol. 1, 1998.

G. Paul D. Thomas, Conformal Projections in Geodesy and Cartography, U.S. Dept. of Commerce, Coast and Geodetic Survey, Special Publication No. 251.

H. DOT/FAA/PM-83/36 MTR-83W241. System Safety Study of Minimum TCAS II. 1983.

I. "Safety Analysis of Proposed Change to TCAS RA Reversal Logic", RTCA/DO-298, November 8, 2005.

J. "Final Report on the Safety of ACAS II in the European RVSM Environment", ASARP/WP9/72/D, Version 1.1, May 11, 2006.

K. "Minimum Operational Performance Standards (MOPS) for Aircraft Surveillance Applications (ASA) Systems", RTCA/DO-317A, December 13, 2011 and all revisions thereto.

L. "Minimum Operational Performance Standards for Traffic Alert and Collision Avoidance System II (TCAS II) Version 7.1 Attachment A (Syntax of Pseudocode)", June 19, 2008, and all revisions thereto.

M. A.D. Panken, et al., "Measurements of the 1030 and 1090 MHz Environments at JFK International Airport", MIT Lincoln Laboratory Project Report ATC-390, September 2012.

N. M.J. Kochenderfer, L.P. Espindle, J.K. Kuchar, and J.D. Griffith, “Correlated Encounter Model for Cooperative Aircraft in the National Airspace System,” Massachusetts Institute of Technology, Lincoln Laboratory, Project Report ATC-344, 2008.

O. SESAR 9.47 D10 (Performance objectives and functional requirements for the use of improved hybrid surveillance in European environment), Appendix A.

2 EQUIPMENT PERFORMANCE REQUIREMENTS AND TEST PROCEDURES

2.1 General Requirements

TCAS II with passive surveillance capability **shall** meet the requirements stated in Ref. A, §2.1 (General Requirements).

2.2 Equipment Performance – Standard Conditions

2.2.1 General

TCAS II with passive surveillance capability **shall** meet the requirements stated in Ref. A, §2.2 (Minimum Performance Standards), except where those requirements are specifically modified by the requirements stated in §2.2 of these MOPS.

Note: *Equipment designers should be careful to meet the Mode S Address capacity and tracking capacity requirements specified per Ref. A in an environment where all aircraft are transmitting 1090 MHz extended squitter per Ref. C.*

2.2.2 Shared Use of 1090 MHz Receiver with an ADS-B Receiving Subsystem

As described in Ref. C, an ADS-B receiving subsystem may be implemented such that TCAS II and the ADS-B receiving subsystem share the use of the 1090 MHz receiver. In such configurations, the receiver and the Mode S reply processing function used for TCAS **shall** meet the requirements in Ref. C, §2.2.4.2 (Receivers Shared With a TCAS Unit), including the subparagraphs included under that subparagraph.

Note: *The cited requirements are designed to ensure (i) that TCAS does not receive squitters or other asynchronous transmissions from aircraft that are well beyond the maximum range of interest for collision avoidance and (ii) that the Mode S reply processing for TCAS does not get captured by such transmissions, causing TCAS to miss higher-power overlapping transmissions from aircraft within the range of interest.*

2.2.3 Initial Detection of Mode S Targets and Determination of Their Address

The initial detection of Mode S targets and determination of their address is specified in Ref. A, §2.2.3.10.2.1 (Detection), §2.2.3.10.7 (Extended Squitter With Aircraft Identification Message), §2.2.4.4.2.2 (c) (Criteria for Data Block Acceptance in Squitter and Asynchronous Transmissions), and §2.2.4.6.2.2.1 (Squitter Processing).

2.2.4 Use of Extended Squitter Altitude for Determining Target Validity

TCAS II with passive surveillance capability **shall** use valid barometric altitude data received in extended squitter (DF=17) Airborne Position Messages for the same purposes as altitude data received from monitoring DF=0 and DF=4 transmissions. Validity of extended squitter transmissions and of altitude data is specified in §2.2.9 and §2.2.9.2 respectively.

Note: Ref A requires monitoring Mode S altitude reporting transmissions (DF=0 and DF=4) in order to passively acquire the altitude of Mode S equipped aircraft and to determine whether they are valid targets as defined in Ref. A, §2.2.4.6.2.2.1 (Squitter Processing). This paragraph requires that extended squitter altitude also be used for those functions. This affects Ref. A, §2.2.3.10.2.1 (Detection), §2.2.4.4.2.2 (Criteria for Data Block Acceptance in Squitter and Asynchronous Transmissions), §2.2.4.6.2.2.1 (Squitter Processing), and §2.2.4.6.2.2.2 (Acquisition).

2.2.5 Acquisition

Acquisition of valid Mode S targets is done through two methods based on the received signal strength of the target aircraft and quality of the ADS-B data.

2.2.5.1 Acquisition Using Active Interrogations

Acquisition of valid Mode S targets which are not qualified for acquisition as Extended Hybrid Surveillance targets as specified in §2.2.5.2 **shall** be performed as specified in Ref. A, §2.2.4.6.2.2.2 (Acquisition). In addition to the requirements there, the acquisition interrogations **shall** have RL=0.

Note: The requirement that RL=0 is meant to prohibit attempts to use the TCAS crosslink to validate an intruder's Airborne Position Message at the same time as it is being acquired. Transponders that transmit DF=17 extended squitters are not necessarily required to support the TCAS crosslink capability and transponders without crosslink capability will not reply to interrogations with RL=1 per Ref. D. Attempts to combine passive surveillance validation using the TCAS crosslink with acquisition would lead to failure to acquire those transponders.

2.2.5.2 Acquisition Using Passive Position Reports

The system **shall** perform Extended Hybrid Surveillance track establishment in such a way that no interrogations are performed for a track when the conditions of this section are satisfied.

Note: To accomplish this, the system could process airborne extended squitters received below the Standard TCAS MTL in order to ensure that a passive Extended Hybrid Surveillance track is established before an active track would be acquired.

Note: Use of DF=17 below the standard TCAS MTL is permitted for use by Extended Hybrid Surveillance. RTCA/DO-260B prohibits providing DF=17 extended squitters to TCAS below the standard TCAS MTL. This prohibition does not apply to Extended Hybrid Surveillance, but does apply to standard DO-185B TCAS and hybrid surveillance. Additionally, Ref A precludes interrogations to intruders whose signal strength is below the standard TCAS MTL.

A valid Mode S target **shall** be acquired, through the exclusive use of extended squitters, provided that the following criteria are met:

Own aircraft data meets the Extended Hybrid Surveillance quality requirements (§2.2.5.2.1)

Its signal strength is ≤ Extended Hybrid Surveillance MTL (§2.2.5.2.3) or own aircraft is operating on the surface (per §2.2.8)

The Extended Hybrid Surveillance quality requirements are met (§2.2.5.2.1)

There are three acceptable methods of acquiring the required ADS-B message elements:

1. ADS-B reports (not ADS-R or TIS-B) from a DO-260B (Ref. C) compliant receiver.

2. ADS-B reports (not ADS-R or TIS-B) associated with DO-317A AIRB qualified track (but meeting additional requirements of §2.2.5.2.1).

3. Decoded directly per §2.2.9

Note: Use of ADS-R and TIS-B data is not permitted. The received signal level of ADS-B and TIS-B data is not related to the relative range of the corresponding aircraft, and so cannot be used to alert TCAS when that aircraft may be closer than its position report indicates. A portion of UAT equipped ADS-B OUT aircraft will be equipped with ATCRBS transponders.

2.2.5.2.1 Extended Hybrid Surveillance Quality Requirements

Own Ship and Traffic data quality requirements **shall** both be met for a target to qualify for Extended Hybrid Surveillance.

A Mode S intruder **shall** qualify for Extended Hybrid Surveillance when all of the following conditions are true:

a) The ADS-B Version Number ≥ 2

b) The reported NIC ≥ 6 (<0.6 NM)

c) The reported NACp ≥ 7 (<0.1 NM)

d) The reported SIL = 3

e) The reported SDA = 2 or 3

f) The barometric altitude is valid

Own Ship position sources **shall** meet the following data quality standards:

a) Own ship horizontal position uncertainty (95%) is < 0.1 NM

b) Own ship horizontal position integrity bounds is < 0.6 NM with integrity of $1e^{-7}$

2.2.5.2.2 Establishing an Extended Hybrid Surveillance Track

An extended hybrid track **shall** be established when it meets the following conditions:

a) Two valid airborne position messages have been received within 5 surveillance update intervals

b) The altitude in the two airborne position messages are within 500 ft of each other or are within a window large enough to accommodate a 10,000 fpm altitude rate – whichever is greater

c) The Q-bit values in the two airborne position messages are identical

d) The ICAO aircraft address is the same in both airborne position messages and the address is valid (not all zeroes or all ones)

Once the track is considered established periodic surveillance updates using airborne position messages may be used to update TCAS Extended Hybrid Surveillance tracks.

2.2.5.2.3 Extended Hybrid Surveillance MTL

The Extended Hybrid Surveillance MTL **shall** be set to the maximum of -68dBm ±2 dB or the MTL established by the interference limiting algorithms defined in Ref. A.

Note: *Extended Hybrid Surveillance MTL should always be set at least as high as the interference limiting MTL in order to prevent the condition where an intruder's estimated signal strength is above the Extended Hybrid Surveillance MTL, but below the interference limiting MTL – this would result in the undesirable dropping of a target.*

2.2.5.2.4 Determination of Estimated Signal Strength

The signal strength for an intruder **shall** be estimated using DF=11 and DF=17 squitters. The signal strength **shall** be estimated at least once every surveillance processing cycle if DF=11 or DF=17 squitters are available. The estimated signal strength **shall** be set to the maximum signal strength of the DF=11 and DF=17 squitters received since the last estimated signal strength was determined.

Note: *The purpose of these requirements is to ensure a timely update rate of an intruder's estimated signal strength. Using the maximum received signal strength provides a more conservative estimate of the received signal strength.*

Note: *Filtering of signal strength to avoid frequent changes between hybrid surveillance and extended hybrid surveillance provides no benefit since the requirements of §2.2.7.1.3 preclude unnecessary re-validation interrogations due to extended hybrid to hybrid surveillance transitions.*

Note: *If DF=17 messages are used to estimate the signal strength, then it is acceptable to just use position messages.*

2.2.6 Maintenance of Tracks Using Active Surveillance

2.2.6.1 Conditions for Active Surveillance of a Track

An established Mode S track enters the active surveillance state if any of the following are true:

a) It is acquired and established by means of active surveillance as specified in §2.2.5.1 and Ref. A

b) It fails the validation test during a transition from extended hybrid surveillance to hybrid surveillance as specified in §2.2.7.1.3

c) It fails the revalidation test while under hybrid surveillance, as specified in §2.2.7.5

d) It is under passive surveillance (either hybrid or extended hybrid) and satisfies the hybrid threat criteria for transition to active surveillance as specified in §2.2.6.1.4

e) It is under passive surveillance and its Airborne Position Messages continue to be received, but have missing or invalid position data as specified in §2.2.7.4

f) It is under passive surveillance and the source of own aircraft latitude and longitude data is declared invalid or unavailable as specified in §2.2.10

2.2.6.1.1 Persistence of Active Surveillance

An established track that is under active surveillance **shall** be maintained under active surveillance as specified in §2.2.6.2 unless it:

a) Transitions to hybrid surveillance as specified in §2.2.6.1.2 or

b) Transitions to extended hybrid surveillance as specified in §2.2.6.1.3

Note: *This requirement addresses only surveillance state transitions while the track remains established. A track will also leave the active surveillance state if it is dropped according to any of the requirements of this MOPS or Ref. A.*

2.2.6.1.2 Active to Hybrid Surveillance Transition

An active surveillance track **shall** transition to hybrid surveillance if the conditions of §2.2.7.1.2 are met and it passes the validation test specified in §2.2.6.3. However, if there have been one or more attempts to validate or revalidate the track, and the last prior such attempt was unsuccessful, transition to hybrid surveillance **shall** occur only if the conditions of §2.2.7.1.2 are met and the validation test in §2.2.6.3 is passed on two consecutive validation attempts. The rate of validation attempts is specified in §2.2.6.2.

Note: *An equipment manufacturer may limit the number of validation attempts for any given track as a method of managing processing time and/or resources.*

2.2.6.1.3 Active to Extended Hybrid Surveillance Transition

An active surveillance track transitions to extended hybrid surveillance under the conditions specified in §2.2.7.2.2.1.

Note: Transition from active surveillance directly to extended hybrid surveillance is only permitted when own aircraft is operating on the airport surface, otherwise an active track must first transition to hybrid surveillance for validation before transitioning to extended hybrid surveillance.

2.2.6.1.4 Active Surveillance Region

A track under passive surveillance **shall** transition to active surveillance if the following conditions are all true:

1) $-(s - 4500 \text{ ft})/\min(-1\text{ft/sec}, \dot{s}) \leq 60 \text{ sec}$

2) $-(r - 3\text{NM})/\min(-6\text{kt}/3600, \dot{r}) \leq 60 \text{ sec}$

3) Own aircraft is taking off or airborne per section 2.2.8

where:

$$s = |\text{own altitude} - \text{track altitude}| = \text{altitude separation, in ft}$$

$$\dot{s} = (\text{own altitude rate} - \text{track altitude rate})\,\text{sign}(\text{own altitude} - \text{track altitude});$$

$$= \text{rate of change of } s, \text{ in ft/s, with negative values indicating decreasing separation};$$

$$r = \text{track slant range, in NM};$$

$$\dot{r} = \text{rate of change of } r \text{ in NM/s, with negative values indicating decreasing range};$$

$$\text{sign}(x) = 1 \text{ if } x \geq 0; -1 \text{ if } x < 0.$$

Conditions 1) and 2) are referred to as the hybrid threat criteria.

The range and range rate used in the computation above **shall** be based on passive range measurements only. When a track initially transitions to passive surveillance it is possible for a period no longer than 5 surveillance update intervals that sufficient passive reports are not available to determine a range rate (Ref. §2.2.7.3). While a passive surveillance range rate is not available the 2nd condition above **shall** be considered false.

Note: Ref. §2.2.7.1.2 Hybrid Surveillance Region defines the criteria for the passive surveillance region to be slightly larger than the active surveillance region. The difference in the active and passive surveillance regions creates a hybrid surveillance transition window (hysteresis) of a 5 sec tau, 400 ft alt, and 0.2 NM range between active and passive tracking.

If no altitude rate has been determined for a track, then the track's altitude rate **shall** be assumed to be ±10,000 ft/min, with the sign chosen to be sign (own altitude – track altitude).

Note: ±10,000 ft/min (±167 ft/sec) is the maximum intruder altitude rate for which TCAS was designed. Using the worst case vertical closure rate when no data is available ensures that the system will not miss a potential threat and delay transition from passive to active surveillance.

When a track is in the active surveillance region all interrogations of the track **shall** have RL=0.

Note: When it is determined that a transition to active surveillance is required the target is interrogated. The altitude, slant range, and bearing of the reply will be used to update the track based on the requirements in §2.2.6.2.

2.2.6.2 Active Surveillance Requirements

Established Mode S tracks under active surveillance **shall** be maintained as specified in Ref. A, §2.2.4.6.2.2.3 (Maintenance of Established Tracks).

Note: The intent of this section is to establish that active Mode S tracking is performed as per Ref. A through the exclusive use of Mode S replies, not through the use of range and bearing derived from extended squitter (DF=17) reports.

Note: Since there can be a significant offset (bias) between the calculated range derived from the Airborne Position Message and the measured range from interrogations, even for reports that meet the validation criteria, and since the calculated range may have a larger variance than the measured range, depending on the source of the position data, it is important not to mix these two sources of data in order to avoid problems with the tracked range and range rate.

Note: Care should be taken to avoid large range rate transients when a track transitions from active to passive surveillance or vice versa. One way to avoid a range rate transient during transitions between active and passive surveillance and vice versa would be to coast the range rate until both the position report used for the previous track update and the current position report are of the same type.

If a track under active surveillance satisfies the modified hybrid surveillance criteria of §2.2.7.1.2, but has not been given a validation test as specified in §2.2.6.1.2, then each active interrogation required in Ref. A, §2.2.4.6.2.2.3 (Maintenance of Established Tracks) **shall** also be used as a validation interrogation as specified in §2.2.6.3, and any reply **shall** be subjected to the validation test. If the validation test succeeds, the track transitions to hybrid surveillance.

Mode S surveillance **shall** be performed in such a way that a track **shall** not be dropped for a nominal transition from passive to active surveillance. A nominal transition is defined as one in which qualification, validation, or revalidation tests passed successfully. Therefore, the range correlation window used during this transition **shall** be at least as large as the revalidation window.

Note: The purpose of this requirement is to ensure that implementations of TCAS with passive surveillance do not drop and restart tracks or change track numbers on the same aircraft during normal transitions between passive and active *surveillance. For example, the range correlation window used for Mode S tracks should be at least as large as the range validation window.*

The maximum delay from the time it is determined that an aircraft (that was passively tracked) has entered the active surveillance region to the time a track with active reply data is provided to the CAS subsystem **shall** not be more than 3 surveillance update intervals. This requirement applies only to surveillance conditions where nominal active surveillance link margins exist.

When a track transitions to active surveillance and active data does not correlate with both the predicted range and the predicted altitude of the track (previously updated with passive data), the track **shall** be dropped and a new track established based only on active data. Only one track **shall** be presented to the CAS subsystem at any time for a given Mode S address. A new track in this case implies a new track number so that all trackers are reset. In this condition, under nominal link margin conditions, the timing requirements of the previous paragraph apply.

Table 1 below illustrates the intent of these requirements with a scenario.

Table 1. Active Transition Scenario With No Correlation

T	Surveillance Event	Surveillance Data to CAS Logic	Comment
<0	Track outside active surveillance region; tracked passively	SURVNO = X SURV_MODE = REDUCED RFLG = TRUE Range derived from passive data	
0	Track within the active surveillance region. Active reply does not correlate to predicted range because of large difference between active and passive data.	SURVNO = X SURV_MODE = REDUCED RFLG = FALSE	Although it did not correlate, active reply data is saved to restart the track.
1	Active reply does not correlate to predicted range because of large difference between active and passive data.	SURVNO = X SURV_MODE = REDUCED RFLG = FALSE	Although it did not correlate, active reply data is saved to restart the track.
2	Active reply does not correlate to predicted range because of large difference between active and passive data.	SURVNO = Y SURV_MODE = NORMAL RFLG = TRUE	Because the track did not correlate again, the existing track is dropped and a new track is presented to CAS logic using the saved reply data. The reply data must meet the requirements of Ref. A for initializing a Mode S track.

Note: *The purpose of this requirement is to minimize the delay in generating an established active track in a case where an aircraft track that was being updated with passive data meets the criteria where it is required to be updated with active data (e.g. within the active surveillance region or failed validation). Consider the case where the error is sufficiently large that the range correlation criteria for the track fails and the CAS logic will be presented with a coast (S.RFLG =*

FALSE). In this case the Surveillance Mode will continue to be marked as not Normal (e.g. Reduced). This requirement guarantees (under nominal link margin conditions) that the maximum time delay in transitioning to active surveillance and establishing is 3 surveillance update intervals.

2.2.6.3 Validation of Airborne Position Message Data

The Airborne Position Message data from a Mode S transponder **shall** be validated by comparing Airborne Position Message data to measured range, bearing, and the reported altitude using standard TCAS surveillance interrogations with a UF=0, RL=0. If no reply is received, additional validation interrogations **shall** be transmitted. However, all validation interrogations **shall** count as tracking interrogations with respect to the interrogation limits in Ref. A, §2.2.4.6.2.2.3 (Maintenance of Established Tracks), and those interrogation limits **shall** be observed.

Note: *The purpose of requiring interrogations with RL=0 is to prevent the use of the TCAS crosslink for validation of Airborne Position Message data thus reducing the overall usage of the 1090 MHz downlink.*

If a reply is received, the position and altitude data from an Airborne Position Message or multiple Airborne Position Messages **shall** be combined with position and altitude data of own aircraft at a common reference time, in order to determine a calculated slant range and bearing based on these reported positions. The overall error in the calculated slant range **shall** meet the requirements of §2.2.7.6. The calculated slant range and bearing and the altitude reported in the Airborne Position Message **shall** be compared at a common reference time (e.g., the time of the active reply) to values determined from measured range and bearing data and the reported altitude from standard TCAS surveillance interrogations with UF=0, RL=0.

Note: *Section 2.2.9 defines the requirements for determining valid latitude, longitude, and altitude.*

Note: *Specific equations for the transformation from reported positions to calculated slant range are provided as guidance material in Appendix A.*

The Airborne Position Message data from a Mode S transponder **shall** pass the validation test if:

|slant range difference| ≤ 290 meters; and

|bearing difference| ≤ 45 degrees; and

|altitude difference| ≤ 100 feet.

If bearing data is available then the active and passive bearing **shall** meet the criteria above. However, if bearing is not available then the bearing comparison **shall** not be required to meet the validation requirements.

Note: *One reason that bearing may not be available is the case of an aircraft that is tracked only with an omni-directional lower antenna.*

2.2.7 Maintenance of Established Tracks Using Passive Surveillance

2.2.7.1 Conditions for Hybrid Surveillance

An established Mode S track will enter the hybrid surveillance state if:

a) It is in active surveillance state, satisfies the modified hybrid threat criteria specified in §2.2.7.1.2, and passes one or two successive validation tests as specified in §2.2.6.1.2.

b) It is in extended hybrid surveillance state, but the conditions for extended hybrid surveillance in §2.2.5.2 (own aircraft and intruder report quality, power level) are no longer satisfied, as specified in §2.2.7.1.3.

2.2.7.1.1 Persistence of Hybrid Surveillance

An established track that is under hybrid surveillance **shall** be maintained under hybrid surveillance unless:

1. It is required to transition to active surveillance as specified in §2.2.6.1.

2. It is required to transition to extended hybrid surveillance as specified in §2.2.7.2.2.2.

Note: This requirement addresses only surveillance state transitions while the track remains established. A track will also leave the hybrid surveillance state if it is dropped according to any of the requirements of this MOPS or Ref. A.

2.2.7.1.2 Hybrid Surveillance Region

A track under active surveillance **shall** transition to hybrid surveillance if it does not satisfy the conditions requiring active surveillance specified in §2.2.6.1 and any of the following conditions are true:

1) $-(s - 4900\ \text{ft})/\min(-1\text{ft/sec}\ ,\ \dot{s}) \geq 65\ \text{sec}$ (which implies s ≥ 4900ft)

OR

2) $-(r - 3.2\,\text{NM})/\min(-6\text{kt}/3600\ ,\ \dot{r}) \geq 65\ \text{sec}$ (which implies r ≥ 3.2NM)

OR

3) Own aircraft is operating on the surface as defined in §2.2.8 and the track does not qualify for extended hybrid surveillance as specified in §2.2.5.2.

where terms are defined in §2.2.6.1.4.

Conditions 1) and 2) are referred to as the modified hybrid threat criteria in Appendix D.

The range rate used in the computation above **shall** be based on active range measurements only. If a range rate estimate is not available -1200 kt **shall** be assumed.

Note: Ref. §2.2.6.1.4 Active Surveillance Region defines the criteria for the active surveillance region to be slightly smaller than the hybrid surveillance region. The difference in the hybrid and active surveillance regions creates a hybrid surveillance transition window (hysteresis) of a 5 sec tau, 400 ft alt and 0.2 NM range between hybrid and active tracking.

Note: The transition criteria specified above ensure that a track does not transition to hybrid surveillance if it qualifies for a TA or RA.

2.2.7.1.3 Extended Hybrid to Hybrid Surveillance Transitions

A track that is under extended hybrid surveillance **shall** transition to hybrid surveillance if it does not satisfy the requirement stated in §2.2.6.1.4 and no longer qualifies for extended hybrid surveillance as specified in §2.2.5.2.

The first time a track transitions from extended hybrid to hybrid surveillance the track's Airborne Position Message data **shall** be validated per the requirements of §2.2.6.3 prior to transitioning to hybrid surveillance. Failure of validation when a reply is received **shall** cause the track to transition to active surveillance. Failure of validation when no reply is received **shall** cause the track to be deleted according to the requirements of Ref. A §2.2.4.6.2.2.3. Measured range and bearing from the validation replies **shall** not be used to update the track. If the extended hybrid surveillance track had been previously validated it **shall** transition to hybrid surveillance and be revalidated per §2.2.7.5.

Note: The measured range and bearing are not used to update the track because of the undesirability of mixing measured and calculated range data in updating the track, as noted in §2.2.6.2.

Note: The purpose of the last requirement is to ensure that if a validation interrogation was previously performed on a track, another interrogation may not be required solely based on the track transitioning to hybrid surveillance.

2.2.7.2 Conditions for Extended Hybrid Surveillance

An established Mode S track will enter the extended hybrid surveillance state if any of the following are true:

a) It is initially acquired and established using passive surveillance, as specified in §2.2.5.2

b) It is in the active surveillance state and the transition criteria in §2.2.7.2.2.1 are satisfied

c) It is in the hybrid surveillance state and the transition criteria in §2.2.7.2.2.2 are satisfied

2.2.7.2.1 Persistence of Extended Hybrid Surveillance

An established track that is under extended hybrid surveillance **shall** be maintained under extended hybrid surveillance if it qualifies for extended hybrid surveillance (per §2.2.5.2) and it does not satisfy any conditions requiring active surveillance as specified in §2.2.6.1.

Note: *This requirement addresses only surveillance state transitions while the track remains established. A track will also leave the extended hybrid surveillance state if it is dropped according to any of the requirements of this MOPS or Ref. A.*

2.2.7.2.2 Extended Hybrid Surveillance Transitions

2.2.7.2.2.1 Active to Extended Hybrid Surveillance Transition

A track under active surveillance **shall** transition to extended hybrid surveillance only if own is operating on the surface (per §2.2.8) and it qualifies for extended hybrid surveillance as specified in §2.2.5.2.

Note: *This requirement does not preclude passive track initiation and establishment as described in §2.2.5.2. However, once an intruder is under active surveillance, this requirement ensures that the track will not transition directly to extended hybrid surveillance unless own is operating on the airport surface. If own is airborne, then it will first transition to hybrid surveillance before transitioning to extended hybrid surveillance.*

2.2.7.2.2.2 Hybrid to Extended Hybrid Surveillance Transition

A track under hybrid surveillance **shall** transition to extended hybrid surveillance if it qualifies for extended hybrid surveillance as specified in §2.2.5.2.

2.2.7.3 Track Updates Using Airborne Position Messages

Established Mode S tracks under passive surveillance **shall** be updated when all of the following apply:

a. A valid Airborne Position Message is received for that track's Mode S address. Section 2.2.9 defines how valid latitude, longitude and altitude are determined.

b. That Airborne Position Message contains both valid position (latitude / longitude) and valid altitude data.

c. The calculated slant range derived by combining the position and altitude data from the Airborne Position Message with own aircraft's position and altitude falls within a range window centered on a range predicted from previous track update history.

d. The reply altitude falls within an altitude window centered on an altitude predicted from the previous track update history. In no case **shall** the altitude window be larger than ±500 ft.

In addition to the above criteria, Established Mode S tracks under extended hybrid surveillance **shall** be updated only if the quality parameters of the track and the airborne position message qualify per §2.2.5.2.

Mode S surveillance **shall** be performed in such a way that a track **shall** not be dropped for nominal transitions between surveillance modes (active, hybrid and extended hybrid).

Note: *The purpose of this requirement is to ensure that implementations of TCAS with passive surveillance do not drop and restart tracks on the same aircraft during normal transitions between passive and active surveillance. For example, the range correlation window used for Mode S tracks should be at least as large as the range validation window.*

When track capacity is exhausted, TCAS **shall** use DF=17 extended squitters that qualify for Extended Hybrid Surveillance instead of using active interrogations. As required in Ref. A, in overload conditions excess targets are deleted in order of decreasing range.

Note: *The maximum number of extended hybrid surveillance tracks that are retained at any time is thus one less than the maximum that the system can accommodate.*

Note: *This avoids the need for an active interrogation on the sole grounds that it is not possible to use extended hybrid surveillance for one more intruder.*

2.2.7.4 Tracking in the Absence of Airborne Position Messages

If an established track that is being updated using Airborne Position Messages is not updated (because of a missed Airborne Position Message or an Airborne Position Message with invalid altitude or position as defined in §2.2.9) during a surveillance update interval then the track **shall** follow the requirements in Ref. A, §2.2.4.6.2.2.3 (Maintenance of Established Tracks) for missed replies.

Note: *The idea is that Airborne Position Messages can be treated as "pseudo replies". Therefore if an Airborne Position Message is not received when the active track normally would have been updated then the track should be coasted.*

If the passive track is not updated with Airborne Position Message data at the nominal active interrogation rate (0.2 Hz or 1 Hz) required by Ref. A, §2.2.4.6.2.2.3 (Maintenance of Established Tracks) due to messages with missing or invalid position data then the track **shall** transition to an active track.

If the passive track is coasted due to lack of Airborne Position Message data for more time than is allowed per Ref. A then the track **shall** be dropped.

Note: *This requirement ensures that a track will not be deleted based solely on invalid Airborne Position Messages.*

Note: *In order for an Airborne Position Message to update a track it is required to contain a valid altitude and position. If the transponder stops reporting altitude, updates will cease and the requirements in this section will cause the track to transition to active surveillance or be dropped. The altitude reported in the Airborne Position Message is important to the safety of passive surveillance, and if it is not available for an intruder then passive surveillance should be discontinued for that target.*

Note: *In summary, the first paragraph of this section requires coasting if no squitter is received or an invalid squitter is received during any given second as is required of active surveillance in Ref. A. The second paragraph requires transition to active surveillance if the minimum update interval that would normally be required by active surveillance in Ref. A is not achieved with valid Airborne Position data. The third paragraph requires a passive track to be coasted and dropped if no Airborne Position data is received. There are cases where a track that would have normally been updated at a 1 Hz rate can qualify for passive surveillance (Appendix D, §D.4.1).*

Note: *If a valid Airborne Position Message is received for a track, but the track is not updated because the range calculated from that message does not fall within the correlation window required in §2.2.7.3(c) or the altitude in that message does not fall within the altitude correlation window required in §2.2.7.3(d), then it should be treated as required by Ref. A for such correlation failures.*

2.2.7.5 Revalidation

An established track that is under hybrid surveillance (per §2.2.7.1) **shall** be subject to revalidation. If a track under hybrid surveillance does not satisfy the first (altitude) condition of §2.2.6.1.4, it **shall** be subject to revalidation every 60th surveillance update interval; if it satisfies the first condition of §2.2.6.1.4 but not the second (range) condition, it **shall** be subject to revalidation at intervals calculated according to the following procedure. The revalidation interval *t* **shall** be calculated at the time of the initial successful validation and at the time of each successful revalidation. It **shall** be used as the number of surveillance update intervals until the next revalidation attempt.

1. If $v_0 \geq +300$ kt, then set the revalidation interval, *t*, to 60 seconds.
2. Otherwise, the revalidation interval, *t*, is determined from the equation below.

$$t = \max\left(10, \min\left(60, \operatorname{trunc}\left(\frac{-(v_0 + a t_{thr}) - \sqrt{(v_0 + a t_{thr})^2 - 2a(r_0 + v_0 t_{thr} - s_{mod})}}{a}\right)\right)\right)$$

The revalidation interval, *t*, is the time in seconds that it would take to satisfy the range condition for active interrogation under the assumed acceleration, starting from the time of the current successful revalidation, truncated to the next smaller integer, and constrained to values between 10 and 60 seconds. r_0 is the estimated range in feet of the intruder determined from passive surveillance. v_0 is the estimated range rate in ft/s of the intruder, with positive range rates indicating divergence in range, also determined from passive surveillance. Since *t* is only calculated at the time of a successful validation or revalidation, the r_0 and v_0 values are those at the time of that validation or revalidation. a is the assumed range acceleration of -11 ft/s^2; the negative value indicating acceleration toward own aircraft. s_{mod} is a range offset of 18228 ft (3 NM) that appears in the range condition for transitioning from passive to active surveillance. t_{thr} is the range tau threshold of 60 seconds for transition from passive to active surveillance. The function 'trunc' is the truncation function that converts a real number to the next smaller integer.

Alternatively, instead of using the procedure specified above, the revalidation interval may be determined according to Table 2 below, where the range and range rate have been quantized as shown and the value of *t* determined by the above procedure has been further quantized to the values 10, 20, 30, 40 and 60 seconds by selecting the largest of those values that is equal to or smaller than the calculated value.

Active interrogations **shall** be transmitted and the replies **shall** be used to revalidate the Airborne Position Message data using the procedure specified in §2.2.6.3 with a maximum slant range difference of 340 m. When the required revalidation rate changes, the first revalidation at the new rate **shall** be timed from the last revalidation at the old rate. If a valid reply is not received during the current TCAS Processing Cycle then attempts to elicit a valid reply **shall** be performed during subsequent TCAS Processing Cycles. The revalidation interrogations **shall** count as tracking interrogations with respect to the interrogation limits in Ref. A §2.2.4.6.2.2.3 and those interrogation limits **shall** be observed.

Failure of revalidation when a reply is received **shall** cause the track to transition to active surveillance.

Failure of revalidation when no reply is received **shall** cause the track to be deleted according to the requirements of Ref. A §2.2.4.6.2.2.3.

Measured range and bearing from the revalidation replies **shall** not be used to update the track.

Note: The measured range and bearing are not used to update the track because of the undesirability of mixing measured and calculated range data in updating the track, as noted in §2.2.6.2.

Note: Validation and revalidations do not apply to established tracks under extended hybrid surveillance.

Table 2. Interval Between Revalidations

	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

Notes: The table entries are the safe time interval in seconds until the next revalidation, or equivalently the number of surveillance update intervals until the next revalidation.

Range = track slant range, in NM. A given column applies to a track if the track's range is greater than or equal to the range in the column header but less than the range of the next column to the right.

Range Rate = rate of change of Range in kt (NM/hour), with negative values indicating decreasing range. A given row applies to a track if the track's range rate is greater than or equal to the range rate in the row header but less than the range rate in the row header of the row above.

A = All of the range and range rate combinations in that cell satisfy the conditions for transitioning to active interrogations, and therefore that cell should never be accessed to determine the safe interval until the next revalidation.

2.2.7.6 Error Budget Allocated to TCAS for Calculating Slant Range from Positions and Comparing it to TCAS Range

To get the benefit of hybrid surveillance, the errors under the control of hybrid surveillance should be minimized as much as practical to ensure that aircraft that could be validated as hybrid are validated, and that slant range is computed sufficiently accurate for the purpose of TCAS. To ensure timely transition from passive to active surveillance, the range and range rate estimates developed from tracking passive position reports must be sufficiently accurate. To develop a reasonable error budget for the hybrid data processing errors, the size of the error sources for the system as a whole was estimated and compared with the validation threshold. Based on this analysis, the hybrid data processing errors **shall** add no more than 145 m of error, 95% of the time, at the reference time for which that slant range is calculated, and for own aircraft speeds up to 600 kt, own aircraft altitude rates within the range ±10,000 ft/min, and own aircraft horizontal and vertical accelerations less than 0.5 g (16 ft/sec^2).

Note: The own aircraft lateral and vertical rates were derived from Ref. A, §2.2.4.6.

Appendix A provides information on different methods of computing slant range and bearing from latitude, longitude, and altitude. Details on the error analysis are provided in Appendix B. The requirements for developing a sufficiently accurate range rate estimate based on tracking successive range reports are developed in Appendix D, §D.3.4.2.4. Note that Appendix B and Appendix D, §D.3.4.2.4 make assumptions about the maximum uncompensated latency of own aircraft position reports at the time of their delivery to the TCAS unit and also about the maximum variation in that uncompensated latency from its average value. Both of those parameters are outside the control of the TCAS hybrid surveillance system and so outside the scope of this MOPS. If the uncompensated latency or the variation in that latency in an installed system under realistic operational loading will be substantially larger than the assumptions in Appendices B and D, those analyses should be revisited to ensure both beneficial and safe operation. It might be possible to reduce the budget allowed for errors in hybrid surveillance data processing to compensate for a larger uncompensated latency in own aircraft's position reports, for example. The assumed variations in the uncompensated latency do not have a major effect in comparison to the other sources of range variation, but much larger values might affect the tracking parameters used to track passive position reports, increase the time required to obtain sufficient range rate accuracy, and increase the required size of the range correlation windows.

2.2.8 Determining Whether Own Aircraft Operating on Surface or Taking Off/Airborne

This section specifies when own aircraft is operating in one of two conditions:

1. Taking Off/Airborne
2. Operating on the surface

Note: The operating on the surface state or condition is used in determining when the exclusive use of 1090 MHz ADS-B reports is permitted. The taking off/airborne condition is used to detect when own ship is either airborne or about to be airborne so that the exclusive use of ADS-B report is terminated.

Own **shall** be considered to be taking off/airborne when any of the following are true:

- Ground speed is invalid
- Ground speed input is valid AND is $\geq$35 knots
- TCAS Air/Ground (OOGROUN) indicates in air

Once own ship has satisfied the tests above to be considered to be taking off/airborne, it **shall** continue to be considered to be taking off/airborne until the tests for considering it be operating on the surface are satisfied.

The system **shall** use Ground Speed input that remains valid even when own aircraft is stationary.

Note: The above requirement is to prevent a system from deriving ground speed from the GNSS receiver reported North South/ East West velocities which do become invalid when own ship is stationary or moving slowly.

Own **shall** be considered to be operating on the surface when all these conditions are true:

- Ground speed input is valid AND is < 25 knots
- TCAS Air/Ground (OOGROUN) indicates on-ground

At power up, own aircraft **shall** be assumed to be taking off/airborne until required inputs above become available.

Note: OOGROUN is the CAS Logic Pseudo code variable in attachment A of Ref. A which defines the own aircraft air/ground state for own aircraft. This is equivalent to Own_Air_Status state variable defined in Volume II of Ref. A.

2.2.9 Decoding the Extended Squitter ME Field

If a Mode S transmission is accepted as a valid extended squitter (DF=17 and an appropriate value for the PI field), the ME message field in bits 33 through 88 of the extended squitter are decoded as indicated in §2.2.9.1 through §2.2.9.13 in order to support passive surveillance.

Note: *The format of the DF=17 extended squitter and its fields and subfields are specified in Ref. C, §2.2.3.2 (ADS-B and TIS-B Message Baseline Format and Structures), and its subparagraphs. TCAS II with hybrid surveillance capability uses the Capability (CA), ICAO address (AA), and Parity/Identity (PI) fields of all DF=17 extended squitter transmissions for purposes of Mode S target detection and address determination, as described in §2.2.3 of this document. TCAS II with hybrid surveillance capability may use the data in the ME field for purposes of altitude determination and passive surveillance when that field contains an Airborne Position Message. The type of message in the ME field is determined from the TYPE subfield of the ME field, located in bits 1 to 5 of the ME field (bits 33 to 37 of the overall extended squitter).*

Horizontal position and altitude are determined from receipt of Airborne Position Messages by extracting the appropriate data elements per §2.2.9.2 - §2.2.9.5. Horizontal position data initialized from receipt of an Airborne Position Message per §2.2.9.3 **shall** be checked for reasonableness per the following requirements:

1) A global unambiguous CPR decode and validation per Ref. C §2.2.10.3.1.

2) The local unambiguous decode from the receipt of the Airborne Position Message completing the global unambiguous CPR decode in 1) above validated per Ref. C §2.2.10.6.2 subparagraph c.

Note: *Horizontal position data using ADS-B Reports from DO-260B compliant receivers is initialized by performing a globally unambiguous CPR decode per Ref. C §2.2.10.3.1 and undergoes an additional reasonableness test per §2.2.10.6.2. Since receipt of an Airborne Position Message per §2.2.9.3 uses a local unambiguous CPR decode to initialize position data, the above requirements are applied to validate the position computation.*

Horizontal position for aircraft reporting the surface formats of extended squitter is determined from receipt of Surface Position Messages by extracting the appropriate data elements per §2.2.9.11 - §2.2.9.13.

2.2.9.1 TYPE Subfield of the ME Field

If the TYPE subfield of the ME field has the value 0, the Altitude subfield of that ME field **shall** be decoded. If the TYPE subfield has one of the values in the range 9 to 18, the Altitude, CPR Format, Encoded Latitude and Encoded Longitude subfields of that ME field **shall** be decoded. If the TYPE subfield has the value of 29, the NACp and SIL subfields of that ME field **shall** be decoded. If the TYPE subfield has one of values in the range 5 to 8, the CPR Format, Encoded Latitude and Encoded Longitude subfields of that ME field **shall** be decoded when required to satisfy the requirements of §2.2.13. If the TYPE subfield has the value of 29, the NACp and SIL subfields of that ME field **shall** be decoded. If the TYPE subfield has the value of 31, the ADS-B Version Number, NACp, SIL, and SDA subfields of that ME field **shall** be decoded.

Note: If the TYPE field has the value 0, the ME field contains an Airborne Position Message without valid position data, but may contain either a barometric altitude or no altitude data. If the TYPE field has one of the values in the range 9 to 18, the ME field contains an Airborne Position Message with valid position data and either a barometric altitude or no altitude data. If the TYPE field has one of the values in the range 5 to 8, the ME field contains a Surface Position Message. If the TYPE field has the value of 29, the ME field contains a Target State and Status Message. If the TYPE field has the value of 31, the ME field contains an Aircraft Operational Status Message.

Note: TCAS II passive surveillance does not make use of Airborne Position Messages with TYPE field values in the range 20 to 22.

If the TYPE field has the value 1, 2, 3 or 4, the ME field contains an Aircraft Identification and Type message. This may optionally be decoded as specified in Ref. A, §2.2.3.10.7 (Extended Squitter With Aircraft Identification Message).

Note: The remaining ME field message types, 19, 23 to 28 and 30 are Airborne Velocity Messages, Extended Squitter Aircraft Status Messages (Emergency/Priority Status), Test Messages, or reserved message types. None of these message types are used by TCAS II passive surveillance.

2.2.9.2 Altitude from Airborne Position Message

The Altitude subfield of an Airborne Position Message is located in bit positions 9 to 20 of the ME field (bit positions 41 to 52 of the extended squitter). If the ME field of a valid extended squitter transmission has a TYPE subfield with the value 0 or with a value in the range 9 to 18, then the Altitude subfield of the ME field **shall** be decoded. If all bits in the Altitude subfield have the value 0, then the message contains no valid altitude data, and the Altitude subfield **shall** be ignored. Otherwise, the Altitude subfield contains altitude data encoded as specified in Ref. C, §2.2.3.2.3.4.3 ("Altitude Encoding" in ADS-B Airborne Position Messages), and **shall** be decoded into an appropriate value for use in initial altitude determination and in passive surveillance.

2.2.9.3 CPR Format from Airborne Position Message

The CPR Format subfield of an Airborne Position Message is located in bit position 22 of the ME field (bit position 54 of the extended squitter). This field indicates whether the Encoded Latitude and Encoded Longitude subfields of that Airborne Position Message use the even or odd encoding method specified in Ref. C. If the ME field of a valid extended squitter transmission has a TYPE subfield with a value in the ranges 9 to 18, then the CPR Format subfield **shall** be used in conjunction with the Encoded Latitude and Encoded Longitude fields to decode them into latitude and longitude in accordance with Ref. C, Appendix A, §A.1.7.5 (Computations for Airborne, TIS-B and Intent Lat/Lon).

Note: Since the range of squitter reception for TCAS is specified to be much less than 180 NM, the position calculated will be unambiguous without the need to decode both even and odd reports, as noted in Ref. C, Appendix A, §A.1.7.1 (Principle of the CPR Algorithm), Note 4. A global unambiguous CPR decode is computed as part of the reasonableness tests in §2.2.9 when a DO-260B report generator is not used since a local unambiguous CPR decode is used for initialization per this section.

The computed position for any Airborne Position Message received subsequent to successful reasonableness test validation per §2.2.9 **shall** be checked for reasonableness per Ref. C §2.2.10.6.3.

Note: An erroneous local unambiguous CPR decode could result in an incorrect position that potentially remains incorrect for the life of the track.

2.2.9.4 Encoded Latitude from Airborne Position Message

The Encoded Latitude subfield of an Airborne Position Message is located in bit positions 23 to 39 of the ME field (bit positions 55 to 71 of the extended squitter). If the ME field of a valid extended squitter transmission has a TYPE subfield with a value in the ranges 9 to 18, then the Encoded Latitude is valid and **shall** be decoded into a latitude value in accordance with Ref. C, Appendix A, §A.1.7.5 (Computations for Airborne, TIS-B and Intent Lat/Lon).

2.2.9.5 Encoded Longitude from Airborne Position Message

The Encoded Longitude subfield of an Airborne Position Message is located in bit positions 40 to 56 of the ME field (bit positions 72 to 88 of the extended squitter). If the ME field of a valid extended squitter transmission has a TYPE subfield with a value in the ranges 9 to 18, then the Encoded Longitude is valid and **shall** be decoded into a longitude value in accordance with Ref. C, Appendix A, §A.1.7.5 (Computations for Airborne, TIS-B and Intent Lat/Lon).

2.2.9.6 ADS-B Version Number from Aircraft Operational Status Message

The ADS-B "Version Number" (VN) subfield of an Aircraft Operational Status Message is located in bit positions 41 to 43 of ME field bit positions 73 to 75 of the extended squitter). If the ME field of a valid extended squitter transmission has a TYPE subfield with a value of 31, then the ADS-B Version Number is valid and **shall** be decoded in accordance with Ref. C §2.2.3.2.7.2.5.

2.2.9.7 Navigation Integrity Category (NIC) from Airborne Position Message

The Navigation Integrity Category (NIC) **shall** be decoded from the TYPE subfield in the Airborne Position Messages in accordance with Ref. C §2.2.3.2.7.2.6. The NIC Supplement subfields are not required for TCAS II passive surveillance.

2.2.9.8 Navigation Accuracy Category for Position (NACp)

The NACp field is encoded in the Aircraft Operational Status Message and the Target State and Status Message.

2.2.9.8.1 NACp from Aircraft Operational Status Message

The NACp subfield of an Aircraft Operational Status Message is located in bit positions 45 to 48 of the ME field (bit positions 77 to 80 of the extended squitter). If the ME field of a valid extended squitter transmission has a TYPE subfield with a value of 31, then the NACp is valid and **shall** be decoded in accordance with Ref. C §2.2.3.2.7.2.7.

2.2.9.8.2 NACp from Target State and Status Message

The NACp subfield of a Target State and Status Message is located in bit positions 40 to 43 of the ME field (bit positions 72 to 75 of the extended squitter). If the ME field of a valid extended squitter transmission has a TYPE subfield with a value of 29, then the NACp is valid and **shall** be decoded in accordance with Ref. C §2.2.3.2.7.1.3.8.

2.2.9.9 Source Integrity Level (SIL)

The SIL field is encoded in the Aircraft Operational Status Message and the Target State and Status Message.

2.2.9.9.1 SIL from Aircraft Operational Status Message

The SIL subfield of an Aircraft Operational Status Message is located in bit positions 51 to 52 of the ME field (bit positions 83 to 84 of the extended squitter). If the ME field of a valid extended squitter transmission has a TYPE subfield with a value of 31, then the SIL is valid and **shall** be decoded in accordance with Ref. C §2.2.3.2.7.2.9.

2.2.9.9.2 SIL from Target State and Status Message

The SIL subfield of a Target State and Status Message is located in bit positions 45 to 46 of the ME field (bit positions 77 to 78 of the extended squitter). If the ME field of a valid extended squitter transmission has a TYPE subfield with a value of 29, then the SIL is valid and **shall** be decoded in accordance with Ref. C §2.2.3.2.7.1.3.10.

2.2.9.10 System Design Assurance (SDA)

The SDA subfield of an Aircraft Operational Status Message is located in bit positions 31 to 32 of the ME field (bit positions 63 to 64 of the extended squitter). If the ME field of a valid extended squitter transmission has a TYPE subfield with a value of 31, then the SDA is valid and **shall** be decoded in accordance with Ref. C §2.2.3.2.7.2.4.6.

2.2.9.11 CPR Format from Surface Position Message

The CPR Format subfield of a Surface Position Message is located in bit position 22 of the ME field (bit position 54 of the extended squitter). This field indicates whether the Encoded Latitude and Encoded Longitude subfields of that Surface Position Message use the even or odd encoding method specified in Ref. C. If the ME field of a valid extended squitter transmission has a TYPE subfield with a value in the ranges 5 to 8, then the CPR Format subfield **shall** be used in conjunction with the Encoded Latitude and Encoded Longitude fields to decode them into latitude and longitude in accordance with Ref. C, Appendix A, §A.1.7.6, Locally Unambiguous Decoding for Surface Position.

2.2.9.12 Encoded Latitude from Surface Position Message

The Encoded Latitude subfield of a Surface Position Message is located in bit positions 23 to 39 of the ME field (bit positions 55 to 71 of the extended squitter). If the ME field of a valid extended squitter transmission has a TYPE subfield with a value in the ranges 5 to 8, then the Encoded Latitude is valid and **shall** be decoded into a latitude value in accordance with Ref. C, Appendix A, §A.1.7.6, Locally Unambiguous Decoding for Surface Position.

2.2.9.13 Encoded Longitude from Surface Position Message

The Encoded Longitude subfield of a Surface Position Message is located in bit positions 40 to 56 of the ME field (bit positions 72 to 88 of the extended squitter). If the ME field of a valid extended squitter transmission has a TYPE subfield with a value in the ranges 5 to 8, then the Encoded Longitude is valid and **shall** be decoded into a longitude value in accordance with Ref. C, Appendix A, §A.1.7.6, Locally Unambiguous Decoding for Surface Position.

2.2.10 Monitoring Requirements

Each TCAS processing cycle, the system will monitor the status of own aircraft latitude and longitude source for reported status and availability. If the source is declared invalid or unavailable, maintenance of tracks using passive data **shall** be disabled and all tracks **shall** transition to active surveillance.

Each TCAS processing cycle, the system **shall** monitor the own ship ground speed input. If the ground speed source is declared invalid or unavailable then use of own ship ground speed for determination of whether own is operating on the airport surface is not permitted as specified in §2.2.8.

TCAS **shall** continue to operate during a failure in own latitude/longitude input or own ground speed input.

The TCAS system **shall** provide an output indicating when the capabilities of hybrid surveillance have been degraded due to the failure of own ship latitude/longitude input, or own ship horizontal position integrity (GPS HPL/HIL), or own ship horizontal position uncertainty (GPS HFOM), or the own ship ground speed input. This output may be used by aircraft display systems or aircraft maintenance systems to alert the flight crew and/or maintenance crew to the input failures.

2.2.11 Interface to CAS Logic

Position data for tracks under passive surveillance may be provided to the CAS logic via the interface specified in Ref. A, §2.2.4.8.1. If this is done, information **shall** be provided in addition to that required in Ref. A, §2.2.4.8.1(a) to distinguish a position report that resulted from a passive reception of an Airborne Position Message from one that resulted from an active interrogation.

The system **shall** not allow tracks under passive surveillance to enter into the Potential_Threat or Threat substates of Intruder_Status (Ref. B, §2.2.4.1.2). To prevent that, the Surveillance_Mode input to the Other_Aircraft state (Ref. B, §2.2.1) **shall** be set to a value other than Normal when a position report from the surveillance interface indicates that it resulted from passive reception of an Airborne Position Message.

When own aircraft is operating on the airport surface per section 2.2.8, the surveillance mode of all aircraft provided to the CAS logic **shall** be set to a value other than Normal to ensure that traffic advisories are not declared against any intruder (active or passive).

Note: The CAS tracking logic is used to process position data for non-threatening traffic prior to displaying it on the pilot's traffic display, as specified in Ref. B. In that role, the CAS tracking logic processes 5-sec position updates that must not be used by the threat detection logic for safety reasons. 5-sec position updates cause the Surveillance_Mode input to be set to Reduced. This allows those targets to enter into the Other_Traffic and Proximate_Traffic substates of Intruder_Status, which may lead to their being displayed to the pilot, but not into the Potential_Threat and Threat substates that lead to Traffic Advisories and Resolution Advisories respectively. Passive reports may be processed similarly, either by using the Reduced value for Surveillance_Mode defined in Ref. B, §2.2.1, or by defining a new value. However, if a new value is defined, there must be a specification of how position reports with that value are to be processed by the CAS logic.

Note: Special consideration should be given to setting the bearing valid flag. A track under passive surveillance that is not expected to have valid active bearing when it transitions to active surveillance should have its bearing flag set to invalid. This prevents a track from being displayed when it would not normally be displayed by TCAS, and therefore prevents a track from being dropped from the display on transition to active surveillance just because hybrid surveillance was implemented.

2.2.12 Hybrid Surveillance Indication in the Data Link Capability Report

The Data Link Capability Report format specified in RTCA/DO-185B, Volume I uses bit 69 to indicate whether the TCAS unit is hybrid surveillance capable. Bit 69 **shall** be set to zero when the unit's 'hybrid surveillance is not operational'. Bit 69 **shall** be set to = 1 when 'hybrid surveillance is fitted and operational'.

Note: The hybrid surveillance algorithms require data concerning own aircraft, e.g. latitude/longitude position information. Hybrid surveillance is not operational unless all the required data are made available and provided to TCAS. Additionally, should flight crew have the capability to enable or disable hybrid surveillance, it is not operational when disabled.

There are five TCAS-related bits in the Data Link Capability Report (Bits 48 and 69-72). These five bits are set or cleared as appropriate by the TCAS unit and sent to the Mode S transponder for downlink to a Mode S ground sensor. Execution of the default DO-185B logic will clear bit 69, meaning that in order to set bit 69, an implementer must modify the TCAS logic so that bit 69 will be set to one when the logic is executed. For details, see DO-185B Volume II, "Interface: Data_Link_Capability_Report," and DO-185B Attachment A, "PROCESS Send_owndata_to_trans."

2.2.13 ADS-B NTA3/NTA6 Range Determination for On-Ground Intruders

When own aircraft is airborne and at or below 2000 ft AGL, the range of Mode S aircraft that are determined to be both on the ground according to their extended squitter CA field, and TCAS-equipped, according to the TCAS Broadcast Interrogations, **shall** have their range determined through use of Surface Position Messages (for the purposes of computation of NTA3 and NTA6 in Ref. A) which meet any of the following criteria:

a) DF=17 Format Type Code 5, 6, 7 or 8
b) On-Ground Ref. K tracks which quality for AIRB of SURF application

A TCAS that does not use Ref. K tracks for determining NTA3 and NTA6 of on-ground TCAS **shall** not use active interrogations to monitor the range unless Surface Position Messages have not been received for over 25 seconds.

Note: The purpose of this requirement is to eliminate interrogations (once every five surveillance intervals) of other on-ground TCAS intruders which are required in Ref. A, §2.2.4.6.2.2.2 when own aircraft is airborne and at or below 2000 ft AGL.

Note: For simplicity, the use of Format Type Code 8 surface squitters without examination of NIC supplement is permitted. The potential error associated with the use of Format Type Code 8 surface squitters will only impact the NTA3 and NTA6 estimates, but will not impact on the TCAS collision avoidance function. It is permissible for an equipment manufacturer to limit the use of Format Type Code 8 squitters through examination of the NIC supplement or NACp as specified in Ref. K or §2.2.5.2.

Legacy TCAS originally certified to TSO-C119c or earlier are not required to implement the requirements of this section if the manufacturer adequately documents that the legacy hardware cannot support this requirement. See the verification test §2.4.2.12 for documentation requirements.

Note: Manufacturers expressed concerns that some legacy TCAS hardware implementations were not designed to handle surface squitters. Although simulations showed that passive monitoring of NTA3 and NTA6 contributed about 1/10 to the 1090 MHz reduction of this system over an RTCA DO-185B system, it was not sufficiently critical to force costly hardware changes to legacy TCAS systems.

2.3 Equipment Performance – Environmental Conditions

TCAS II with hybrid surveillance capability **shall** meet all the requirements stated in Ref. A, §2.3 (Equipment Performance – Environmental Conditions) and Ref. C, §2.3.2.3 (Receivers Shared with a TCAS Unit).

2.4 Equipment Test Procedures

TCAS II with hybrid surveillance **shall** be tested in accordance with Ref. A, §2.4 except where those tests are specifically modified by the tests stated in this subsection. Tests from Ref. C are also called out in some cases.

The test procedures set forth in the following subparagraphs are considered satisfactory for use in determining required performance under standard and stressed conditions. Although specific test procedures are cited, it is recognized that other methods may be preferred by the testing facility. These alternate procedures may be used if the equipment 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 alternate procedures.

2.4.1 Definition of Terms and Condition of Tests

See Ref. A, §2.4.1 and Ref. C, §2.4.1.

2.4.2 Detailed Test Procedures

2.4.2.1 General Scenario Description

This section defines common scenario parameters that are applicable to all tests in this section unless otherwise stated.

2.4.2.1.1 TCAS (Own) Aircraft

Altitude = 12,000 ft.
Position always available
Position: The following positions will be used for own aircraft in the tests. These were selected to check the Airborne Position Message decoding for different geographic areas and areas of high density.

- London lat/lon: 51° 32’ N / 0° 5’ W
- Frankfurt lat/lon: 50° 7’ N / 8° 41’ E
- New York lat/lon: 40° 47’ N / 73° 58’ W
- Dallas lat/lon: 32° 51’ N / 96° 51’ W
- Sydney lat/lon: 33° 52’ S / 151° 12’ E
- São Paulo lat/lon: 23° 33’ S / 46° 38’ W

Velocity	= 0 kt
Heading	= 0 degrees
Sensitivity level Selection	= Automatic
Horizontal Position Uncertainty	= 0.05 NM
Horizontal Position Integrity Bound	= 0.5 NM

2.4.2.1.2 Intruder Aircraft

All the tests specify a range and relative velocity of intruder aircraft with respect to own aircraft. The equipment manufacturer may select what relative azimuth the intruder is with respect to own aircraft.

Set up a nominal difference between all passive and active data so that the correct data source (active or passive) is output or provided to the CAS logic to be verified. The suggested difference is:

- in altitude: 25 ft when quantization is 25 ft.
- in range: 100 ft.

Altitude Q	= 25 ft
CC	= true
Reply/Squitter Power	= -50 dBm
Reply/Squitter Power	= -70 dBm (for version ≥2 ADS-B)

Note: It is acceptable to set the signal level of version ≥2 ADS-B to below the TCAS minimum threshold for up to 10 seconds before the start of the test (T=0) to allow the track to be acquired passively before TCAS.

<u>Active Interrogation Reply (DF=0)</u>
Always available per the intruder set-up in each test scenario. Formatted per Ref. D.

<u>Active Squitter (DF=11)</u>
Always available per the intruder set-up in each test scenario. Formatted per Ref. D.

<u>Long Active Interrogation Reply (DF=16)</u>
Always available per the intruder set-up in each test scenario. Formatted per Ref. D. Used to support the crosslink interrogation.

<u>Airborne Position Message (DF=17)</u>
All intruders, unless otherwise stated, should transmit their Airborne Position Message as required by Ref. C and per the specific field settings defined.

The intruder **shall** transmit DF=17 airborne position squitters at a nominal rate of 2/sec when TCAS is in squitter listening mode. These squitters alternate their CPR Format 0,1,0,1,,,,,,with respective even, odd position encoding.

The following provide the standard data content for Airborne Position Messages.

CA (6-8) =5 (airborne)
AA (9-32) = intruder's address
ME

- Type Code (33-37) = 9
- Surv Status (38-39) = 0
- Single Ant (40) = 0
- Altitude (41-52) = value specified in test, encoding per Ref. C
- Time (53) = 1
- CPR Format (54) = 0/1 alternating with even/odd encoding
- Encoded Latitude (55-71) = Value determined from test own lat, lon, and range to intruder
- Encoded Long (72-88) = Value determined from test own lat, lon, and range to intruder

Airborne Velocity Message

All intruders, unless otherwise stated, should transmit their Airborne Velocity Message per the required encoding and rate as required by Ref. C. This section defines example settings for subfields settings defined in this section. All values are encoded per Ref. C.

CA (6-8) = 5 (airborne)
AA (9-32) = intruder's address
ME

- Type Code (33-37) = 19
- Subtype (38-40) = 1
- Intent Change Flag (41) = 0
- IFR Capability Flag (42) = 1
- NAC_v (43-45) = 4
- E/W Direction Bit (46) = value specified in test
- E/W Velocity (47-56) = value specified in test
- N/S Direction Bit (57) = value specified in test
- N/S Velocity (58-67) = value specified in test
- Vert Rate Source (68) = 1
- Vert Rate Sign (69) = value specified in test
- Vert Rate (70-78) = value specified in test
- Reserved (79-80) = 0
- Difference from Barometric Altitude Sign (81) = 0
- Difference from Barometric Altitude (82-88) = 0

Flight Identification Message

All intruders, unless otherwise stated, should transmit their Flight Identification Message per the required encoding and rate as required by Ref. C and per the subfield settings defined in this section. The equipment manufacturer may specify Ident Chars (41-88) that allow the test aircraft to be individually identified. All values are encoded per Ref. C.

CA (6-8) = 5 (airborne)
AA (9-32) = intruder's address
ME

- Type Code (33-37) = 4
- ADS-B Emitter Category (38-40) = 0
- Ident Char #1 (41-46) = manufacturer specified
- Ident Char #2 (47-52) = manufacturer specified
- Ident Char #3 (53-58) = manufacturer specified
- Ident Char #4 (59-64) = manufacturer specified
- Ident Char #5 (65-70) = manufacturer specified
- Ident Char #6 (71-76) = manufacturer specified
- Ident Char #7 (77-82) = manufacturer specified
- Ident Char #8 (83-88) = manufacturer specified

Note: Squitter Bit field numbering. All the bit field numbering identified in this tests is referenced to the entire DF=17 message and not the ME field numbering.

For intruders that are identified in the test sections to be ADS-B Version Number $\geq$2 targets the Target State and Status Message and the Aircraft Operational Status Message should be transmitted, otherwise these messages should not be transmitted (this identifies them as version=0 intruders).

<u>Target State and Status Message</u>

When specified in the test, ADS-B version 2 intruders should transmit their Target State and Status Message per the required encoding and rate as required by Ref. C and per the subfield settings defined in this section. All values are encoded per Ref. C. Only the subfields applicable to passive surveillance are defined for this message.

CA (6-8) = 5 (airborne)
AA (9-32) = intruder's address
ME
- NACp (72-75) = 7
- SIL (77-79) = 3

<u>Aircraft Operational Status Message</u>

When specified in the test, ADS-B version 2 intruders should transmit their Aircraft Operational Status Message per the required encoding and rate as required per Ref. C and per the subfield settings defined in this section. All values are encoded per Ref. C. Only the subfields applicable to passive surveillance are defined for this message.

CA (6-8) = 5 (airborne)
AA (9-32) = intruder's address
ME
- ADS-B Version Number (73-75) = 2
- NACp (77-80) = 7
- SIL (83-84) = 3
- SDA (63-64) = 2

2.4.2.1.3 Test Success Criteria

The success criteria specified for each test includes margin to account for timing differences between different implementations. Some timing success criteria have as much as 10 sec of allowed variation. These timing variations account for the low interrogation rates (0.1 Hz or 0.016 Hz) required for aircraft being tracked with passive surveillance. The tests, even with the allowed variation in timing, verify correct implementation of the requirements.

Many of the tests specify verifying interrogation rates or intervals. For example tests that indicate that an interrogation interval should be verified from T=A to B are not requiring an interrogation at T=A or B but that the correct interrogation rate is maintained within the interval. Also, the interrogation interval requirements should be checked after that corresponding intruder has become an established track.

Results specified to occur at or within X sec may occur at or within X TCAS surveillance update intervals.

2.4.2.2 Verification of Shared Use of 1090 MHz Receiver with an ADS-B Receiving Subsystem (§2.2.2)

Receivers shared with a TCAS unit **shall** be tested to comply with the test requirements of Ref. C, §2.4.4.2.

Note: The only requirement in this section is for shared receiver systems to meet the requirements of DO-260B §2.2.4.2. The above Hybrid test requirement references the DO-260B test section defined for §2.2.4.2.

2.4.2.3 Verification of Initial Detection of Mode S Targets and Determination of Their Address (§2.2.3)

Performing the tests of Ref. A, Test §2.4.2.1.5.3 accomplish this verification.

2.4.2.4 Verification of Use of Extended Squitter Altitude for Determining Target Validity (§2.2.4)

This test verifies that the TCAS correctly uses the DF=17 encoded altitude for the purposes of monitoring altitude.

Scenario Description

- Intruder 1 verifies §2.2.4 by having an intruder which squitters DF=17 Airborne Position Messages, not qualifying for Extended Hybrid Surveillance, but with valid altitude just within the 10,000 ft TCAS surveillance volume.
- Intruder 2 verifies §2.2.4 by having an intruder which squitters DF=17 Airborne Position Messages, not qualifying for Extended Hybrid Surveillance, but with valid altitude just outside the 10,000 ft TCAS surveillance volume.

TCAS Aircraft
Altitude = 12,000 ft
Altitude Rate = 0 FPM
Position = London

Intruder Aircraft #1
DF=11 transmitted at T=3 and 4
Altitude = 21,900 ft
Altitude Rate = 0 FPM
Range = 2.9 NM at T=0 sec
Relative Speed = 0
DF=17 extended squitters contain invalid position data (format type code is set to 0) or with a reported NACp value < 7, not qualifying for Extended Hybrid Surveillance.

Intruder Aircraft #2
DF=11 transmitted at T=3 and 4
Altitude = 22,100 ft
Altitude Rate = 0 FPM
Range = 2.9 NM at T=0 sec
Relative Speed = 0
DF=17 extended squitters contain invalid position data (format type code is set to 0) or with a reported NACp value < 7, not qualifying for Extended Hybrid Surveillance.

Success Criteria

Intruder 1
The intruder is placed into track by T=8 sec because it is within the altitude surveillance volume.

Intruder 2
The intruder is NOT placed into track. No UF=0 interrogations to this intruder are made by TCAS because the intruder is outside the TCAS altitude surveillance volume.

2.4.2.5 Verification of Acquisition and Maintenance of Established Tracks Using Active Surveillance (§2.2.6)

Test 1 Active Surveillance

Verify that the requirements for maintaining a track under Active Surveillance are met (§2.2.6.1).

Note: *Although this test has multiple intruders, the purpose of this test can be met by running each intruder as an individual test.*

This test verifies that active tracking is maintained for the following reasons: non-correlating Mode S address, lack of DF=17 data, non-crosslink capable transponders, failure to validate intruders, and for being outside of the passive surveillance region.

Scenario Description

- Intruder 1 tests §2.2.6.1.1 by having mismatched active and passive Mode S addresses.
- Intruder 2 tests §2.2.6.1.1, §2.2.9.4 and §2.2.9.5 by having invalid intruder DF=17 position data.
- Intruder 3 tests §2.2.6.1.1 and §2.2.9.2 by having invalid intruder altitude data.
- Intruder 4 tests §2.2.6.3 by having the intruder fail the range validation criteria in the 10 sec interrogation area.
- Intruder 5 tests §2.2.6.3 by having the intruder fail the altitude validation criteria in the 10 sec interrogation area.
- Intruder 6 tests §2.2.6.3 by having the intruder fail the bearing validation criteria in the 10 sec interrogation area.
- Intruder 7 tests that when an initiating track does not meet the passive surveillance region requirements (§2.2.7.1.2) the intruder is tracked actively.
- Intruder 8 tests the condition where validation fails, but subsequent validation passes (§2.2.6.1.1).
- Intruder 9 tests the condition where validation passes, but subsequent revalidation fails and then passes again (§2.2.6.1.2).

TCAS Aircraft
Altitude = 12,000 ft
Altitude Rate = 0 FPM
Position = London

Note: *For easier identification of intruders 1-6, different altitudes and ranges may be used as long as they are within 9,000 ft and 25 NM of own ship; but, ranges less than those defined for intruders 1-6 should not be used.*

<u>Intruder Aircraft #1</u>
Altitude = 17,000 ft
Altitude Rate = 0 FPM
Range = 10 NM at T=0 sec
Relative Speed = -144 kt (-0.04 NM/sec)
DF=17 extended squitters contain a different Mode S address than the Active Replies and DF=11 squitters.
At T=30 the intruder is terminated.

<u>Intruder Aircraft #2</u>
Altitude = 17,000 ft
Altitude Rate = 0 FPM
Range = 10 NM at T=0 sec
Relative Speed = -144 kt (-0.04 NM/sec)
DF=17 extended squitters contain invalid position data (format type code is set to 0).
At T=30 the intruder is terminated.

<u>Intruder Aircraft #3</u>
Altitude = 17,000 ft
Altitude Rate = 0 FPM
Range = 10 NM at T=0 sec
Relative Speed = -144 kt (-0.04 NM/sec)
DF=17 extended squitters contain invalid altitude (AC field is all zeroes).
At T=30 the intruder is terminated.

<u>Intruder Aircraft #4</u>
Altitude = 16,000 ft
Altitude Rate = 0 FPM
Range = 12 NM at T=0 sec
Relative Speed = -360 kt (-0.1 NM/sec)
The Range Difference is 305 m.
At T=30 the intruder is terminated.

<u>Intruder Aircraft #5</u>
Altitude = 16,000 ft
Altitude Rate = 0 FPM
Range = 12 NM at T=0 sec
Relative Speed = -360 kt (-0.1 NM/sec)
The Altitude Difference is 150 ft.
At T=30 the intruder is terminated.

<u>Intruder Aircraft #6</u>
Altitude = 16,000 ft
Altitude Rate = 0 FPM
Range = 12 NM at T=0 sec
Relative Speed = -360 kt (-0.1 NM/sec)
The Bearing Difference is 50 degrees.
At T=30 the intruder is terminated.

Intruder Aircraft #7

Altitude	= 7400 ft
Altitude Rate	= 0 FPM
Range	= 3.1 NM at T=0 sec
Relative Speed	= 0 kt

At T=30 the intruder is terminated.

Intruder Aircraft #8

Altitude	= 17500 ft
Altitude Rate	= 0 FPM
Range	= 10 NM at T=0 sec
Relative Speed	= -144 kt (-0.04 NM/sec)

From T=0 to T=30, DF =17 extended squitters result in a range difference that is 390 m.
From T=31 to T=60, DF=17 extended squitters result in a range difference that is 150 m.
At T=60 the intruder is terminated.

Intruder Aircraft #9

Altitude	= 17,500 ft
Altitude Rate	= 0 FPM
Range	= 2.9 NM at T=0 sec
Relative Speed	= 0 kt

From T=30 to T=50, DF =17 extended squitters result in a range difference that is 390 m.
From T=51 to T=70, DF=17 extended squitters result in a range difference that is 150 m.
At T=90 the intruder is terminated.

Success Criteria

Intruder 1, 2, & 3
UF=0 and RL=0 for all interrogations.
Interrogation interval is 5 sec.
Verify the intruder is tracked using active surveillance.

Intruder 4, 5, & 6
Each interrogation after T=5 is a UF=0, RL=0 interrogation. By T=5, the Mode S track will have had a chance to be acquired and established.
Interrogation interval is no greater than 5 sec.
Verify the intruder is tracked using active surveillance.

Intruder 7
UF=0 and RL=0 for all interrogations.
Interrogation interval is no greater than 5 sec.
Verify the intruder is tracked using active surveillance.

Intruder 8
Each interrogation after T=5 is a UF=0, RL=0 interrogation. By T=5, the Mode S track will have had a chance to be acquired and established.
Interrogation interval is 5 sec.
Verify that at T>=40 that passive data is provided to the CAS Logic/Displays.

Intruder 9
Interrogation rate after T=10 sec is 0.1 Hz (Hybrid).
Interrogation rate after T=40 should be 1 Hz (Active).
Interrogation rate should change to 0.1 Hz after T=52 – this is to verify that only after two successful validation attempts at T=51 and T=52 that the track is transitioned to passive.

Test 2 – Own ship on-ground, Poor intruder quality

Verify that the requirements for maintaining a track under Active Surveillance are met (, §2.2.7.2.2.1).

This test verifies that active tracking is maintained for the following reason: target quality is poor.

Scenario Description

- Intruder 1 tests §2.2.7.2.2.1 by having a target that doesn't meet the ADS-B version criteria (§2.2.5.2.1).
- Intruder 2 tests §2.2.7.2.2.1 by having a target that doesn't meet the reported NIC criteria (§2.2.5.2.1).
- Intruder 3 tests §2.2.7.2.2.1 by having a target that doesn't meet the reported NACp criteria (§2.2.5.2.1).
- Intruder 4 tests §2.2.7.2.2.1 by having a target that doesn't meet the reported SIL criteria (§2.2.5.2.1).
- Intruder 5 tests §2.2.7.2.2.1 by having a target that doesn't meet the reported SDA criteria (§2.2.5.2.1).

TCAS Aircraft
Altitude = 0 ft (Ground Level)
Altitude Rate = 0 FPM
Position = London
Radio altitude input = 0 ft
Ground Speed is valid and at 0 knots and TCAS Air/Ground (OOGROUN) indicates on-ground.

Intruder Aircraft #1
Altitude = 2,800 ft
Altitude Rate = 0 FPM
Range = 3 NM at T=0 sec
Relative Speed = -144 kt (-0.04 NM/sec)
Reply level = -70 dBm
Intruder ADS-B Version Number is 1 for the duration of the test.
At T=30 the intruder is terminated.

Intruder Aircraft #2
Altitude = 2,800 ft
Altitude Rate = 0 FPM
Range = 3 NM at T=0 sec
Relative Speed = -144 kt (-0.04 NM/sec)
Intruder NIC is 5 for the duration of the test.
Intruder ADS-B Version Number is 2 for the duration of the test.
At T=30 the intruder is terminated.

Intruder Aircraft #3

Altitude	= 2,800 ft
Altitude Rate	= 0 FPM
Range	= 3 NM at T=0 sec
Relative Speed	= -144 kt (-0.04 NM/sec)

Intruder NACp is 6 for the duration of the test.
Intruder ADS-B Version Number is 2 for the duration of the test.
At T=30 the intruder is terminated.

Intruder Aircraft #4

Altitude	= 2,800 ft
Altitude Rate	= 0 FPM
Range	= 3 NM at T=0 sec
Relative Speed	= -144 kt (-0.04 NM/sec)

Intruder SIL is 2 for the duration of the test.
Intruder ADS-B Version Number is 2 for the duration of the test.
At T=30 the intruder is terminated.

Intruder Aircraft #5

Altitude	= 2,800 ft
Altitude Rate	= 0 FPM
Range	= 3 NM at T=0 sec
Relative Speed	= -144 kt (-0.04 NM/sec)

Intruder SDA is 1 for the duration of the test.
Intruder ADS-B Version Number is 2 for the duration of the test.
At T=30 the intruder is terminated.

Success Criteria

Intruders 1 through 5
Each interrogation after T=5 is a UF=0, RL=0 interrogation. By T=5, the Mode S track will have had a chance to be acquired and established.
Interrogation interval is 1 sec.
Verify the intruder is tracked using active surveillance.

Test 3a – Own ship on-ground with bad horizontal position uncertainty

Verify that the requirements for maintaining a track under Active Surveillance are met (§2.2.7.2.2.1).

This test verifies that active tracking is maintained for the following reason: Own ship horizontal position uncertainty is bad.

Scenario Description

- Intruder 1 tests §2.2.7.2.2.1 by having an own ship that doesn't meet the quality criteria (§2.2.5.2.1).

TCAS Aircraft
Altitude = 0 ft (Ground Level)
Altitude Rate = 0 FPM
Position = London
Own ship horizontal position uncertainty (95%) is 0.3 NM
Radio altitude input = 0 ft
Ground Speed is valid and at 0 knots and TCAS Air/Ground (OOGROUN) indicates on-ground.

Intruder Aircraft #1
Altitude = 2,800 ft
Altitude Rate = 0 FPM
Range = 10 NM at T=0 sec
Relative Speed = -144 kt (-0.04 NM/sec)
At T=30 the intruder is terminated.

Success Criteria

Intruder 1
Each interrogation after T=5 is a UF=0, RL=0 interrogation. By T=5, the Mode S track will have had a chance to be acquired and established.
Interrogation interval is 5 sec.
Verify the intruder is tracked using active surveillance.

Test 3b – Own ship on-ground with bad horizontal position integrity bounds

Verify that the requirements for maintaining a track under Active Surveillance are met (§2.2.7.2.2.1).

This test verifies that active tracking is maintained for the following reason: Own ship horizontal position integrity bound is poor.

Scenario Description

- Intruder 1 tests §2.2.7.2.2.1by having an own ship that doesn't meet the quality criteria (§2.2.5.2.1).

TCAS Aircraft
Altitude = 0 ft (Ground Level)
Altitude Rate = 0 FPM
Position = London
Own ship horizontal position integrity bounds is > 0.6 NM with an integrity level of $1e^{-7}$
Radio altitude input = 0 ft
Ground Speed is valid and at 0 knots and TCAS Air/Ground (OOGROUN) indicates on-ground.

Intruder Aircraft #1
Altitude = 2,800 ft
Altitude Rate = 0 FPM
Range = 10 NM at T=0 sec
Relative Speed = -144 kt (-0.04 NM/sec)
At T=30 the intruder is terminated.

Success Criteria

Intruder 1
Each interrogation after T=5 is a UF=0, RL=0 interrogation. By T=5, the Mode S track will have had a chance to be acquired and established.
Interrogation interval is 5 sec.
Verify the intruder is tracked using active surveillance.

Test 4a– Own ship on-ground with extended hybrid

Verify that the requirements for maintaining a track under Extended Hybrid Surveillance are met (§2.2.7.2.2.1).

This test verifies that passive tracking is maintained for the following reasons: own ship is on-ground with good own ship and target traffic quality.

Scenario Description

- Intruder 1 tests §2.2.7.2.2.1by having a target that meets the Extended Hybrid Surveillance criteria. (§2.2.5.2).

TCAS Aircraft
Altitude = 0 ft (Ground Level)
Altitude Rate = 0 FPM
Position = London
Radio altitude input = 0 ft
Ground Speed is valid and at 0 knots and TCAS Air/Ground (OOGROUN) indicates on-ground.

Intruder Aircraft #1
Altitude = 2,800 ft
Altitude Rate = 0 FPM
Range = 3 NM at T=0 sec
Relative Speed = -144 kt (-0.04 NM/sec)
At T=30 the intruder is terminated.

Success Criteria

Intruder 1
Verify that there are no interrogations after T=5 since the target is tracked by Extended Hybrid surveillance. By T=5, the Mode S track will have had a chance to be acquired and established.
Verify the intruder is tracked using passive surveillance.

Test 4b – Own ship transitions to on-ground with extended hybrid

Verify that the requirements for maintaining a track under Extended Hybrid Surveillance are met (§2.2.7.2.2.1).

This test verifies that passive tracking is maintained for the following reasons: own ship transitions to on-ground with good own ship and target traffic quality.

Scenario Description

- Intruder 1 tests §2.2.7.2.2.1by having a target that meets the Extended Hybrid Surveillance criteria. (§2.2.5.2).

TCAS Aircraft
Altitude = 0 ft (Ground Level)
Altitude Rate = 0 FPM
Position = London
Own ship horizontal position uncertainty (95%) is 0.05 NM
Own ship horizontal position integrity bounds is < 0.5 NM with an integrity level of $1e^{-7}$
Ground Speed is valid and at 0 knots
Radio altitude input > 100 ft prior to T=15, at T=15 it transitions to < 50 ft (this forces TCAS Air/Ground, OOGROUN, to transition from airborne to ground after T=15).

Intruder Aircraft #1
Altitude = 2,800 ft
Altitude Rate = 0 FPM
Range = 3 NM at T=0 sec
Relative Speed = -144 kt (-0.04 NM/sec)
Reply/Squitter Power = -50dBm
At T=30 the intruder is terminated.

Success Criteria

Intruder 1
Each interrogation from T=5 to T=15 is a UF=0, RL=0 interrogation. By T=5, the Mode S track will have had a chance to be acquired and established.
Interrogation interval is 1 sec.
Verify the intruder is tracked using active surveillance from T=5 to T=15.
Verify that there are no interrogations after T=20 since the target is tracked by Extended Hybrid surveillance.
Verify the intruder is tracked using passive surveillance after T=20.

2.4.2.6 Verification of Maintenance of Established Tracks Using Passive Surveillance (§2.2.7)

Note: Although this test has multiple intruders, the purpose of this test can be met by running each intruder as an individual test.

Test 1
This test will verify that tracks that do not meet the range or altitude criteria of §2.2.7.1 are tracked using passive surveillance while being revalidated with TCAS active range measurements at the correct rate per §2.2.7.5. The test also verifies that the Surveillance Mode is set correctly per §2.2.7.6. Additional requirement coverage is identified in the tests scenarios descriptions below.

Scenario Description

- Intruders 1 & 2 start out far enough beyond the criteria taus to be revalidated at a 60 sec interval. Intruder 2 will then meet the criteria to switch to a 10 sec interrogation interval.
- Intruder 1 will meet the active range criteria (§2.2.6.1.4), but it will never meet the altitude criteria and therefore is tracked passively with a 60 second revalidation rate. This test also demonstrates correct decoding of the TYPE subfield (§2.2.9.1).
- Intruder 2 will meet the active altitude criteria (§2.2.6.1.4), but it will never meet the range criteria and therefore is tracked passively with a 60 second revalidation rate when the altitude criteria is false and a 10 second revalidation rate when the altitude criteria is true.
- Intruder 3 meets the criteria to be passively tracked with a 10 sec interrogation interval even though the bearing is unavailable (§2.2.6.3).

TCAS Aircraft
Altitude = 12,000 ft
Altitude Rate = 0 FPM
Position = Sydney

Intruder Aircraft #1
Altitude = 17,000 ft
Altitude Rate = 0 FPM
Range = 10 NM at T=0 sec
Relative Speed = -144 kt (-0.04 NM/sec)
At T=200 the intruder is terminated.

Intruder Aircraft #2
Altitude = 18,100 ft at T=0
Altitude Rate = -600 FPM
Range = 3.5 NM
Relative Speed = 0 kt
At T=200 the intruder is terminated.

Note: *In a realistic simulation it is not possible to maintain a constant slant range while changing the relative altitude. Some small relative speed is permitted.*

Intruder Aircraft #3
Altitude = 8000 ft
Altitude Rate = 0 FPM
Range = 9 NM at T=0 sec
Relative Speed = -360 kt (-0.1 NM/sec)

At T=15 the Active Bearing becomes unavailable. One method for achieving this is to have the target tracked only on a bottom OMNI antenna.
At T=45 the intruder is terminated.

Success Criteria

Intruder 1
Verify the following:
1) Acquisition interrogations have RL=0.
2) From T=10 to T=200 validation interrogations, spaced by 60 seconds, are transmitted to this intruder.
3) All validation interrogations (after T=10) are standard TCAS surveillance interrogations (UF=0 RL=0).
4) After T=10 the Surveillance Mode is always marked as not Normal (Reduced).
5) Verify the intruder is tracked using passive surveillance by at least T=10.

Intruder 2
Verify the following:
1) From T=10 to T=90 validation interrogations, spaced by 60 seconds, are transmitted to this intruder.
2) All validation interrogations (after T=10) are standard TCAS surveillance interrogations (UF=0, RL=0).
3) From T=110 to T=200 a validation interrogation is transmitted once every 10 sec to the intruder aircraft.
4) After T=10, the Surveillance Mode is always marked as not Normal (Reduced).
5) Verify the intruder is tracked using passive surveillance after T=10.

Intruder 3
Verify the following:
1) From T=10 to T=45, a validation interrogation is transmitted to the intruder aircraft once every 10 seconds.
2) After T=10, the Surveillance Mode is always marked as not Normal (Reduced).
3) Verify that passive data is passed to the CAS Logic/Displays after T=10.

Test 2
This test verifies basic tracking when updating the track with Airborne Position Messages.

Scenario Description

- Intruder 1 shows the implementation of range correlation windows (§2.2.7.3) and correct CPR decoding (§2.2.9.3).
- Intruder 2 shows the implementation of altitude correlation windows for passive tracks (§2.2.7.3).
- Intruder 3 shows that the passive track will be coasted when a position squitter is not received for a short period of time (§2.2.7.4).
- Intruder 4 shows that the passive track will be coasted when an invalid position squitter is received for a short period of time (§2.2.7.4).

TCAS Aircraft

Altitude	= 12,000 ft
Altitude Rate	= 0 FPM
Position	= New York

Intruder Aircraft #1

Altitude	= 17,000 ft
Altitude Rate	= 0 FPM
Range	= 10 NM at T=0 sec
Relative Speed	= -144 kt (-0.04 NM/sec)

At T=15 the reported position data jumps so that the calculated slant range value jumps ≥0.25 and < 0.6NM for 1 sec. The range jump is timed so as not to occur during validation.
At T=45 the intruder is terminated.

Intruder Aircraft #2

Altitude	= 18,100 ft at T=0
Altitude Rate	= -600 FPM
Range	= 3.5 NM
Relative Speed	= 0 kt

At T=15 the reported altitude jumps so that the altitude is reported as 18,550 ft for 1 sec. This should produce a jump in altitude of 600 ft, resulting in miscorrelation, and therefore coasting of the altitude. The altitude jump is timed so as not to occur during validation.
At T=45 the intruder is terminated.

Intruder Aircraft #3

Altitude	= 7000 ft
Altitude Rate	= 0 FPM
Range	= 10 NM at T=0 sec
Relative Speed	= -144 kt (-0.04 NM/sec)

At T=30 – 31 No Position Squitters.
At T=45 the intruder is terminated.

Intruder Aircraft #4

Altitude	= 7000 ft
Altitude Rate	= 0 FPM
Range	= 10 NM, at T=0 sec
Relative Speed	= -144 kt (-0.04 NM/sec)

At T=30 – 31 Invalid Position Squitters (format type code set to 0).
At T=45 the intruder is terminated.

Success Criteria

Intruder 1
The surveillance reports to the CAS logic are present for the duration of the track.
Verify that the track is under passive surveillance.
The surveillance report's range valid flag (Ref. A, §2.2.4.8.1a) is always set to valid except for the time of the range jump when this flag is set to coast.
No interrogations of the intruder aircraft from T = 10 to T = 45.

Intruder 2
The surveillance report's altitude valid flag (Ref. A, §2.2.4.8.1a) is always set to valid except for the time of the altitude jump when this flag is set to coast.
Verify that the track is under passive surveillance.
No interrogations of the intruder aircraft from T = 10 to T = 45.

Intruder 3
The surveillance report's range valid flag (Ref. A, §2.2.4.8.1a) is always set to valid except for the time of the No Position Squitters when this flag is set to coast.
Verify that the track is under passive surveillance.
No interrogations of the intruder aircraft from T = 10 to T = 45.

Intruder 4
The surveillance report's range valid flag (Ref. A, §2.2.4.8.1a) is always set to valid except for the time of the Invalid Position Squitters when this flag is set to coast.
Verify that the track is under passive surveillance.
No interrogations of the intruder aircraft from T = 10 to T = 45.

Test 3 (range tau=false after active to passive transition §2.2.6.1.4)
This test verifies that when a track initially transitions to passive surveillance that the 2nd criteria (range tau) of §2.2.6.1.4 is assumed to be false until a passive range rate estimate is available or until the track is dropped or transitions back to active surveillance.

The requirement being tested is a corner case, and designing a test which is design independent is difficult. Therefore the equipment manufacturer must design a test that shows coverage of the requirement identified above.

Test 4 (Establish an Extended Hybrid Surveillance Track §2.2.5.2.2)
This test verifies that when qualifying ADS-B reports are received an Extended Hybrid Surveillance Track is established. It also verifies that a track is not established if the reports do not meet the required criteria of §2.2.5.2.2.

(The following tests may be performed using ADS-B reports or directly decoded ADS-B messages. TIS-B and ADS-R data is not permitted.)

Scenario Description

- Intruder 1 will provide ADS-B reports at T = 1 and 6 seconds which is just outside the limit (2 within 5 seconds) for establishing an extended hybrid surveillance track. (§2.2.5.2.2).
- Intruder 2 will provide ADS-B reports at T= 1, 2 and 3 which meets the criteria for extended hybrid surveillance, however, the reported altitude in the reports is not within 500 feet. (§2.2.5.2.2).
- Intruder 3 will provide ADS-B reports at T= 1 and 2 which meets the criteria for extended hybrid surveillance, however, the Q-bit values in the reports are different. (§2.2.5.2.2).
- Intruder 4 will provide ADS-B reports at T= 1, 2, 3, and 4 which meet the criteria for extended hybrid surveillance, however, the ICAO address in the reports are different (1st and 2nd are different valid addresses, 3rd is all ones, 4th is all zeros.) (§2.2.5.2.2).
- Intruder 5 will meet all criteria for extended hybrid surveillance (ADS-B reports at T= 1 and 5 that have same altitude, same Q-bit value and same valid ICAO address. (§2.2.5.2.2).

TCAS Aircraft

Altitude	= 12,000 ft
Altitude Rate	= 0 FPM
Position	= Sydney

<u>Intruder Aircraft #1</u>
Altitude = 17,000 ft
Altitude Rate = 0 FPM
Range = 3.2 NM at T=0 sec
Relative Speed = 0 kt
ADS-B Version Number=2
ADS-B report at T= 1 and 6 seconds
At T=10 the intruder is terminated.

<u>Intruder Aircraft #2</u>
Altitude = 17,200 ft
Altitude Rate = 0 FPM
Range = 3.4 NM at T=0 sec
Relative Speed = 0 kt
ADS-B Version Number=2
ADS-B report at T= 1 (Altitude = 17,200), 2 (Altitude = 17725) and 3 (Altitude = 16,675)
At T=10 the intruder is terminated.

<u>Intruder Aircraft #3</u>
Altitude = 17,400 ft
Altitude Rate = 0 FPM
Range = 3.6 NM at T=0 sec
Relative Speed = 0 kt
ADS-B Version Number=2
ADS-B report at T= 1 (Q-bit = 0), and 2 (Q-bit = 1)
At T=10 the intruder is terminated.

<u>Intruder Aircraft #4</u>
Altitude = 17,600 ft
Altitude Rate = 0 FPM
Range = 3.8 NM at T=0 sec
Relative Speed = 0 kt
ADS-B Version Number=2
ADS-B report at T= 1, 2, 3, 4 and 5 seconds with ICAO address = assigned address at T=1, Assigned Address + 1 at T=2, all zeros at T=3, all ones at T=4.
At T=10 the intruder is terminated.

<u>Intruder Aircraft #5</u>
Altitude = 17,800 ft
Altitude Rate = 0 FPM
Range = 4.0 NM at T=0 sec
Relative Speed = 0 kt
ADS-B Version Number=2
ADS-B report at T= 1 and 5 seconds.
At T=10 the intruder is terminated.

Success Criteria

Intruders 1, 2, 3 and 4
The intruder is not established as an extended hybrid surveillance track.

Intruder 5
The Intruder is established as an Extended Hybrid Surveillance track after reception of the 2nd ADS-B report.

Test 5 (track using extended hybrid surveillance based on range/altitude criteria §2.2.6.1.4)
This test verifies that when a track meets the range/altitude conditions for extended hybrid surveillance it will be passively tracked without validation. Two intruder aircraft will be simulated. One will qualify for extended hybrid surveillance based on altitude and the other will qualify based on range.

(The following tests may be performed using ADS-B reports or directly decoded ADS-B messages. TIS-B and ADS-R data is not permitted.)

Scenario Description

- Intruder 1 shows that when an intruder meets all conditions for extended hybrid surveillance and is within the range but not the altitude criteria of the active surveillance region it is tracked passively without validation. (§2.2.5.2; §2.2.5.2.1; §2.2.5.2.2, §2.2.5.2.3, §2.2.6.1.4).
- Intruder 2 shows that when an intruder meets all conditions for extended hybrid surveillance and is within the altitude but not the range criteria of the active surveillance region it is tracked passively without validation. (§2.2.5.2; §2.2.5.2.1; §2.2.5.2.2, §2.2.5.2.3; §2.2.6.1.4).

TCAS Aircraft
Altitude = 12,000 ft
Altitude Rate = 0 FPM
Position = Sydney

Intruder Aircraft #1
Altitude = 16,600 ft
Altitude Rate = 0 FPM
Range = 2.8 NM at T=0 sec
Relative Speed = 0 kt
ADS-B Version Number=2
At T=100 the intruder is terminated.

Intruder Aircraft #2
Altitude = 12,000 ft
Altitude Rate = 0 FPM
Range = 3.2 NM at T=0 sec
Relative Speed = 0 kt
ADS-B Version Number=2
At T=100 the intruder is terminated.

Success Criteria

Intruder 1 and 2
The surveillance reports to the CAS logic are present for the duration of the track.
Verify that the track is under passive surveillance.
No validation/revalidation interrogations are transmitted to the intruders.

Test 6 (Validation required due to Own Ship Horizontal Position Uncertainty §2.2.5.2, §2.2.5.2.1)

This test verifies that an intruder that would otherwise qualify for extended hybrid surveillance will require validation when the own aircraft traffic quality requirement (Own Ship Horizontal Position Uncertainty (95%) is < 0.1 NM) is not met. (§2.2.5.2; §2.2.5.2.1)

(The following tests may be performed using ADS-B reports or directly decoded ADS-B messages. TIS-B and ADS-R data is not permitted.)

TCAS Aircraft
Altitude = 12,000 ft
Altitude Rate = 0 FPM
Position = Sydney
Own Ship Horizontal Position Uncertainty (95%) is ≥ 0.1 NM

Intruder Aircraft #1
Altitude = 13,000 ft
Altitude Rate = 0 FPM
Range = 3.2 NM at T=0 sec
Relative Speed = 0 kt
ADS-B Version Number = 2
At T=40 the intruder is terminated.

Success Criteria

Intruder 1
The surveillance reports to the CAS logic are present for the duration of the track.
Verify that the track is under passive surveillance.
Verify that validation/revalidation interrogations are transmitted to the intruder every 10 seconds.

Test 7 (Validation required due to Own Ship Horizontal Position Integrity §2.2.5.2, §2.2.5.2.1)

This test verifies that an intruder that would otherwise qualify for extended hybrid surveillance will require validation when the own aircraft traffic quality requirement (Own Ship Horizontal Position Integrity bounds is < 0.6 with an integrity level of $1e^{-7}$) is not met. (§2.2.5.2; §2.2.5.2.1)

(The following tests may be performed using ADS-B reports or directly decoded ADS-B messages. TIS-B and ADS-R data is not permitted.)

TCAS Aircraft
Altitude = 12,000 ft
Altitude Rate = 0 FPM
Position = Sydney
Own Ship Horizontal Position Integrity bounds is ≥ 0.6 with an integrity level of $1e^{-7}$

Intruder Aircraft #1

Altitude	= 13,000 ft
Altitude Rate	= 0 FPM
Range	= 3.2 NM at T=0 sec
Relative Speed	= 0 kt

ADS-B Version Number = 2
At T=40 the intruder is terminated.

Success Criteria

Intruder 1
The surveillance reports to the CAS logic are present for the duration of the track.
Verify that the track is under passive surveillance.
Verify that validation/revalidation interrogations are transmitted to the intruder every 10 seconds.

Test 8 (Validation required due to Intruder Aircraft Traffic Quality or Signal Level Requirements §2.2.5.2, §2.2.5.2.1, §2.2.5.2.3)

This test verifies that when one of the Intruder Aircraft Traffic Quality requirements for extended hybrid surveillance is not met the hybrid surveillance track will require validation.

(The following tests may be performed using ADS-B reports or directly decoded ADS-B messages. TIS-B and ADS-R data is not permitted.)

Scenario Description

- Intruder 1 shows that when an intruder meets all conditions for extended hybrid surveillance except for Traffic Quality Requirements (ADS-B Version Number) it will be tracked passively with validation (§2.2.5.2.1).
- Intruder 2 shows that when an intruder meets all conditions for extended hybrid surveillance except for Traffic Quality Requirements (Reported NIC) it will be tracked passively with validation (§2.2.5.2.1).
- Intruder 3 shows that when an intruder meets all conditions for extended hybrid surveillance except for Traffic Quality Requirements (Reported NACp) it will be tracked passively with validation (§2.2.5.2.1).
- Intruder 4 shows that when an intruder meets all conditions for extended hybrid surveillance except for Traffic Quality Requirements (Reported SIL≠3) it will be tracked passively with validation (§2.2.5.2.1).
- Intruder 5 shows what when an intruder meets all conditions for extended hybrid surveillance except for Traffic Quality Requirements (Reported SDA ≠2 or 3) it will be tracked passively with validation (§2.2.5.2.1).
- Intruder 6 shows that when an intruder meets all conditions for extended hybrid surveillance except for Traffic Quality Requirements (Invalid Barometric Altitude) it will be tracked passively with validation (§2.2.5.2.1).
- Intruder 7 shows that when an intruder meets all conditions for extended hybrid surveillance (extended hybrid surveillance MTL) it will be tracked passively with validation (§2.2.5.2.3).

TCAS Aircraft

Altitude	= 12,000 ft
Altitude Rate	= 0 FPM
Position	= Sydney

Intruder Aircraft #1

Altitude	= 13,000 ft
Altitude Rate	= 0 FPM
Range	= 3.2 NM at T=0 sec
Relative Speed	= 0 kt

ADS-B Version Number = 2
At T=40 the intruder is terminated.

Intruder Aircraft #2

Altitude	= 13,200 ft
Altitude Rate	= 0 FPM
Range	= 3.4 NM at T=0 sec
Relative Speed	= 0 kt

ADS-B Version Number=2
Reported NIC < 6
At T=40 the intruder is terminated.

Intruder Aircraft #3

Altitude	= 13,400 ft
Altitude Rate	= 0 FPM
Range	= 3.6 NM at T=0 sec
Relative Speed	= 0 kt

ADS-B Version Number=2
Reported NACp < 7
At T=40 the intruder is terminated.

Intruder Aircraft #4

Altitude	= 13,600 ft
Altitude Rate	= 0 FPM
Range	= 3.8 NM at T=0 sec
Relative Speed	= 0 kt

ADS-B Version Number=2
Reported SIL ≠ 3
At T=40 the intruder is terminated.

Intruder Aircraft #5

Altitude	= 13,800 ft
Altitude Rate	= 0 FPM
Range	= 4.0 NM at T=0 sec
Relative Speed	= 0 kt

ADS-B Version Number=2
Reported SDA ≠ 2 or 3
At T=40 the intruder is terminated.

Intruder Aircraft #6
Altitude = 14,000 ft
Altitude Rate = 0 FPM
Range = 4.2 NM at T=0 sec
Relative Speed = 0 kt
ADS-B Version Number=2
Invalid Barometric Altitude
At T=100 the intruder is terminated.

Intruder Aircraft #7
Altitude = 14,200 ft
Altitude Rate = 0 FPM
Range = 4.4 NM at T=0 sec
Relative Speed = 0 kt
ADS-B Version Number=2
At T=40 the intruder is terminated.

Success Criteria

Intruder 1 through 7
The surveillance reports to the CAS logic are present for the duration of the track.
Verify that the track is under passive surveillance.
Verify that validation/revalidation interrogations are transmitted to each of the intruders every 10 seconds.

Test 9 (Validation required due to Signal Level Requirements based Interference Limiting MTL §2.2.5.2, §2.2.5.2.1, §2.2.5.2.3)
This test verifies that when interference limiting is invoked the system correctly uses the interference limiting MTL to determine whether an intruder aircraft should be tracked using extended hybrid surveillance.

(The manufacturer will devise a test that demonstrates that when interference limiting is in effect and the interference limiting MTL is greater than the extended hybrid surveillance MTL the system uses the interference limiting MTL to determine whether validation/revalidation should be performed.)

Scenario Description

Intruder Simulation begins once the interference limiting criteria are established.

- Intruder 1 shows that when an intruder meets all conditions for extended hybrid surveillance except for the Intruder Signal Strength > IL MTL (extended Interference Limiting MTL) it will be tracked passively with validation (§2.2.5.2.3).
- Intruder 2 shows that when an intruder meets all conditions for extended hybrid surveillance and the Intruder Signal Strength < IL MTL (extended Interference Limiting MTL) it will be tracked passively without validation (§2.2.5.2.3).

TCAS Aircraft
Altitude = 12,000 ft
Altitude Rate = 0 FPM
Position = Sydney
Interference Limiting in effect such that MTL is raised to $\geq$ -64 dBm

Intruder Aircraft #1
Altitude = 13,000 ft
Altitude Rate = 0 FPM
Range = 3.2 NM at T=0 sec
Relative Speed = 0 kt
Reply Power = -62 dBm
ADS-B Version Number = 2
At T=40 the intruder is terminated.

Intruder Aircraft #2
Altitude = 13,200 ft
Altitude Rate = 0 FPM
Range = 3.4 NM at T=0 sec
Relative Speed = 0 kt
Reply Power = -66 dBm
ADS-B Version Number = 2
At T=40 the intruder is terminated.

Success Criteria

Intruder 1
The surveillance reports to the CAS logic are present for the duration of the track.
Verify that the track is under passive surveillance.
Verify that validation/revalidation interrogations are transmitted to the intruder every 10 seconds.

Intruder 2
The surveillance reports to the CAS logic are present for the duration of the track.
Verify that the track is under passive surveillance.
Verify that validation/revalidation interrogations are not transmitted to the intruder.

Test 10 (Track Using Extended Hybrid Surveillance when on Surface. §2.2.5.2, §2.2.7.1.1, §2.2.7.6, §2.2.8)

This test verifies that an intruder that would otherwise be tracked using hybrid or active surveillance will be tracked using extended hybrid surveillance (no validation) when own aircraft is on the surface. (§2.2.5.2; §2.2.7.1.1, §2.2.7.6, §2.2.8)

(The following tests may be performed using ADS-B reports or directly decoded ADS-B messages. TIS-B and ADS-R data is not permitted.)

- Intruder 1 shows that when an intruder meets the conditions for extended hybrid surveillance and is within both the range and altitude criteria of the active surveillance region it is tracked passively without validation as long as own aircraft is on the surface. (§2.2.5.2; §2.2.7.1.1; §2.2.8). It will also demonstrate that no TCAS advisories are issued for the "Passive" track. (§2.2.7.6)

<u>TCAS Aircraft</u>

Altitude = 12,000 ft
Altitude Rate = 0 FPM
Position = Sydney
From T= 0 – 30
On Surface – Radio Altitude = 40 feet
AND Ground Speed = 20 knots
From T= 31 – 60
Airborne/Taking Off- Radio Altitude = 0 feet
Ground Speed = 40 knots
From T= 61 – 90
On Surface – Radio Altitude = 40 feet
AND Ground Speed = 20 knots
From T= 91 – 120
Airborne/Taking Off- Radio Altitude = 55 feet
Ground Speed = 0 knots

<u>Intruder Aircraft #1</u>

Altitude = 12,000 ft
Altitude Rate = 0 FPM
Range = 0.2 NM at T=0 sec
Relative Speed = 0 kt (-0.03 NM/s)
ADS-B Version Number=2
At T=120 the intruder is terminated.

<u>Success Criteria</u>

Intruder 1
The surveillance reports to the CAS logic are present for the duration of the track.
Verify that the track is under passive surveillance and no validation/revalidation interrogations are transmitted to the intruder from T=0 to 30 and T = 66 to 90 seconds.
Verify that the track is under active surveillance from T=36 to 60 and T=96 to 120 seconds.
Verify that the track is identified as a "Reduced Surveillance" track in the CAS record and no "Traffic" advisories are issued when the track is under passive surveillance.

<u>Test 11 (Intruder Revalidation Rate §2.2.7.5)</u>

This test verifies the revalidation rate based on intruder range and range rate (§2.2.7.5).

(The following tests may be performed using ADS-B reports or directly decoded ADS-B messages. TIS-B and ADS-R data is not permitted.)

<u>Scenario Description</u>

- Intruder 1 - 10 show that when an intruder is within the altitude but not the range criteria for active surveillance it will be tracked using hybrid surveillance with a variable revalidation rate according to the requirements in (§2.2.7.5).
- Intruder 11 shows that when and intruder does not meet the altitude criteria for active surveillance but is within the range criteria it will be tracked using hybrid surveillance with a 60 second revalidation rate (§2.2.7.5).

TCAS Aircraft

Altitude	= 12,000 ft
Altitude Rate	= 0 FPM
Position	= Sydney

Intruder Aircraft #1

Altitude	= 12,000 ft
Altitude Rate	= 0 FPM
Range	= 13 NM
Relative Speed	= 0 kt

At T=100 the intruder is terminated.

Intruder Aircraft #2

Altitude	= 12,000 ft
Altitude Rate	= 0 FPM
Range	= 12 NM
Relative Speed	= 0 kt

At T=100 the intruder is terminated.

Intruder Aircraft #3

Altitude	= 12,000 ft
Altitude Rate	= 0 FPM
Range	= 9 NM
Relative Speed	= 0 kt

At T=100 the intruder is terminated.

Intruder Aircraft #4

Altitude	= 12,000 ft
Altitude Rate	= 0 FPM
Range	= 8 NM
Relative Speed	= 0 kt

At T=100 the intruder is terminated.

Intruder Aircraft #5

Altitude	= 12,000 ft
Altitude Rate	= 0 FPM
Range	= 7 NM
Relative Speed	= 0 kt

At T=100 the intruder is terminated.

Intruder Aircraft #6

Altitude	= 12,000 ft
Altitude Rate	= 0 FPM
Range	= 6 NM
Relative Speed	= 0 kt

At T=100 the intruder is terminated.

Intruder Aircraft #7

Altitude	= 12,000 ft
Altitude Rate	= 0 FPM
Range	= 5 NM
Relative Speed	= 0 kt

At T=100 the intruder is terminated.

Intruder Aircraft #8

Altitude	= 12,000 ft
Altitude Rate	= 0 FPM
Range	= 34 NM
Relative Speed	= -1200 kt

At T=100 the intruder is terminated.

Intruder Aircraft #9

Altitude	= 12,000 ft
Altitude Rate	= 0 FPM
Range	= 30 NM
Relative Speed	= -600 kt

At T=100 the intruder is terminated.

Intruder Aircraft #10

Altitude	= 12,000 ft
Altitude Rate	= 0 FPM
Range	= 3.4 NM
Relative Speed	= 300 kt

At T=100 the intruder is terminated.

Intruder Aircraft #11

Altitude	= 17,000 ft
Altitude Rate	= 0 FPM
Range	= 2.8 NM
Relative Speed	= 0 kt

At T=100 the intruder is terminated.

Success Criteria

For the tests in this section the revalidation rate for each applicable success criteria was identified using the table in §2.2.7.5. If the implementation uses the equation method then the revalidation interval can be longer by 10 to 20 seconds. Care should be taken to verify that they success criteria matches the value expected based on the implementation.

For each intruder:

> The surveillance reports to the CAS logic are present for the duration of the track.
> Verify that the track is under passive surveillance.

Intruder 1
Verify that revalidation interrogations are transmitted every 60 seconds.

Intruder 2
Verify that revalidation interrogations are transmitted every 40 seconds.

Intruder 3
Verify that revalidation interrogations are transmitted every 40 seconds.

Intruder 4
Verify that revalidation interrogations are transmitted every 30 seconds.

Intruder 5
Verify that revalidation interrogations are transmitted every 20 seconds.

Intruder 6
Verify that revalidation interrogations are transmitted every 20 seconds.

Intruder 7
Verify that revalidation interrogations are transmitted every 10 seconds.

Intruder 8
Verify that the first revalidation interrogation is transmitted 20 seconds after initial validation and then every 10 seconds until the intruder transitions to active tracking at 20 NM.

Intruder 9
Verify that the first revalidation interrogation is transmitted 40 seconds after initial validation, the 2nd at 30 seconds after the 1st revalidation and the 3rd at 20 seconds after the 2nd revalidation.

Intruder 10
Verify that revalidation interrogations are transmitted every 60 seconds.

Intruder 11
Verify that revalidation interrogations are transmitted every 60 seconds.

<u>Test 12 (Signal Strength Estimation (§2.2.5.2.4)</u>
This test verifies the signal strength is estimated from DF=11 or DF=17 squitters every surveillance processing cycle and is set to the maximum signal strength of the squitters received since the last estimate (§2.2.5.2.4).

(The following tests may be performed using ADS-B reports or directly decoded ADS-B messages. TIS-B and ADS-R data is not permitted.)

<u>Scenario Description</u>

- Intruder 1 will simulate DF=11 and DF=17 squitters at signal strength < -68 dBm. While all of the squitters are < -68 dBm the track is maintained in extended hybrid surveillance. When the power of one of the DF=17 squitters is raised to > -68 dBm the track will transition to hybrid surveillance (§2.2.5.2.4).

- Intruder 2 will simulate DF=11 and DF=17 squitters at signal strength < -68 dBm. While all of the squitters are < -68 dBm the track is maintained in extended hybrid surveillance. When the power of the DF=11 squitter is raised to > -68 dBm the track will transition to hybrid surveillance (§2.2.5.2.4).

<u>TCAS Aircraft</u>
Altitude = 12,000 ft
Altitude Rate = 0 FPM
Position = Sydney

<u>Intruder Aircraft #1</u>
Altitude = 17,000 ft
Altitude Rate = 0 FPM
Range = 3.2 NM
Relative Speed = 0 kt
ADS-B Version Number=2
At T=1-20 the intruder sends at least 1 DF=11 and 2 DF=17 airborne position squitters per second all with power of -70 dBm. At T=21 the transmission power of one of the DF=17 squitters will be raised to -66 dBm.
At T=25 the intruder is terminated.

<u>Intruder Aircraft #2</u>
Altitude = 17,200 ft
Altitude Rate = 0 FPM
Range = 4.0 NM
Relative Speed = 0 kt
At T=1-20 the intruder sends at least 1 DF=11 and 2 DF=17 airborne position squitters per second all with power of -70 dBm.
At T=21 the transmission power of one of the DF=17 squitters will be raised to -66 dBm.
At T=25 the intruder is terminated.

<u>Success Criteria</u>

Intruder 1 and 2
The surveillance reports to the CAS logic are present for the duration of the track.
Verify that the track is under extended passive surveillance (no validation) until T=20.
Verify that a validation interrogation is transmitted after T=20 seconds.

<u>Test 13 (Validation of Airborne Position §2.2.6.3)</u>
This test verifies that ADS-B airborne position is correctly validated (§2.2.6.3).

(The following tests may be performed using ADS-B reports or directly decoded ADS-B messages. TIS-B and ADS-R data is not permitted.)

<u>Scenario Description</u>

- Intruders 1 and 2 will qualify for hybrid surveillance and require validation.
- Intruder 1 will not reply to validation interrogations.
- Intruder 2 will pass the validation even though bearing is not available (§2.2.6.3).

TCAS Aircraft

Altitude	= 12,000 ft
Altitude Rate	= 0 FPM
Position	= Sydney

Intruder Aircraft #1

Altitude	= 12,400 ft
Altitude Rate	= 0 FPM
Range	= 3.6 NM
Relative Speed	= 0 kt
Bearing	= 0 degrees

DF=0 replies are not transmitted.
At T=10 the intruder is terminated.

Intruder Aircraft #2

Altitude	= 12,600 ft
Altitude Rate	= 0 FPM
Range	= 3.8 NM
Relative Speed	= 0 kt
Bearing	= 0 degrees

DF=0 replies are transmitted with:
slant range = 3.94 NM
altitude = 12,700 feet
bearing = none available.
At T=10 the intruder is terminated.

Success Criteria

Intruder 1
Verify that validation/acquisition interrogations are transmitted to the intruder according to the interrogation rate limits implemented per requirements of Ref. A, §2.2.4.6.2.2.2 (Acquisition)
Verify that a track is not initiated for the intruder.

Intruder 2
Verify that a single validation interrogation is transmitted to the intruder.
Verify that the intruder is established as a passive track.

Test 14 (Re-Validation of Airborne Position §2.2.7.5)
This test verifies that ADS-B airborne position is correctly re-validated (§2.2.7.5).

(The following tests may be performed using ADS-B reports or directly decoded ADS-B messages. TIS-B and ADS-R data is not permitted.)

Scenario Description

- Intruders 1 and 2 will qualify for hybrid surveillance and pass initial validation. Re-validation will be attempted 10 seconds later.
- Intruder 1 will not reply to re-validation interrogations.
- Intruder 2 will pass the re-validation even though bearing is not available (§2.2.7.5).

TCAS Aircraft
Altitude = 12,000 ft
Altitude Rate = 0 FPM
Position = Sydney

Intruder Aircraft #1
Altitude = 12,400 ft
Altitude Rate = 0 FPM
Range = 3.6 NM
Relative Speed = 0 kt
Bearing = 0 degrees
DF=0 replies (after initial validation) are not transmitted.
At T=20 the intruder is terminated.

Intruder Aircraft #2
Altitude = 12,600 ft
Altitude Rate = 0 FPM
Range = 3.8 NM
Relative Speed = 0 kt
Bearing = 0 degrees
DF=0 replies (after initial validation) are transmitted with:

slant range = 3.97 NM (note the range was selected to be just inside the range re-validation window of 340 m … 3.8 +0.185)
altitude = 12,700 feet
bearing = None available.

At T=20 the intruder is terminated.

Success Criteria

Intruder 1
Verify that a single validation interrogation is transmitted to the intruder.
Verify that the intruder is established as a passive track.
Verify that, beginning at 10 seconds after validation, re-validation interrogations are transmitted to the intruder according to the interrogation rate limits implemented per requirements of Ref. A, §2.2.4.6.2.2.2 (Maintenance of Established Tracks)
Verify that a track is dropped.

Intruder 2
Verify that a single validation interrogation is transmitted to the intruder.
Verify that the intruder is established as a passive track.
Verify that, at 10 seconds after validation, a single re-validation interrogation is transmitted to the intruder.
Verify the track is maintained as a passive track.

Test 15 (Maintain Extended Hybrid Surveillance Track §2.2.7.3, §2.2.7.4)
This test verifies that a track under extended hybrid surveillance will be tracked providing ADS-B position updates are received according to the requirement in (§2.2.7.3, §2.2.7.4).

(The following tests may be performed using ADS-B reports or directly decoded ADS-B messages. TIS-B and ADS-R data is not permitted.)

Scenario Description

- Intruders 1 - 3 will demonstrate that a track is maintained in extended hybrid surveillance when valid ADS-B position updates are received.
- Intruder 1 demonstrates range criteria.
- Intruder 2 demonstrates altitude criteria (§2.2.7.3).
- Intruder 3 will demonstrate coast capability when some reports are missing (§2.2.7.4).

TCAS Aircraft
Altitude = 12,000 ft
Altitude Rate = 0 FPM
Position = Sydney

Intruder Aircraft #1
Altitude = 17,000 ft
Altitude Rate = 0 FPM
ADS-B Version Number=2
The range and relative speed of the intruder will vary to demonstrate that the ADS-B reports are used to update the track when they fall within the appropriate range window. The range will be maintained such that the intruder remains in extended hybrid surveillance.
At T=60 the intruder is terminated.

Intruder Aircraft #2
The Altitude and Altitude Rate of the intruder will vary to demonstrate that the ADS-B reports are used to update the track when they fall within the appropriate altitude window. The altitude will be maintained such that the intruder remains in extended hybrid.
Range = 3.4 NM
Relative Speed = 0 kt
ADS-B Version Number=2
At T=60 the intruder is terminated.

Intruder Aircraft #3
Altitude = 17,000 ft
Altitude Rate = 0 FPM
Range = 3.4 NM
Relative Speed = 0 kt
ADS-B Version Number=2
The intruder will provide a valid ADS-B position report every 5 seconds from T=0 through T=45.
The intruder will provide an ADS-B report with altitude outside of the altitude window twice every 5 seconds.
The intruder will provide and ADS-B report with range outside of the range window twice every 5 seconds.
At T=60 the intruder is terminated.

Success Criteria

Intruder 1 and 2
Verify that the intruder is established and maintained as a passive track.
Verify that no validation/re-validation interrogations are transmitted.
Verify the intruder position is updated every second (no coasting).

Intrude 3
Verify that the intruder is established and maintained as a passive track.
Verify that no validation/re-validation interrogations are transmitted.
Verify the intruder position in updated only once every 5 seconds and is coasted for the other update intervals.
Verify that after T=45 the track is coasted and dropped.

2.4.2.7 Verification of Requirements Related to Transitions between Passive and Active Surveillance

Test 1 – Hybrid to Active
This test shows correct transitions to active surveillance based on the criteria of §2.2.6.1.4.
Also the scenario tests the 4500 ft and 3 NM altitude and range offsets in the tau equations.

Scenario Description

- Intruder 1 verifies the range criteria of §2.2.6.1.4, and verifies the requirement of §2.2.6.2 that a track not be dropped for a transition from passive to active surveillance when the passive data correlates well with active data.
- Intruder 2 verifies the altitude criteria of §2.2.6.1.4 when the aircraft is above and descending. Also, verifies the 60 second revalidation interval for intruders, §2.2.7.5.
- Intruder 3 verifies the altitude criteria of §2.2.6.1.4 when the aircraft is below and climbing. Also, verifies the 60 second revalidation interval for intruders, §2.2.7.5.
- Intruder 4 verifies that when tracking the intruder with passive reports and the intruder is accelerating rapidly towards own aircraft in altitude the transition to active occurs in a timely manner (§2.2.6.1.4).

TCAS Aircraft
Altitude = 12,000 ft
Altitude Rate = 0 FPM
Position = Frankfurt

Intruder Aircraft #1
Altitude = 7600 ft
Altitude Rate = 0 FPM
Range = 11 NM at T=0 sec
Range Error of 330 m inserted after T=10 through end of test.
Relative Speed = -360 kt (-0.1 NM/sec)
At T=40 the intruder is terminated.

Intruder Aircraft #2

Altitude	= 20,250 ft at T=0
Altitude Rate	= -1,500 FPM
Range	= 2.9 NM
Relative Speed	= 0 kt

At T=105 the intruder is terminated.

Intruder Aircraft #3

Altitude	= 3,750 ft at T=0
Altitude Rate	= 1,500 FPM
Range	= 2.9 NM
Relative Speed	= 0 kt

At T=105 the intruder is terminated.

Intruder Aircraft #4

Altitude	= 17,500 ft at T=0
Altitude Rate	= 0 FPM at T=0
Altitude Rate	= at T=15 descend rate goes to -6000 FPM at 0.5 g.
Range	= 2.9 NM
Relative Speed	= 0 kt

At T=40 the intruder is terminated.

Success Criteria

Intruder 1
From T=10 to T=19, verify the intruder is tracked using passive surveillance.
From T=10 to T=19, verify that no more than 1 UF=0 interrogation every 10 sec (after the track has transitioned to passive).
Interrogation interval is no greater than 5 sec from T=21 to T=40.
From T=21 to the end of the test, verify the intruder is tracked using active surveillance.
Verify that the track is not dropped and that the track number provided to the CAS Logic for this track is not changed.

Intruder 2
From T=10 to T=85, verify the intruder is tracked using passive surveillance.
From T=10 to T=85, verify that no more than 1 UF=0 interrogation every 60 sec (after the track has transitioned to hybrid surveillance.)
One interrogation every sec of intruder aircraft from T=95 to T=105.
From T=95 to the end of the test, verify the intruder is tracked using active surveillance.
Verify that the track is not dropped and that the track number provided to the CAS Logic for this track is not changed.

Intruder 3
From T=10 to T=85, verify the intruder is tracked using passive surveillance.
From T=10 to T=85, verify that no more than 1 UF=0 interrogation every 60 sec (after the track has transitioned to passive).
One interrogation every sec of intruder aircraft from T=95 to T=105.
From T=95 to the end of the test, verify the intruder is tracked using active surveillance.
Verify that the track is not dropped and that the track number provided to the CAS Logic for this track is not changed.

Intruder 4
From T=10 to T=15, verify that the intruder is tracked using passive data.
From T=20 to the end of the test, verify that the intruder is tracked using active data.

Test 1A – Passive to Active with Accelerating Range

This test shows correct transitions to active surveillance based on the criteria of §2.2.6.1.4. Specifically tests this when there is a range acceleration while the aircraft is still being tracked passively.

Perform test §2.4.2.1.8.2 a) Range Tracking Accuracy test of Ref. A as modified below:

This test should be modified so that the intruder is Mode S and squitters Airborne Position Messages.

Success Criteria

Verify that the track transitions to active surveillance based on the range tau.
Verify the success criteria as specified in the Ref. A test.

Test 2 – Active to Hybrid

This test shows correct transitions to passive surveillance based on meeting criteria of §2.2.7.1.2.
The test verifies the 4900 ft and 3.2 NM altitude and range offsets for switching to passive as well as the 4500 ft and 3 NM altitude and range offsets of §2.2.6.1.4. It also verifies the validation windows of §2.2.6.3 when errors are just within the validation window.
This test verifies that even after initially failing validation an intruder continues to be re-validated and will transition to hybrid surveillance if the validation criteria are met as required by §2.2.6.2. It also shows that two validation attempts are required to transition to hybrid surveillance if a track has failed validation as required by §2.2.6.1.2.

Scenario Description

- Intruder 1 verifies the range criteria of §2.2.7.1.2 when the intruder is outbound.
- Intruder 2 verifies the altitude criteria of §2.2.7.1.2 when the intruder is climbing.
- Intruder 3 verifies that an intruder which initially fails re-validation – can still transition to hybrid surveillance if it subsequently passes the validation window. It also verifies that two validations are required since the initial validation failed.

TCAS Aircraft

Altitude	= 12,000 ft
Altitude Rate	= 0 FPM
Position	= Dallas

Intruder Aircraft #1

Altitude	= 16,400 ft at T=0
Altitude Rate	= 0 FPM
Range	= 1.2 NM

Range Error is 280 m.
The equipment manufacturer should set this error as close to the 290m as possible based on the capabilities of its test equipment.
Relative Speed = +360 kt (+0.1 NM/sec)
At T=40 the intruder is terminated.

Intruder Aircraft #2

Altitude	= 16,400 ft at T=0
Altitude Rate	= 1800 FPM
Range	= 2.9 NM
Relative Speed	= 0 kt

At T=30 the intruder is terminated.

Intruder Aircraft #3

Altitude	= 16,000 ft
Altitude Rate	= 0 FPM
Range	= 20 NM at T=0 sec
Relative Speed	= -360 kt (-0.1 NM/sec)

The Range Difference is 310 m.
At T=20, the Range difference is reduced to 250 m
At T=100 the intruder is terminated.

Success Criteria

Intruder 1
Intruder is tracked with active data until at least T=18.
Intruder is tracked with passive data as soon as T=21, but at least by T=28 and until the end of the scenario.
Intruder is marked with Surveillance Mode of Normal until T=18.
Intruder is marked with Surveillance Mode <> Normal as soon as T=21, but at least by T=28 and until end of scenario.
Verify that the track is not dropped and that the track number provided to the CAS Logic for this track is not changed.

Intruder 2
Verify that the Intruder is tracked with active data until at least T=18.
Verify that the Intruder is tracked with passive data starting no later than T=21 until the end of the scenario.
Intruder is marked with Surveillance Mode of Normal until at least T=18.
Intruder is marked with Surveillance Mode <> Normal no later than T=21 until end of scenario.

Intruder 3
Verify that the Intruder is tracked with active data until at least after T=24. This can be accomplished by showing that interrogations are made to the intruder at least once every 5 seconds.
Verify that by T=32 the intruder is tracked passively and that the interrogation are made to the intruder no more than once every 60 seconds.

Note: A transition to hybrid surveillance is not permitted at T=20 because two (2) successful validation are required once a track has failed validation.

Test 3 – Hybrid to Active Abnormal Conditions

This test primarily verifies abnormal conditions which result in a transition from using passive reports to update a track to using active data.

Scenario Description

- Intruder 1 verifies the handling of momentary and permanent transitions to non-altitude reporting intruders (§2.2.7.4).
- Intruder 2 verifies the transition from passive to active when the range revalidation check fails (§2.2.6.3, §2.2.7.5).
- Intruder 3 verifies the transition from passive to active when the bearing revalidation check fails (§2.2.6.3, §2.2.7.5).
- Intruder 4 verifies the transition from passive to active when the altitude revalidation check fails (§2.2.6.3, §2.2.7.5).
- Intruder 5 verifies the transition from passive to active when the intruder stops reporting position (§2.2.7.4).
- Intruder 6 verifies the revalidation requirements (§2.2.7.5) and that passive data is used to determine that a track should transition to active surveillance (§2.2.6.1.4). It also verifies that the requirements in §2.2.6.2 related to transitioning from passive to active surveillance when the active and passive data do not correlate are met including track transition times, dropping the passive track and creating a new active track.

<u>TCAS Aircraft</u>
Altitude = 12,000 ft
Altitude Rate = 0 FPM
Position = São Paulo

<u>Intruder Aircraft #1</u>
Altitude = 17,000 ft
Altitude Rate = 0 FPM
Range = 10 NM at T=0 sec
Relative Speed = -144 kt (-0.04 NM/sec)
At T=15 the aircraft stops reporting altitude for 1 sec.
At T=20 the aircraft stops reporting altitude.
At T=60 the intruder is terminated.

<u>Intruder Aircraft #2</u>
Altitude = 17,000 ft
Altitude Rate = 0 FPM
Range = 12 NM at T=0 sec
Relative Speed = -360 kt (-0.1 NM/sec)
At T=15 the Range Difference is increased to 390 m.

Note: 390m was selected instead of an error closer to 340m to account for test equipment limitations during black box testing. It is expected that software testing will verify that exact implementation of the 340m window.

At T=60 the intruder is terminated.

<u>Intruder Aircraft #3</u>
Altitude = 17,000 ft
Altitude Rate = 0 FPM
Range = 12 NM at T=0 sec
Relative Speed = -360 kt (-0.1 NM/sec)
At T=15 the Bearing Difference is increased to 50 degrees.
At T=60 the intruder is terminated.

Intruder Aircraft #4
Altitude = 6500 ft
Altitude Rate = 0 FPM
Range = 12 NM at T=0 sec
Relative Speed = -360 kt (-0.1 NM/sec)
At T=15 the Altitude Difference is increased to 150 ft.
At T=60 the intruder is terminated.

Intruder Aircraft #5
Altitude = 17,000 ft
Altitude Rate = 0 FPM
Range = 10 NM at T=0 sec
Relative Speed = -144 kt (-0.04 NM/sec)
At T=15 the aircraft starts reporting invalid position, but continues to provide extended squitters.
At T=60 the intruder is terminated.

Intruder Aircraft #6
Altitude = 16,400 ft at T=0
Altitude Rate = 0 FPM at T=0
Range = 10.0 NM
Relative Speed = -144 kt at T=0
At T=10 the active range jumps to 13 NM (moving the active range causes the active data to fail the revalidation).
At T=120 the intruder is terminated.

Success Criteria

Intruder 1
Verify that from T=5 to T=20 the track is under passive surveillance.
Verify that from T=5 to T=20 the track has valid altitude.
The continuous track is maintained.
The altitude reporting status is changed between T=20 and T=33.
After T=26 the track is updated using active data and is non-altitude reporting.

Intruder 2
Verify that the track is under passive surveillance.
By T=26 the intruder should be interrogated once per surveillance interval (1 sec).
By T=26 active data should be supplied to the CAS Logic/Displays.
By T=26 the Surveillance Mode should be set to Normal.

Note: The 1 sec interrogation rate could start as early as T=16.

Intruder 3
Verify that the track is under passive surveillance.
By T=26 the intruder should be interrogated once per surveillance interval (1 sec).
By T=26 active data should be supplied to the CAS Logic/Displays.
By T=26 the Surveillance Mode should be set to Normal.

Note: The 1 sec interrogation rate could start as early as T=16.

Intruder 4
Verify that the track is under passive surveillance.
By T=26 the intruder should be interrogated once per surveillance interval (1 sec).
By T=26 active data should be supplied to the CAS Logic/Displays.
By T=26 the Surveillance Mode should be set to Normal.

Note: The 1 sec interrogation rate could start as early as T=16.

Intruder 5
Verify that the track is under passive surveillance.
By T=24 active data should be supplied to the CAS Logic/Displays.

Intruder 6
Verify that the intruder is tracked using passive data from T=10 to T=20.

Approximately 20 to 26 seconds after the initial validation, verify that a validation interrogation is performed. The revalidation attempt fails because the active range position does not follow the passive range position. Verify that as a result of the failed revalidation, the track transitions to active surveillance within 3 sec of the failed revalidation attempt

Note: Based on the change in active range at T=10, the revalidation time would be greater if active data was being used.

Verify that after the failed validation attempt, but before the track becomes active that RFLG is set false. Surveillance Mode is NOT set to Normal until a new track based on active data is presented to the CAS logic.
Verify that only one track for this intruder (with the same Mode S address) is provided to the CAS logic for the entire test.

Verify that the new active track has a different track number than the passive track or that some other mechanism is employed to guarantee that the CAS logic treats the active track as a NEW track.

Test 3A –Passive (Extended Hybrid) to Active Abnormal Conditions
This test primarily verifies abnormal conditions which result in a transition from using passive reports to update a track to using active data. It also tests other abnormal conditions.

Scenario Description

- Intruder 1 verifies the handling of momentary and permanent transitions to non-altitude reporting intruders (§2.2.7.4).
- Intruder 2 verifies the requirement to transition from Extended Hybrid to Hybrid Surveillance if the intruder's reported quality does not meet the SIL requirements of §2.2.5.2.1. Also verifies variable revalidation rate of §2.2.7.5.
- Intruder 3 verifies the requirement to transition from Extended Hybrid to Hybrid Surveillance if the intruder's reported quality does not meet the SDA requirements of §2.2.5.2.1. Also verifies variable revalidation rate of §2.2.7.5.
- Intruder 4 verifies the transition from passive to active when the intruder stops reporting valid position (§2.2.7.4).

<u>TCAS Aircraft</u>
Altitude = 12,000 ft
Altitude Rate = 0 FPM
Position = São Paulo

<u>Intruder Aircraft #1</u>
Version = 3
Altitude = 17,000 ft
Altitude Rate = 0 FPM
Range = 10 NM at T=0 sec
Relative Speed = -144 kt (-0.04 NM/sec)
At T=15 the aircraft stops reporting altitude for 1 sec.
At T=20 the aircraft stops reporting altitude.
At T=60 the intruder is terminated.

<u>Intruder Aircraft #2</u>
Version = 2
Altitude = 7600 ft
Altitude Rate = 0 FPM
Range = 25 NM at T=0 sec
Relative Speed = -420 kt (-0.1167 NM/sec)
At T=20 the SIL from the intruder is degraded to 1.
At T=80 the intruder is terminated.

<u>Intruder Aircraft #3</u>
Version = 2
Altitude = 7600 ft
Altitude Rate = 0 FPM
Range = 15 NM at T=0 sec
Relative Speed = -220 kt (-0.06 NM/sec)
At T=20 the SDA from the intruder is degraded to 1.
At T=80 the intruder is terminated.

<u>Intruder Aircraft #4</u>
Version = 2
Altitude = 17,000 ft
Altitude Rate = 0 FPM
Range = 10 NM at T=0 sec
Relative Speed = -144 kt (-0.04 NM/sec)
At T=15 the aircraft starts reporting invalid horizontal position (i.e. latitude and longitude fields encoded with zeros) but continues to provide extended squitters.
At T=60 the intruder is terminated.

<u>Success Criteria</u>

Intruder 1
Verify that the track is under passive surveillance.
Verify that no interrogations are addressed to this intruder from T=0 to T=20.
Verify that a continuous track with no track number change is maintained.
Verify that the altitude reporting status changes from altitude reporting to non-altitude reporting between T=20 and T=33.
Verify after T=26 the track is updated using active data and is non-altitude reporting.

Intruder 2
From T=5 to T=80, verify that the passive data is provided to the CAS Logic/Displays.
From T=1 to T=19, verify that no UF=0 interrogation are made to this intruder.
From T=20 to 25, verify that only one UF=0 interrogation is made to this intruder because of the transition to hybrid surveillance.
From T=25 to 80, verify that only one more additional interrogation is made to the intruder between T=49 and T=59 (nominally T=54).
Verify that the track is not dropped and that the track number provided to the CAS Logic for this track is not changed.

Intruder 3
From T=5 to T=80, verify that the passive data is provided to the CAS Logic/Displays.
From T=1 to T=19, verify that no UF=0 interrogation are made to this intruder.
From T=20 to 25, verify that only one UF=0 interrogation is made to this intruder because of the transition to hybrid surveillance.
From T=25 to 80, verify that only one more additional interrogation is made to the intruder between T=43 and T=53 (nominally T=48).
Verify that the track is not dropped and that the track number provided to the CAS Logic for this track is not changed.

Intruder 4
Verify that the track is under passive surveillance.
By T=24 active data should be supplied to the CAS Logic/Displays.

Test 4 – Passive (Extended Hybrid) to Active or Hybrid Surveillance
This test shows correct transitions to active surveillance as required by §2.2.7.2.1 based on the criteria of §2.2.6.1.4.
Also the scenario tests the 4500 ft and 3 NM altitude and range offsets in the tau equations.
The test shows correct transitions from Hybrid to extended hybrid surveillance as required by §2.2.7.2.2.1.
The test shows correct validation / revalidation rates for the case where an intruder transitions between Extended Hybrid Surveillance and Hybrid Surveillance more than once per §2.2.7.2.1.

Scenario Description

- Intruder 1 verifies the range criteria of §2.2.6.1.4, and verifies the requirement of §2.2.6.2 that a track not be dropped for a transition from passive to active surveillance.
- Intruder 2 verifies the altitude criteria of §2.2.6.1.4 when the aircraft is above and descending.
- Intruder 3 verifies the altitude criteria of §2.2.6.1.4 when the aircraft is below and climbing.
- Intruder 4 verifies that when tracking the intruder with passive reports and the intruder is accelerating rapidly towards own aircraft in altitude the transition to active occurs in a timely manner (§2.2.6.1.4).
- Intruder 5 verifies the requirement to transition from Extended Hybrid to Hybrid Surveillance if the intruder's reported quality does not meet the NACp requirements of §2.2.5.2.1. Also verifies variable revalidation rate of §2.2.7.5.
- Intruder 6 verifies the requirement to transition from Extended Hybrid to Hybrid Surveillance if the intruder's signal strength does not meet the requirements for extended hybrid surveillance per §2.2.5.2 and §2.2.5.2.3.

- Intruder 7 verifies the requirement to transition from Extended Hybrid to Hybrid Surveillance and to active surveillance if the intruder's reported quality does not meet the NACp requirement of §2.2.5.2.1 and subsequently fails validation.
- Intruder 8 verifies the requirement of §2.2.7.2.2.1 to transition from Hybrid to Extended Hybrid Surveillance.
- Intruder 9 verifies the requirement of §2.2.7.1.3 associated with validation and initial transitions from Extended Hybrid Surveillance to Hybrid Surveillance. It also verifies the requirements associated with re-validation for subsequent transitions from Extended Hybrid to Hybrid Surveillance.

TCAS Aircraft
Altitude = 12,000 ft
Altitude Rate = 0 FPM
Position = Frankfurt

Intruder Aircraft #1
Version = 2
Altitude = 7600 ft
Altitude Rate = 0 FPM
Range = 11 NM at T=0 sec
Relative Speed = -360 kt (-0.1 NM/sec)
At T=40 the intruder is terminated.

Intruder Aircraft #2
Version = 2
Altitude = 20,250 ft at T=0
Altitude Rate = -1,500 FPM
Range = 2.9 NM
Relative Speed = 0 kt
At T=105 the intruder is terminated.

Intruder Aircraft #3
Version = 2
Altitude = 3,750 ft at T=0
Altitude Rate = 1,500 FPM
Range = 2.9 NM
Relative Speed = 0 kt
At T=105 the intruder is terminated.

Intruder Aircraft #4
Version = 2
Altitude = 17,500 ft at T=0
Altitude Rate = 0 FPM at T=0
Altitude Rate = at T=15 descend rate goes to -6000 FPM at 0.5g.
Range = 2.9 NM
Relative Speed = 0 kt
At T=40 the intruder is terminated.

Intruder Aircraft #5
Version = 2

Altitude	= 7600 ft
Altitude Rate	= 0 FPM
Range	= 20 NM at T=0 sec
Relative Speed	= -360 kt (-0.1 NM/sec)

At T=20 the NACp from the intruder is degraded to 5.
At T=60 the intruder is terminated.

Intruder Aircraft #6
Version = 2

Altitude	= 7600 ft
Altitude Rate	= 0 FPM
Range	= 20 NM at T=0 sec
Relative Speed	= -360 kt (-0.1 NM/sec)

At T=20 the intruder's Reply / Squitter Power = - 66 dBm
At T=40 the intruder is terminated.

Intruder Aircraft #7
Version = 2

Altitude	= 7600 ft
Altitude Rate	= 0 FPM
Range	= 20 NM at T=0 sec
Relative Speed	= -360 kt (-0.1 NM/sec)

At T=20 the NACp from the intruder is degraded to 5.
At T=20 any replies made to this intruder must differ from the passive data by 400 meters.
At T=40 the intruder is terminated.

Intruder Aircraft #8
Version = 2

Altitude	= 7600 ft
Altitude Rate	= 0 FPM
Range	= 3.5 NM at T=0 sec
Relative Speed	= 0 kt

NACp from the intruder is 5.
At T=30, the NACp improves to 7.
At T=100 the intruder is terminated.

Intruder Aircraft #9
Version = 2

Altitude	= 7600 ft
Altitude Rate	= 0 FPM
Range	= 15 NM at T=0 sec
Relative Speed	= -0 kt

At T=20, the signal level transitions to -66 dBm
At T=25, the signal level transitions to -70 dBm
At T=30, the signal level transitions to -66 dBm
At T=100 the intruder is terminated.

Success Criteria

Intruder 1
From T=10 to T=19, verify that the passive data is provided to the CAS Logic/Displays.
From T=1 to T=19, verify that no interrogation are address to this intruder.
Verify that the interrogation interval is no greater than 5 sec from T=21 to T=40.
From T=21 to the end of the test, verify that the active data is provided to the CAS Logic/Displays.
Verify that the track is not dropped and that the track number provided to the CAS Logic for this track is not changed.

Intruder 2
From T=10 to T=85, verify that the passive data is provided to the CAS Logic/Displays.
From T=1 to T=85, verify that no UF=0 interrogations are made to this intruder
Verify one interrogation every sec of intruder aircraft from T=95 to T=105.
From T=95 to the end of the test, verify that the active data is provided to the CAS Logic/Displays.
Verify that the track is not dropped and that the track number provided to the CAS Logic for this track is not changed.

Intruder 3
From T=10 to T=85, verify that the passive data is provided to the CAS Logic/Displays.
From T=1 to T=85, verify that UF=0 no interrogations are made to this intruder.
Verify one interrogation every sec of intruder aircraft from T=95 to T=105.
From T=95 to the end of the test, verify that the active data is provided to the CAS Logic/Displays.
Verify that the track is not dropped and that the track number provided to the CAS Logic for this track is not changed.

Intruder 4
From T=1 to T=15, verify that the intruder is tracked using passive data.
From T=20 to the end of the test, verify that the intruder is tracked using active data.

Intruder 5
From T=5 to T=60, verify that the passive data is provided to the CAS Logic/Displays.
From T=1 to T=19, verify that no UF=0 interrogation are made to this intruder.
From T=20 to 25, verify that only one UF=0 interrogation is made to this intruder because of the transition to hybrid surveillance.
From T=25 to 60, verify that the next validation occurs within 30 to 40 seconds of the initial validation.
Verify that the track is not dropped and that the track number provided to the CAS Logic for this track is not changed.
From T=5 to T=60, verify that the Surveillance Mode value for this intruder provided to the CAS logic indicates Reduced.

Intruder 6
From T=5 to T=40, verify that the passive data is provided to the CAS Logic/Displays.
From T=1 to T=19, verify that no UF=0 interrogation are made to this intruder.
From T=20 to 40, verify that only one UF=0 interrogation is made to this intruder.
Verify that the track is not dropped and that the track number provided to the CAS Logic for this track is not changed.
From T=5 to T=40, verify that the Surveillance Mode value for this intruder provided to the CAS logic indicates Reduced.

Intruder 7
From T=5 to T=19, verify that the intruder's passive data is provided to the CAS Logic/Displays.
From T=25 to T=40, verify that the intruder's active data is provided to the CAS Logic/Displays.
From T=1 to T=19, verify that no UF=0 interrogation are made to this intruder.
From T=25 to 40, verify that the maximum update interval between UF=0 interrogations to this intruder is 5 seconds.
Verify that the track is not dropped and that the track number provided to the CAS Logic for this track is not changed.

Intruder 8
From T=5 to the end if that test, verify that the intruder's passive data is provided to the CAS Logic/Displays.
From T=5 to T=30, verify that UF=0 interrogation are made no more frequently than once every 10 seconds.
From T=35 to the end of the test, verify that no interrogations are made to this intruder.

Intruder 9
From T=5 to the end if that test, verify that the intruder's passive data is provided to the CAS Logic/Displays.
From T=1 to T=19, verify that no UF=0 interrogation are to the intruder.
Verify that the first UF=0 interrogation to own aircraft occurs after T=19.
Verify that the interrogation interval to the intruder from T=20 to the end of the test is never less than 60 seconds and no more than two interrogations are made to the intruder.

Test 5 Air / Ground Transitions and Transitions between Active and Passive Surveillance

This test shows correct transitions between active and passive (hybrid and extended hybrid) surveillance for air ground transitions per sections §2.2.6.1.4, §2.2.7.1.2, and §2.2.7.2.2.1 and provides requirement coverage related to section §2.2.5.2.
This test also shows correct air to ground transitions per section §2.2.8 and that invalid ground speed is monitored as per §2.2.10.

Scenario Description

Two ADS-B equipped intruders are defined – one is a version = 0 intruder and the other is a version = 2 intruder. A third intruder is Mode S equipped (but not ADS-B) and the fourth intruder is ATCRBS/Mode C equipped.

There are 5 runs for the test where the behavior of own aircraft is modified:

- In runs 1 and 2 Own aircraft is airborne and lands based on different triggering criteria.
- In runs 3 and 4 Own aircraft is on the ground and takes off based on different triggering criteria.
- In run 5 Own aircraft is on the ground but does not have valid ground speed.

- Intruder 1 does not qualify for being tracked with hybrid surveillance while own aircraft is airborne, but will qualify for hybrid surveillance when own aircraft is operating on the surface.
- Intruder 2 does not qualify for being tracked with extended hybrid surveillance while own aircraft is airborne, but will qualify for extended hybrid surveillance when own aircraft is operating on the surface.

- Intruder 3 is a Mode S non-ADS-B equipped traffic.
- Intruder 4 is a Mode C / ATCRBS transponder equipped aircraft.

Intruder Aircraft #1	
Version	= 0
Altitude	= 2,000 ft
Altitude Rate	= 0 FPM
Range	= 2.0 NM
Range Rate	= 0 kt

Intruder Aircraft #2	
Version	= 2
Altitude	= 2,500 ft
Altitude Rate	= 0 FPM
Range	= 0 NM
Range Rate	= 0 kt
Intruder Aircraft #3	
Altitude	= 1,000 ft
Altitude Rate	= 0 FPM
Range	= 1.0 NM
Range Rate	= 0 kt

Mode S transponder equipped
No ADS-B Data

Intruder Aircraft #4	
Altitude	= 1,000 ft
Altitude Rate	= 0 FPM
Range	= 7.0 NM
Range Rate	= 0 kt

ATCRBS/Mode C transponder equipped
No ADS-B Data

All the tests have duration of 60 seconds.

Test Run 1

TCAS Aircraft	
Barometric Altitude	= 340 ft
Radio Altitude	= 340 ft
Altitude Rate	= -600 FPM (descending)

Altitude rate is for both barometric and radio altitudes.

Ground Speed	= 25 kt

Test Run 2

TCAS Aircraft	
Barometric Altitude	= 0 ft
Radio Altitude	= 0 ft
Altitude Rate	= 0 FPM
Ground Speed	= 40 kt

At T=30 Ground Speed is < 25 kt

Test Run 3

TCAS Aircraft
Barometric Altitude = 0 ft
Radio Altitude = 0 ft
Altitude Rate = 0 FPM
At T=14, Altitude Rate = +600 FPM (climbing)
Altitude rate is for both barometric and radio altitudes.
Goal is to transition 60 ft at T=30
Ground Speed = 0 kt

Test Run 4

TCAS Aircraft
Barometric Altitude = 0 ft
Radio Altitude = 0 ft
Altitude Rate = 0 FPM
Ground Speed = 0 kt
Ground Speed increased so at T=30 seconds, Ground Speed > 35 kt

Test Run 5

TCAS Aircraft
Barometric Altitude = 0 ft
Radio Altitude = 0 ft
Altitude Rate = 0 FPM
Ground Speed is invalid or unavailable for the duration of the test.

Success Criteria

The table below summarizes the expected results.

Test Run	Intruder 1	Intruder 2	Intruder 3	Intruder 4
1 and 2 Own Aircraft Landing	Active T < 25 Hybrid T > 35	Active T < 25 Extended Hybrid T > 35	Active for whole test	Active for whole test
3 and 4 Own Aircraft Taking Off	Hybrid T < 25 Extended T > 35	Extended Hybrid T < 25 Active T > 35	Active for whole test	Active for whole test
5 Own aircraft on-ground but ground speed invalid	Active for the whole test.	Active for the whole test.	Active for the whole test.	Active for the whole test.

The first two runs have own aircraft transitioning from Airborne to Operating On the Surface. Intruder 1 and Intruder 2 transition from active surveillance to Hybrid and Extended Hybrid Surveillance respectively. Intruders 3 and 4 are not ADS-B equipped intruders and should remain active tracked for the duration of the entire test.

In test runs 3 and 4 own takes off. Therefore Intruders 1 and 2 are initially tracked using Hybrid and Extended Hybrid Surveillance respectively. Then they transition to active surveillance. Intruders 3 and 4 are tracked using active surveillance the entire time.

The 5th test run verifies that when ground speed is unavailable own aircraft assumes that it is taking off or airborne per section §2.2.8. Therefore all the intruders should be tracked actively.

<u>Test Run 1 and 2</u>

Intruder 1

- Verify that the intruder is interrogated at a rate of 1 Hz from T=5 to T=25.
- Verify that the intruder is interrogated at a rate of 0.1 Hz from T = 35 to the end of the test.
- Verify that the intruder Surv Mode is marked as Normal while T <= 25 and marked as Reduced from T >= 35.

Intruder 2

- Verify that the intruder is interrogated at a rate of 1 Hz from T=5 to T=25.
- Verify that no interrogations are addressed to the intruder from T = 35 to the end of the test.
- Verify that the intruder Surv Mode is marked as Normal while T <= 25 and marked as Reduced from T >= 35.

Intruder 3

- Verify that the intruder is interrogated at a rate of 1 Hz from T=5 to the end of the test.
- Verify that the intruder Surv Mode is marked as Normal while T <= 25 and marked as Reduced from T >= 35.

Intruder 4

- Verify that the Mode C intruder is interrogated and updated every second for the duration of the test.
- Verify that the intruder Surv Mode is marked as Normal while T <= 25 and marked as Reduced from T >= 35.

<u>For Test runs 3 and 4</u>

Intruder 1

- Verify that the intruder is interrogated at a rate from 0.1 Hz from T = 5 to T = 25.
- Verify that the intruder is interrogated at a rate of 1 Hz from T=35 to the end of the test.
- Verify that the intruder Surv Mode is marked as Reduced while T <= 25 and marked as Normal from T >= 35.

Intruder 2

- Verify that no interrogations are addressed to the intruder from while T <= 25.
- Verify that the intruder is interrogated at a rate of 1 Hz from T>= 35 to the end of the test.
- Verify that the intruder Surv Mode is marked as Reduced while T <= 25 and marked as Normal from T >= 35.

Intruder 3

- Verify that the intruder is interrogated at a rate of 1 Hz from T=5 to the end of the test.
- Verify that the intruder Surv Mode is marked as Reduced while T <= 25 and marked as Normal from T >= 35.

Intruder 4

- Verify that the Mode C intruder is interrogated and updated every second for the duration of the test.
- Verify that the intruder Surv Mode is marked as Reduced while T <= 25 and marked as Normal from T >= 35.

For Test Run 5

Intruder 1, 2 3

- Verify that the intruder is interrogated at a rate of 1 Hz from T=5 to the end of the test.
- Verify that the intruder Surv Mode is marked as Normal from T = 5 to the end of test.

Intruder 4

- Verify that the Mode C intruder is interrogated and updated every second for the duration of the test.
- Verify that the intruder Surv Mode is marked as Normal from T = 5 to the end of test.
- Verify that an output is present indicating that hybrid surveillance capability has been degraded.

2.4.2.8 Verification of Error Budget in Computing Slant Range from Passive Data

Test 1

The equipment manufacturer must define a test or document an analysis that demonstrates that the error budget in computing slant range is met by their surveillance design.

If the test method is used to demonstrate compliance to the requirement then this paragraph describes one potential scenario. Own aircraft and intruder aircraft are traveling towards each other at 600 kt at high latitude (near 60 degrees). If the error between the passive range estimate and active range measurement is less than 145 meters then the intent of the requirement is met. The error in range computation of tests at slower closure rates can be used to extrapolate or predict errors at the 1200 kt closure rate.

If an analysis method is used to demonstrate compliance to the requirement then the analysis must identify and/or describe the following:

- Own aircraft latitude / longitude sampling rate and time stamping accuracy / granularity.
- Own aircraft latitude / longitude extrapolation.
- Intruder latitude / longitude time stamping accuracy / granularity.
- Intruder latitude / longitude extrapolation.
- Identify the maximum error in slant range if own aircraft was traveling at 600 kt.
- Identify the maximum error in slant range if intruder aircraft was traveling at 600 kt.
- Identify errors resulting from latitude / longitude to slant range computations.

2.4.2.9 Surveillance Overload and Capacity Tests

Test 1

Replicate Mode S Capacity Test Ref. A, §2.4.2.1.7.5. All 150 intruders squitter both DF=17 and DF=11. Each of the 150 intruders **shall** squitter 2 airborne position squitters per sec, 2 velocity squitters per sec, and one Flight ID squitter every 5 sec and one DF=11 squitter per sec. Intruders 25 to 52, inclusive, squitter Airborne Position Messages that successfully validate. It is not necessary for the other intruders to validate.

Success Criteria

Verify success criteria per Ref. A.

Verify that Mode S tracks which are in the passive surveillance region per §2.2.7.1.2 and have been established for 15 seconds are tracked using hybrid surveillance.

Test 2

Replicate Mode C, Mode S Test Ref. A, §2.4.2.1.8.1. All Mode S intruders squitter both DF=17 and DF=11. Each of the Mode S intruders **shall** squitter 2 airborne position squitters per sec, 2 velocity squitters per sec, and one Flight ID squitter every 5 sec and one DF=11 squitter per sec. Even numbered intruders 26 to 80, inclusive, squitter Airborne Position Messages which successfully validate. It is not necessary for the other intruders to validate.

Success Criteria

Verify success criteria per Ref. A.

Verify that Mode S tracks which are in the passive surveillance region per §2.2.7.1.2 and have been established for 15 seconds are tracked using hybrid surveillance.

Test 3

This test verifies the overload requirements of §2.2.7.3.

TCAS Aircraft
Per §2.4.2.1

Intruder Aircraft
Replicate Mode S Capacity Test Ref. A, §2.4.2.1.7.5 with the following changes:

- All 150 intruders squitter both DF=17 and DF=11 as version=2 intruders per §2.4.2.1.
- All intruders will have a squitter and reply probability of 1.
- As per §2.4.2.1 all intruders have a power signal level of -70 dBm.
- Intruder 1-24 Range Rate = 0
- Intruder 1-24 Range = 3.5 + (Intruder Number * 0.5) NM
- Intruder 1-24 Altitude relative to own = -3000 + (Intruder Number * 200) ft.
- Intruder 1-24 start time is T=10 + (5 * Intruder Number)
- The test ends at T=160 seconds

Success Criteria

Verify that after T=10 there should be no active interrogations to any intruder.

Verify that within 30 seconds of Intruder 1 to 24 being enabled that the surveillance overload function has maintained the closer track and discarded the farthest track.

2.4.2.10 Verification of DF17 Decoding

Test 1

This test shows the correct decode of Intruder Latitudes and Longitudes as well as the calculated Range and Bearing from own aircraft. Ref. C, §2.4.3.2.3.7.1 (Verification of Airborne Latitude and Longitude Data Encoding) identifies the Intruder Latitude and Longitude combinations that can robustly test the decoding function.

Scenario Description

Table 3 defines intruders that verify that the Airborne Position Messages are correctly decoded and that the ranges and bearings from own aircraft to the intruders are correctly calculated. Each intruder is static and the scenario needs to only be as long as it takes to calculate the range and bearing using the Airborne Position Message.

TCAS (Own) Aircraft

Altitude = 12,000 ft
Altitude Rate = 0 FPM
Position = Defined in Table 3 for each intruder
Heading = 0 degrees
Velocity = 0 kt

Intruder Aircraft

Altitude = Defined in Table 3
Altitude Rate = 0 FPM
Position = Defined in Table 3
Velocity = 0 kt

Table 3. Airborne Position Decoding Values With Range and Bearing

Intruder Aircraft No.	Own Latitude (deg)	Own Longitude (deg)	Intruder Latitude (deg)	Intruder Longitude (deg)	Intruder Altitude (ft)	Planar Range (NM)	Slant Range (NM)	Bearing (deg)
1	-89.5	-178	-90	175.5	16000	30.1776	30.1821	-180.0000
2	-89.5	-178	-89.95	-165	16000	27.2457	27.2512	178.5723
3	-89.5	-178	-89.5	-171.5	11000	3.4209	3.4249	93.2499
4	-89.5	-178	-89	-172.5	10000	30.4454	30.4489	10.9495
5	-87.4	62	-87.5	65.75	14000	11.7357	11.7398	122.8010
6	-87.4	62	-86.5	60	15000	54.6840	54.6840	-7.7428
7	-86	-60	-85.85	-60	12000	9.0512	9.0512	0.0000
8	-84.5	136	-85	120	11000	92.9738	92.9846	-116.7081
9	-84.5	136	-83.55	144	14000	76.0987	76.1004	45.2644
10	-83.2	-132	-84.25	-120	10000	101.0281	101.0443	134.5384
11	-83.2	-132	-82.68	-144	13000	94.1512	94.1579	-76.6016
12	-83.2	-132	-81.75	-121	15000	122.9425	122.9542	50.3582
13	-80	121.25	-80.25	121	12000	15.3018	15.3018	-170.3897
14	-80	-154	-79.75	-154.28	11000	15.3702	15.3715	-11.2787
15	-78	-121.1	-78.4	-121	16000	24.1635	24.1703	177.1215
16	-78	121.1	-77.4	121	16000	36.2191	36.2221	-2.0829
17	-76.55	-154.58	-76.55	-154.28	11000	4.2098	4.2131	90.1459
18	-75.6	154.58	-75.6	154.28	10000	4.5007	4.5130	-90.1453
19	-75.6	154.58	-74.75	157.5	14000	68.2458	68.2467	42.7452
20	-73.5	-157.4	-73.65	-157.5	13000	9.2042	9.2055	-169.3670

Intruder Aircraft No.	Own Latitude (deg)	Own Longitude (deg)	Intruder Latitude (deg)	Intruder Longitude (deg)	Intruder Altitude (ft)	Planar Range (NM)	Slant Range (NM)	Bearing (deg)
21	-72.35	-120.76	-72.75	-120	15000	27.7628	27.7654	150.6744
22	-72.35	120.76	-71.55	120	12000	50.2745	50.2759	-16.7737
23	-70	-144.05	-70.65	-144	11000	39.1894	39.1913	178.5388
24	-70	144.05	-69.55	144	10000	27.1394	27.1429	-2.2250
25	-86.7	-143	-86.75	-142.75	13000	3.1379	3.1422	164.1829
26	-69	-114	-68.75	-114.55	16000	19.2375	19.2470	-38.6916
27	-68	115	-67.75	114.55	16000	18.2087	18.2189	-34.3686
28	-66.25	-67.75	-66.55	-67.5	11000	19.0544	19.0556	161.6460
29	-65.75	67.5	-65.55	67.5	10000	12.0470	12.0521	0.0000
30	-64.3	-83	-64.45	-83.08	14000	9.2733	9.2787	-167.0318
31	-64.3	83	-63.25	83.08	13000	63.2722	63.2736	1.9668
32	-62.5	-64.25	-62.25	-64.29	15000	15.0970	15.1040	-4.2668
33	-60.75	64.3	-61.25	64.29	12000	30.1017	30.1020	-179.4480
34	-60.75	-71.75	-60.25	-72	11000	30.9982	30.9997	-13.9624
35	-60.75	-120.25	-59.96	-120.5	10000	48.1292	48.1337	-9.0193
36	-60.75	120	-59.955	120	14000	47.8585	47.8585	0.0000
37	-60.75	-120.25	-59.93	-119.5	13000	54.1954	54.1960	24.7138
38	-58.1	-79	-58	-78.75	15000	9.9925	10.0040	53.0728
39	-58.1	78.5	-58.5	78.75	12000	25.3398	25.3400	161.8935
40	-58.1	-22.3	-57.95	-22.5	11000	11.0556	11.0571	-35.3604
41	-57	22.55	-56.85	22.5	16000	9.1749	9.1976	-10.3512
42	-54.7	-53.05	-55.5	-52.94	16000	48.2732	48.2743	175.5370
43	-54.7	53.05	-54.62	52.94	11000	6.1525	6.1549	-38.6043
44	-53	-29.95	-53.25	-30	10000	15.1383	15.1426	-173.1600
45	-53	29.95	-51.95	30	14000	63.1540	63.1545	1.6854
46	-49.9	-75.8	-50.75	-75.79	13000	51.0842	51.0847	179.5723
47	-49.9	75.8	-49.65	75.79	15000	15.0299	15.0370	-1.4877
48	-47.7	-27.1	-48.25	-27	12000	33.2845	33.2849	173.0765
49	-47.7	27.1	-47	27	11000	42.2405	42.2427	-5.5821
50	-46	-68.6	-45.6	-68.57	10000	24.0502	24.0538	3.0137
51	-43	179	-44.25	180	16000	86.7887	86.7898	150.1813
52	-43	179	-42.85	179.5	16000	23.8248	23.8318	67.9639
53	-43	179	-41.4	178.5	11000	98.5573	98.5699	-13.2494
54	-40.1	175.4	-40	175.5	10000	7.5650	7.5725	37.5746
55	-38	-160.5	-38.5	-160.9	14000	35.4561	35.4564	-147.8773
56	-36	-171.9	-36.9	-171.5	13000	57.3295	57.3303	160.3675
57	-36	-171.9	-35.25	-172.5	15000	53.7036	53.7037	-33.3266
58	-33.65	65.85	-33.6	65.75	12000	5.8402	5.8402	-59.1618
59	-31.14	-142.76	-31.8	-142.75	11000	39.5369	39.5389	179.2586
60	-30	60	-30	59.5	10000	26.0614	26.0649	-90.1250
61	-28.3	-60	-28	-60	14000	17.9637	17.9659	0.0000
62	-25.9	-66.11	-25.9	-66.7	13000	31.9412	31.9412	-90.1289
63	-23.55	-120.05	-23.6	-120	15000	4.0694	4.0989	137.3425
64	-21	41	-21.1	41.5	12000	28.7063	28.7065	102.1168
65	-18.4	-144.2	-18.2	-144	11000	16.5382	16.5395	43.7185
66	-15	-121.22	-14.9	-121	16000	14.1174	14.1314	64.9708
67	-10.2	121.22	-10.5	121	16000	22.1594	22.1671	-144.0362
68	-5	6.25	-5.1	6.25	11000	5.9742	5.9766	180.000
69	-2.11	154.35	-2.5	154.28	10000	23.6731	23.6767	-169.7670

Intruder Aircraft No.	Own Latitude (deg)	Own Longitude (deg)	Intruder Latitude (deg)	Intruder Longitude (deg)	Intruder Altitude (ft)	Planar Range (NM)	Slant Range (NM)	Bearing (deg)
70	0.02	59.76	0	60	14000	14.4848	14.4879	94.7319
71	-0.02	-157.14	0	-157.5	13000	21.6850	21.6852	-86.8414
72	89.9	-179.6	90	-180	15000	6.0353	6.0550	0.0000
73	89.9	-179.6	89.95	179.5	12000	3.0180	3.0180	-0.8998
74	89.9	-179.6	89.5	178.5	11000	24.1406	24.1418	-177.6252
75	89.9	-179.6	89	175.5	10000	54.3270	54.3322	-174.5565
76	87	-167.5	87.5	-165	16000	31.0259	31.0303	12.2435
77	87	-167.5	86.75	-171.5	16000	20.0131	20.0221	-136.8949
78	87	-167.5	86.5	-172.5	11000	34.6529	34.6546	-147.9377
79	85.1	60	85.85	65.75	10000	52.8289	52.8340	28.3243
80	85.2	-143	85	-142.75	14000	12.1377	12.1416	173.7807
81	85.1	60	84.25	60	13000	51.2888	51.2893	180.0000
82	83.25	-60.11	83.55	-60	15000	18.1195	18.1250	2.3588
83	83.25	120.2	82.68	120	12000	34.4222	34.4226	-177.4398
84	81.9	-120.2	81.75	-120	11000	9.2106	9.2123	169.1639
85	80.23	144.15	80.25	144	10000	1.9517	1.9793	-51.7455
86	80.23	-144.15	79.75	-144	14000	29.0016	29.0023	176.8163
87	78.2	-121.3	78.4	-121	13000	12.6105	12.6113	16.7763
88	78.2	121.3	77.4	121	15000	48.4103	48.4105	-175.3209
89	76.65	-154.28	76.55	-154.28	12000	6.0312	6.0312	-180.0000
90	75.35	154.3	75.6	154.28	11000	15.0788	15.0801	-1.1402
91	74	157.65	74.75	157.5	16000	45.2981	45.2995	-3.0127
92	74	-157.65	73.65	-157.5	16000	21.2579	21.2662	173.1162
93	72	-120.2	72.75	-120	11000	45.3602	45.3626	4.5238
94	72	120.2	71.55	120	10000	27.3864	27.3899	-171.9864
95	70.05	-144.11	70.65	-144	14000	36.2368	36.2371	3.4787
96	70.05	144.11	69.55	144	13000	30.2239	30.2239	-175.6007
97	68.2	-114.35	68.75	-114.55	15000	33.4428	33.4444	-7.5134
98	68.2	114.35	67.75	114.55	12000	27.4909	27.4911	170.4359
99	66.1	-67.45	66.55	-67.5	11000	27.1363	27.1376	-2.5345
100	66.1	67.45	65.55	67.5	10000	33.1526	33.1562	177.8427
101	63.99	-82.99	64.45	-83.08	14000	27.8082	27.8090	-4.8294
102	63.99	83.14	63.25	83.08	13000	44.5958	44.5960	-177.9071
103	61.3	-64.45	62.25	-64.29	15000	57.3851	57.3851	4.4905
104	61.3	64.45	61.25	64.29	12000	5.5281	5.5281	-122.9219
105	60.11	-72.14	60.25	-72	11000	9.4142	9.4159	26.4174
106	60.11	-120.25	59.96	-120.5	16000	11.7582	11.7755	-140.0686
107	60.11	120.25	59.955	120	16000	11.9913	12.0082	-140.9877
108	60.11	-120.25	59.93	-119.5	11000	25.0581	25.0594	115.2918
109	58.01	-78.5	58	-78.75	10000	8.0076	8.0148	-94.2031
110	58.01	79	58.5	78.75	14000	30.5364	30.5371	-14.9467
111	58.01	-22.55	57.95	-22.5	13000	3.9485	3.9519	156.1007
112	58.01	22.55	56.85	22.5	15000	69.8191	69.8194	-178.6471
113	55.09	-53.04	55.5	-52.94	12000	24.8978	24.8980	7.8818
114	54.39	53.04	54.62	52.94	11000	14.2672	14.2686	-14.1584
115	53.4	-29.76	53.25	-30	10000	12.4884	12.4933	-136.1344
116	52.4	30.34	51.95	30	14000	29.8307	29.8314	-154.9498
117	50	-75.65	50.75	-75.79	13000	45.3938	45.3940	-6.7536
118	50	75.65	49.65	75.79	15000	21.7278	21.7319	165.4381

Intruder Aircraft No.	Own Latitude (deg)	Own Longitude (deg)	Intruder Latitude (deg)	Intruder Longitude (deg)	Intruder Altitude (ft)	Planar Range (NM)	Slant Range (NM)	Bearing (deg)
119	47.82	-27.22	48.25	-27	12000	27.3095	27.3097	18.8576
120	47.82	27.22	47	27	11000	50.0603	50.0631	-169.5970
121	45.3	-69	45.6	-68.57	16000	25.5929	25.5991	45.0997
122	42.9	179	44.25	180	16000	92.0437	92.0454	27.9609
123	42.9	179	42.85	179.5	11000	22.2733	22.2746	97.5725
124	42.9	179	41.4	178.5	10000	92.7234	92.7369	-165.9010
125	39.23	176.02	40	175.5	14000	52.1115	52.1116	-27.4132
126	38.2	-160.05	38.5	-160.9	13000	43.9906	43.9907	-65.5953
127	35.5	-172.04	36.9	-171.5	15000	87.9376	87.9399	17.2014
128	35.5	-172.04	35.25	-172.5	12000	27.1024	27.1026	-123.4334
129	33.4	65.8	33.6	65.75	11000	12.2440	12.2454	-11.8157
130	31.75	-142.95	31.8	-142.75	10000	10.6634	10.6690	73.6352
131	29.8	60.02	30	59.5	14000	29.6624	29.6631	-66.0522
132	28.2	-60.02	28	-60	13000	12.0222	12.0230	174.9278
133	25.32	-67.1	25.9	-66.7	15000	40.9471	40.9478	31.9318
134	23.55	-120.2	23.6	-120	12000	11.4289	11.4289	74.7847
135	21	41	21.1	41.5	11000	28.7049	28.7063	77.8832
136	18.35	-144.22	18.2	-144	16000	15.4436	15.4561	125.4809
137	15.35	-120.75	14.9	-121	16000	30.5742	30.5787	-151.6126
138	10.6	121.2	10.5	121	11000	13.2499	13.2512	-116.7895
139	5.11	6.43	5.1	6.25	10000	10.7984	10.8040	-93.1633
140	2.8	155.54	2.5	154.28	14000	77.7921	77.7940	-103.2903
141	-0.03	60.11	0	60	10000	6.8534	6.8617	-74.8423
142	-0.03	-157.65	0	-157.5	9000	9.1963	9.2102	78.7638

<u>Success Criteria</u>

All Intruders.
For all of the Intruders with Latitudes within ±60 degrees, verify that the range for each intruder is within 145 m of the calculated range identified in Table
For all of the Intruders with Latitudes within ±60 degrees, verify that the bearing for each intruder is within 3 deg of the calculated bearing identified in Table 3.
Verify that the error in range from the calculated range does not use more of the error budget allowed for range based on the completion of Test §2.4.2.8 (Verification of Error Budget in Computing Slant Range from Passive Data) Test 1.

2.4.2.11 Verification of Monitoring Requirements

<u>Test 1</u>
This test verifies that passive surveillance is not performed in the absence of valid own latitude and longitude information (§2.2.9).

<u>Scenario Description</u>

- Intruder 1 will meet the requirements for being tracked passively.

TCAS Aircraft
Altitude = 12,000 ft
Altitude Rate = 0 FPM
Position = Sydney
At T=60 own latitude and longitude input is made unavailable.

Intruder Aircraft #1
Altitude = 17,000 ft
Altitude Rate = 0 FPM
Range = 10 NM at T=0 sec
Relative Speed = 0 kt
At T=90 the intruder is terminated.

Note: The equipment manufacturer should repeat this test for each own aircraft latitude and longitude source.

Success Criteria

Intruder 1
Verify that the acquisition interrogations have RL=0.
No more than one interrogation of intruder aircraft from T=10 to T=59.
At least by T=65 the intruder is interrogated once every 5 sec indicating a transition to active surveillance.
Verify that by at least T=70 that an output is provided indicating that the capabilities of passive surveillance have been degraded.
Verify that the track is not dropped.

2.4.2.12 Verification of On-Ground TCAS Range Determination Using ADS-B (§2.2.13)

Test 1
This test will verify that when own should include on-ground TCAS in its NTA3 and NTA6 estimates, as required by Ref. A, that it does not interrogate on-ground TCAS equipped aircraft that provide sufficient quality ADS-B OUT information.

Scenario Description

- Own aircraft is at 1500 ft AGL.
- One TCAS equipped intruder is on the ground and at a range of 2 NM.
- One TCAS equipped intruder is on the ground and at a range of 4 NM.
- One TCAS equipped intruder is on the ground and at a range of 5 NM.

TCAS Aircraft
Altitude = 1500 ft
Radio Altitude = 1500 ft
Altitude Rate = 0 FPM
Position = Sydney

Intruder Aircraft #1

Altitude = 500 ft
Altitude Rate = 0 FPM
Range = 2 NM at T=0 sec
Relative Speed = 0 kt
Intruder is on the ground.
CA field of all squitters indicates on the ground.
Intruder generates DF=17 Surface Position Messages at a rate of once every 5 seconds per §2.2.9 with values determined to validate tests objective.
DF=17 Format Type Code = 5.
Intruder generates TCAS broadcasts per Ref. A.
At T=40 the intruder is terminated.

Intruder Aircraft #2

Altitude = 700 ft
Altitude Rate = 0 FPM
Range = 5 NM at T=0 sec
Relative Speed = 0 kt
Intruder is on the ground.
CA field of all squitters indicates on the ground.
Intruder generates DF=17 Surface Position Messages per §2.2.9 with values determined to validate test objective.
DF=17 Format Type Code = 7.
Intruder generates TCAS broadcasts per Ref. A.
At T=40 the intruder is terminated.

Intruder Aircraft #3

Altitude = 300 ft
Altitude Rate = 0 FPM
Range = 4 NM at T=0 sec
Relative Speed = 0 kt
Intruder is on the ground.
CA field of all squitters indicates on the ground.
Intruder generates DF=17 Surface Position Messages per §2.2.9 with values determined to validate test objective.
DF=17 Format Type Code = 8.
Intruder generates TCAS broadcasts per Ref. A.
At T=40 the intruder is terminated.

Success Criteria

Verify the following:

1) No interrogations to Intruder #1 or Intruder #2 are performed.
2) That the System sets NTA3 to 1 from T=10 to T=40
3) That the System sets NTA6 to 3 from T=10 to T=40
4) That the System sets NTA3 and NTA6 to zero by T=70

If legacy TCAS equipment (originally certified to TSO-C119c or earlier) has limitations which prevent it from implementing the requirements of §2.2.13 then the following will be documented in the test results:

- Identify the TSO to which the unit was previously certified.
- Identify and document the rationale which makes the implementation of the requirement in §2.2.13 not feasible.

2.4.3 Cross-Reference of Requirements and Associated Tests

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 (§2.2.2)	
§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 Address (§2.2.3)	
§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 (§2.2.4)	
§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

Requirement	Test	Sub Test
§2.2.5.2.3 Extended Hybrid Surveillance 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 1,2,37,8,9
§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
§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
§2.2.6.2 Active Surveillance Requirements	§2.4.2.7 Verification of Requirements Related to Transitions between Passive and Active Surveillance	Test 1 – Intruder 1 Test 2 – Intruder 3
§2.2.6.3 Validation of Airborne Position Message Data	§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

Requirement	Test	Sub Test
§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
§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 – Intruder 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

Requirement	Test	Sub Test
§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 Verification of Use of Extended Squitter Altitude for Determining Target Validity	
	§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	
§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

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<tr><th>Requirement</th><th>Test</th><th>Sub Test</th></tr>
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§2.4.2.7 Verification of Requirements Related to Transitions between Passive and Active Surveillance

§2.4.2.10 Verification of DF17 Decoding</td><td rowspan="3">

Test 1</td></tr>
<tr><td>§2.2.9.4 Encoded Latitude from Airborne Position Message</td></tr>
<tr><td>§2.2.9.5 Encoded Longitude from Airborne Position Message</td></tr>
<tr><td>§2.2.9.6 ADS-B Version Number from Aircraft Operational Status Message</td><td rowspan="9">§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</td><td rowspan="9"></td></tr>
<tr><td>§2.2.9.7 Navigation Integrity Code (NIC) from Airborne Position Message</td></tr>
<tr><td>§2.2.9.8 Navigation Accuracy Category for Position (NACp)</td></tr>
<tr><td>§2.2.9.8.1 NACp from Aircraft Operational Status Message</td></tr>
<tr><td>§2.2.9.8.2 NACp from Target State and Status Message</td></tr>
<tr><td>§2.2.9.9 Source Integrity Level (SIL)</td></tr>
<tr><td>§2.2.9.9.1 SIL from Aircraft Operational Status Message</td></tr>
<tr><td>§2.2.9.9.2 SIL from Target State and Status Message</td></tr>
<tr><td>§2.2.9.10 System Design Assurance (SDA)</td></tr>
<tr><td>§2.2.10 Monitoring Requirements</td><td>§2.4.2.11 Verification of Monitoring Requirements</td><td>Test 5</td></tr>
<tr><td>§2.2.11 Interface to CAS Logic</td><td>§2.4.2.6 Verification of Maintenance of Established Tracks using Passive Surveillance</td><td>Test 10</td></tr>
<tr><td>§2.2.13 ADS-B NTA3/NTA6 Range Determination for On-Ground TCAS Intruders</td><td>§2.4.2.12 Verification of On-Ground TCAS Range Determination Using ADS-B</td><td></td></tr>
</table>

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3 INSTALLED EQUIPMENT PERFORMANCE

3.1 General

TCAS II equipment with passive surveillance capability **shall** meet all the requirements stated in Ref. A, §3 (Installed Equipment Performance).

3.2 Passive Surveillance Flight Tests

The following key objectives **shall** be demonstrated through flight test:

1. TCAS Mode S surveillance performance is not degraded.
2. Ability to validate and track an aircraft passively.
3. Ability to correctly transition to active surveillance.
4. Ability to correctly transition from active surveillance back to passive surveillance.

A ground test **shall** be performed to demonstrate correct performance of the DF=17 squitter capability of flight test aircraft and that correct own aircraft data is provided to the TCAS prior to flight testing.

Objective 1 **shall** be met by performing the Passive Surveillance Flight Test specified in §3.3

Objectives 2, 3 and 4 can be demonstrated with planned encounters or with targets of opportunity during the Passive Surveillance flight test of §3.3. If Extended Hybrid Surveillance target of opportunity tests are conducted, the Extended Hybrid Surveillance Traffic Quality Requirements of §2.2.5.2.1 **shall** be met. If planned encounters are performed to demonstrate correct performance of DF=17 squitter capability of the planned encounter aircraft, a ground test **shall** be performed prior to flight testing. In addition, prior to flight testing, own ship position sources **shall** meet the requirements or §2.2.5.2.1 and these required quality standards **shall** be established with both targets of opportunity or planned encounters flights.

3.3 Mode S Passive Surveillance Flight Test

The Mode S surveillance flight test of Ref. A **shall** be performed with the following modifications:

a. The minimum number of unique TCAS broadcasts received **shall** be 75.

Note: Previous hybrid surveillance flights have shown that the New York City area provides the stressful environment necessary for proper evaluation of TCAS Mode S hybrid surveillance. The most effective flight path has proven to be a 5 NM orbit over the John F. Kennedy Terminal Area. Other locations would be suitable as long as they meet the requirements specified here and in Ref. A.

b. The target of opportunity flight test **shall** collect the quantity of Mode S track seconds required by Ref. A, but a minimum of one hour of flight tests and 14 passive surveillance tracks **shall** be analyzed. If planned encounters are conducted, the flight program **shall** include those performance characteristics listed in section 2.

c. The Certification Authority will evaluate the passive surveillance performance within the available data for those characteristics contained in section 2 of this document.

4 MEMBERSHIP

RTCA Special Committee 147

Traffic Alert and Collision Avoidance – Hybrid Surveillance

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J. Stuart Searight	Federal Aviation Administration

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Appendix A

Conversion of Reported Positions to Slant Range

This appendix provides useful guidance on computing range from own and reported position data. However, this section does not recommend a particular implementation and should be used for reference only. The equipment manufacturer must meet the computational accuracy requirements of §2.2.7.6.

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A.1 Overview

This appendix provides useful guidance on computing range from own and reported position data. This appendix does not recommend a particular implementation and should be used for reference only.

First, the exact conversion equations from position to slant range are given. The computational requirements for the exact conversion equations are reasonable and could be used as is for modern processors and typical TCAS traffic loads.

Second, several approximate conversion equations from position to slant range are presented. For circumstances where hybrid surveillance is implemented as a software upgrade to existing processors, it may be desirable to use approximations to the conversion equations to reduce the computational requirements. The errors in the approximate equations are presented and compared to the computational accuracy requirements of §2.2.7.6, which requires a maximum 145 m processing error when calculating slant range.

A.2 Exact Conversion Equations

The following equations (Ref. E, Appendix 3.A.1, p. 115) give the exact conversion from latitude, longitude, and height above the WGS 84 ellipsoid to x, y, z earth-centered earth-fixed coordinates, based on the WGS 84 ellipsoidal earth model used by GPS.

$$x = (N + h) \cos \varphi \cos \lambda \qquad \text{(A2-1)}$$

$$y = (N + h) \cos \varphi \sin \lambda \qquad \text{(A2-2)}$$

$$z = (N(1 - e^2) + h) \sin \varphi \qquad \text{(A2-3)}$$

where:

$N = a / (1 - e^2 \sin^2 \varphi)^{1/2}$ = the length of a line normal to the ellipsoid between the point (φ, λ) on the surface of the ellipsoid and the point where it intersects the axis of the ellipsoid

h = height above the WGS 84 ellipsoid

φ = geodetic latitude

λ = geodetic longitude

$e^2 = (a^2 - b^2)/a^2$ = the square of the first eccentricity of the WGS 84 ellipsoid = $6.69437999014 \times 10^{-3}$

a = the semi-major axis of the WGS 84 ellipsoid = 6378137.0 m

b = the semi-minor axis of the WGS 84 ellipsoid = 6356752.3142 m

By converting both own and other aircraft's positions to x, y, z, the slant range can then be obtained by the standard equation:

$$r^2 = (x_{other} - x_{own})^2 + (y_{other} - y_{own})^2 + (z_{other} - z_{own})^2 \qquad \text{(A2-4)}$$

Note that N is a function of φ and so the exact result requires calculating separate values of N for own aircraft and the other aircraft. However, N is a slowly varying function of latitude (see Table A - 1) and could probably be calculated accurately enough by table lookup and interpolation with a small table of values.

The exact equations for slant range given above should not be difficult for modern computers to process in real time for the traffic loads typical for TCAS. They involve the calculation of four trigonometric functions (the sine and cosine of both latitude and longitude) and a square root to calculate x, y, and z. That must be done for own aircraft and for each of the other aircraft. An additional square root is then required for each of the other aircraft to calculate its slant range. Additional calculations may be required to extrapolate own aircraft's position to the time of validity of the other aircraft's reported position, and the conversion of own aircraft's position to x, y, z may therefore need to be performed for each report received from other aircraft.

Table A - 1. Comparison of R and N for a Spherical Earth Radius as a Function of Latitude

Assumed spherical earth radius A = 6,366,707 m WGS 84 semi-major axis = 6,378,137.0 m WGS 84 semi-minor axis = 6,356,752.3142 m				
Latitude (deg)	R (m)	A – R (m)	N (m)	A – N (m)
89	6399574	-32867	6399587	-32880
80	6397643	-30936	6398943	-32236
70	6392033	-25326	6397072	-30365
60	6383454	-16747	6394209	-27502
50	6372956	-6249	6390702	-23995
40	6361816	4891	6386976	-20269
30	6351377	15330	6383481	-16774
20	6342888	23819	6380636	-13929
10	6337358	29349	6378781	-12074
0	6335439	31268	6378137	-11430
-10	6337358	29349	6378781	-12074
-20	6342888	23819	6380636	-13929
-30	6351377	15330	6383481	-16774
-40	6361816	4891	6386976	-20269
-50	6372956	-6249	6390702	-23995
-60	6383454	-16747	6394209	-27502
-70	6392033	-25326	6397072	-30365
-80	6397643	-30936	6398943	-32236
-89	6399574	-32867	6399587	-32880

A.3 Height Above Ellipsoid vs. Barometric Altitude

The h term in the above equations is the height above the WGS 84 ellipsoid, also known as HAE. This may be available for own aircraft, but is not usually provided in the Airborne Position Messages of other aircraft. For the purpose of range calculations for TCAS hybrid surveillance, it turns out to be sufficiently accurate to substitute uncorrected barometric altitude for HAE, both for own and other aircraft (large errors may result if it is not done for both).

The difference between uncorrected barometric altitude and true HAE is the sum of two effects. The geoid is the surface that represents Mean Sea Level in the WGS 84 system. The geoid is not the same as the WGS 84 ellipsoid. The geoid may be above or below the WGS 84 ellipsoid. The difference between the geoid and the WGS 84 ellipsoid is termed the geoidal height. Thus the first error effect is the geoidal height, which ranges from –104 m to +75 m (Ref. C, p. 83), where positive values indicate the geoid is above the ellipsoid, and negative values indicate it is below.

The second error effect is the difference between the uncorrected barometric altitude and the true (corrected) altitude above mean sea level (above the geoid). This is due to atmospheric pressure variations. The maximum variation likely to be encountered by an aircraft can be estimated by observing the range of adjustment provided in the Kollsman window of an aircraft altimeter. The pilot sets the value in this window to the reported sea level barometric pressure at or near own aircraft's location. This then corrects the altitude shown on the face of the altimeter to the true altitude with respect to mean sea level. The range of sea level pressure settings for one such altimeter was observed to be from 28.1 inches of mercury (in. Hg) to 31.0 in. Hg. In units of millibars, this is 952 mbar to 1050 mbar. The standard atmospheric pressure assumed in uncorrected barometric altitudes is 29.92 in. Hg (1013 mbar). Thus, the uncorrected barometric pressure difference measured by the altimeter could be in error (measured - true) from -61 to +37 mbar. At sea level, the pressure varies with altitude at a rate of 3.5 mbar per 30 m (Ref. F); these pressure differences would give altitude errors (reported – true) in the range of -523 m to +317 m (-1716 ft to +1040 ft).

The combination of both error effects could lead to errors (measured – true) in the range of –627 m to +392 m (-2057 ft to 1286 ft) when uncorrected barometric altitude is substituted for HAE. As a crosscheck, note that the Extended Squitter Airborne Velocity Message provides a range of ±3125 ft (±953 m) for the "Geometric Height Difference from Barometric Altitude" field (Ref. C, Appendix A, p. A-58).

Numerical tests performed by inserting a common altitude error into the h values used for both own and other aircraft, such as would occur if the uncorrected barometric altitude was substituted for HAE for both aircraft, and assuming the aircraft are approximately 15 NM apart, indicate that common errors in h of ±1000 m result in an error in the calculated slant range r of no more than ±5 m. This is negligible with respect to the 145 m processing error budget specified in §2.2.7.6.

A.4 Spherical Earth Approximation

One approximation to the slant range calculation is to assume a spherical earth. The equations are the same as those for the ellipsoidal earth, simplified by substituting the assumed constant earth radius for the varying value N and setting the eccentricity e to zero. In terms of calculation, this saves one square root per aircraft due to eliminating the calculation of N.

Table A - 2 illustrates the error in the spherical earth approximation for one condition using an earth radius of 6,366,707 m. The delta latitude and the delta longitude at the equator assumed for these results was 0.175 deg. The delta longitude was adjusted with latitude by dividing the equatorial value by the cosine of the latitude in order to give approximately the same slant range at all latitudes. Own aircraft HAE was 40,000 feet, and other aircraft's HAE was 30,000 feet. Similar results are obtained at other relative bearings, except that the error at the equator can become roughly as large as the error at the pole when the aircraft are primarily north-south of each other.

Table A - 2. Example of Errors in Spherical Earth Approximation

Aircraft 1 altitude = 40,000 ft Aircraft 2 altitude = 30,000 ft Aircraft 2 latitude = Aircraft 1 latitude + 0.175 deg Aircraft 2 longitude = Aircraft 1 longitude + Delta longitude			
Aircraft 1 latitude (deg)	Delta longitude (deg)	True slant range (NM)	Spherical earth slant range – true slant range (m)
89	10.027	14.368	-135
80	1.008	14.974	-135
70	0.512	14.998	-119
60	0.350	14.997	-95
50	0.272	14.987	-65
40	0.228	14.973	-33
30	0.202	14.960	-3
20	0.186	14.949	21
10	0.178	14.943	37
0	0.175	14.942	42
-10	0.178	14.947	37
-20	0.186	14.958	21
-30	0.202	14.973	-3
-40	0.228	14.992	-33
-50	0.272	15.013	-65
-60	0.350	15.036	-95
-70	0.512	15.060	-120
-80	1.008	15.102	-136
-89	10.027	15.667	-147

A.5 Approximation Assuming N is the Same for All Aircraft

A second approximation to the slant range calculation is to assume that N is the same for both own and other aircraft in the exact equations. This saves one square root per other aircraft. Some numerical results from such an approximation are given in Table A-3. Since N varies with latitude but not longitude, the example shows a case where the aircraft are north-south of each other, resulting in the greatest latitude difference. If they had the same latitude, the error would be zero. If the parameters used in Table A - 3. are modified by setting the altitude of aircraft 2 to 40,000 ft (no altitude difference), the errors are reduced to under 0.5 m at all latitudes.

Table A - 3. Example of Errors Using the Same N for Both Aircraft

Aircraft 1 altitude = 40,000 ft Aircraft 2 altitude = 30,000 ft Aircraft 2 latitude = Aircraft 1 latitude + 0.25 deg Aircraft 2 longitude = Aircraft 1 longitude			
Aircraft 1 latitude (deg)	Delta longitude (deg)	True slant range (NM)	Slant range assuming N1=N2 – true slant range (m)
89	0.000	15.192	0.3
80	0.000	15.188	3.4
70	0.000	15.175	6.5
60	0.000	15.154	8.9
50	0.000	15.130	10.2
40	0.000	15.104	10.3
30	0.000	15.079	9.0
20	0.000	15.059	6.6
10	0.000	15.046	3.5
0	0.000	15.042	0.0
-10	0.000	15.046	-3.3
-20	0.000	15.059	-6.2
-30	0.000	15.079	-8.3
-40	0.000	15.103	-9.4
-50	0.000	15.129	-9.4
-60	0.000	15.154	-8.3
-70	0.000	15.174	-6.2
-80	0.000	15.187	-3.4
-89	0.000	15.192	-0.4

A.6 Ellipsoidal Differential Approximation

A third approximation to the slant range calculation is to treat the distances involved as if they were small enough to be treated as infinitesimals. The differential distance element on the surface of an ellipsoid is (Ref. G)[1]:

$$ds^2 = (R\, d\varphi)^2 + (N \cos\varphi\, d\lambda)^2 \tag{A6-1}$$

$$R = a(1 - e^2) / (1 - e^2 \sin^2 \varphi)^{3/2} \tag{A6-2}$$

where R is the radius of curvature of the meridian ellipse.

To convert this to an equation for slant range, the assumption is made that the distances involved can be treated as if they are infinitesimal, and that the (φ, λ, h) coordinate system can be treated as linear, rather than curvilinear, over those distances. (The true coordinate axes are orthogonal at own aircraft's location, but two of them curve as they move away, while the approximation assumes they are straight lines.) Adjustments must also be made to account for the height of own aircraft above the reference ellipsoid, and to account for the height difference between the two aircraft. The resulting equation is:

$$r^2 = ((R + h)\, \Delta\varphi)^2 + ((N + h) \cos\varphi\, \Delta\lambda)^2 + \Delta h^2$$

R, N, h and cos φ are evaluated at own aircraft's location, and the latitude and longitude differences are substituted for the infinitesimals. This involves only two trigonometric functions (sine and cosine of latitude) and one square root (the calculations of R and N can share the result), and only for own aircraft. Using table lookup and interpolation for R and N can reduce the computations further, as they are both slowly varying functions of latitude (see Table A - 1). For each of the other aircraft, only a square root is required.

Various numerical results using this approximation are shown in Table A - 4, Table A - 5, and Table A - 6. The HAE of one aircraft is 40,000 ft and the HAE of the other aircraft is 30,000 ft. In Table A - 4, the delta longitude has been set to zero in order to show the accuracy of the approximation when only latitude differences are involved. The delta latitude is 0.25 deg. The approximation is excellent at all latitudes. The errors shown are due to having a combined height and latitude difference and the coordinate system not being truly linear over the distances involved. If the height difference is set to zero, the resulting errors are less than 1 m.

In Table A - 5, the delta latitude has been set to zero in order to show the accuracy of the approximation when only longitude differences are involved. The delta longitude at the equator is 0.25 deg, and it is adjusted with latitude by dividing by the cosine of the latitude in order to keep the slant range approximately constant. The approximation is

[1] This is a somewhat obscure publication, and derives the equation for the differential of arc length on a spheroid (ellipsoid of rotation) from the fundamental equations for the differential of arc length of an arbitrary smooth curve on a smooth surface, which is a complex approach. However, a heuristic derivation is as follows. R is the radius of curvature of the meridian ellipsoid. The equation for R can be derived using the general equation for the radius of curvature found in advanced calculus texts. The differential of arc length Rdθ for a circle of radius R is a direct result of the definition of θ in radians. Similarly, N cos φ is the radius of the circle of constant latitude and N cos φ dλ gives the differential arc length along that circle. Assuming these two quantities are orthogonal in the infinitesimal limit gives the desired result.

again excellent at all latitudes except close to the poles, where the assumptions underlying the approximation break down. Once again, if the height difference is set to zero the errors are less than a meter except for the values at ±89 deg, which become 73 m.

In Table A - 6, the delta latitude and the delta longitude at the equator have both been set to 0.175 deg. The same cosine correction is made to the delta longitude as a function of latitude. These are the same values used to generate Table A - 2. The approximation is still quite good at most middle latitudes, but not as good as in Table A - 4 and Table A - 5, again showing the deviation from the assumed linearity over the distances involved. This approximation is better than the spherical earth approximation at latitudes within ± 80 deg. The error is less than the bias allowance for Mode S transponders within a range slightly larger than ±50 deg latitude, which would cover most of the dense traffic regions of the world except northern Europe, including the United Kingdom. If the height difference is set to zero, about 6-7 m is subtracted from these errors, reducing the magnitude of the errors in the northern hemisphere but increasing it in the southern hemisphere, making the errors more symmetrical with respect to north-south latitude.

The net result of using an ellipsoidal differential approximation is a significant reduction in the calculations required to compute slant range, balanced by moderate errors at most latitudes. At higher latitudes the approximation becomes progressively less accurate, depending on the azimuth of the other aircraft.

Table A - 4. Example of Errors in Ellipsoidal Differential Approximation with No Longitude Difference

Aircraft 1 altitude = 40,000 ft Aircraft 2 altitude = 30,000 ft Aircraft 2 latitude = Aircraft 1 latitude + 0.25 deg Aircraft 2 longitude = Aircraft 1 longitude			
Own latitude (deg)	Delta longitude (deg)	True slant range (NM)	Differential slant range – true slant range (m)
89	0.000	15.192	7
80	0.000	15.188	6
70	0.000	15.175	6
60	0.000	15.154	6
50	0.000	15.130	6
40	0.000	15.104	6
30	0.000	15.079	6
20	0.000	15.059	6
10	0.000	15.046	6
0	0.000	15.042	7
-10	0.000	15.046	7
-20	0.000	15.059	7
-30	0.000	15.079	7
-40	0.000	15.103	7
-50	0.000	15.129	7
-60	0.000	15.154	7
-70	0.000	15.174	7
-80	0.000	15.187	7
-89	0.000	15.192	7

Table A - 5. Example of Errors in Ellipsoidal Differential Approximation with No Latitude Difference

Aircraft 1 altitude = 40,000 ft Aircraft 2 altitude = 30,000 ft Aircraft 2 latitude = Aircraft 1 latitude Aircraft 2 longitude = Aircraft 1 longitude + Delta longitude			
Own latitude (deg)	Delta longitude (deg)	True slant range (NM)	Differential slant range – true slant range (m)
89	14.325	15.153	79
80	1.440	15.190	7
70	0.731	15.186	7
60	0.500	15.179	7
50	0.389	15.171	7
40	0.326	15.162	7
30	0.289	15.154	7
20	0.266	15.148	7
10	0.254	15.143	7
0	0.250	15.142	7
-10	0.254	15.143	7
-20	0.266	15.148	7
-30	0.289	15.154	7
-40	0.326	15.162	7
-50	0.389	15.171	7
-60	0.500	15.179	7
-70	0.731	15.186	7
-80	1.440	15.190	7
-89	14.325	15.153	79

Table A - 6. Example of Errors in Ellipsoidal Differential Approximation with Combined Latitude, Longitude and Height Differences

Aircraft 1 altitude = 40,000 ft Aircraft 2 altitude = 30,000 ft Aircraft 2 latitude = Aircraft 1 latitude + 0.175 deg Aircraft 2 longitude = Aircraft 1 longitude + Delta longitude			
Own latitude (deg)	Delta longitude (deg)	True slant range (NM)	Differential slant range – true slant range (m)
89	10.027	14.368	1253
80	1.008	14.974	126
70	0.512	14.998	64
60	0.350	14.997	43
50	0.272	14.987	31
40	0.228	14.973	24
30	0.202	14.960	18
20	0.186	14.949	14
10	0.178	14.943	10
0	0.175	14.942	7
-10	0.178	14.947	3
-20	0.186	14.958	-1
-30	0.202	14.973	-5
-40	0.228	14.992	-11
-50	0.272	15.013	-18
-60	0.350	15.036	-30
-70	0.512	15.060	-51
-80	1.008	15.102	-112
-89	10.027	15.667	-1153

A.7 Spherical Differential Approximation

A fourth approximation to the slant range equations is a spherical differential approximation. The spherical differential approximation is presented in Ref. C, §2.2.3.2.3.7, §2.2.3.2.3.8 and subparagraphs. The equations can be obtained from that given for the ellipsoid in §A.6 by substituting the assumed radius for the spherical earth (6,366,707 m) for both R and N. The spherical differential approximation in Ref. C does not include the correction for own aircraft's height. A height of 40,000 ft corresponds to 12,192 m, which would be added to the earth's radius. For extrapolations of no more than 2 s as specified in Ref. C this difference can be neglected. However, ignoring it for a slant range of 15 NM would result in an error on the order of 53 m, so it should be taken into account in the slant range calculation.

Table A - 7, Table A - 8, and Table A - 9 give numerical results for the spherical differential approximation under the same conditions as Table A - 4, Table A - 5, and Table A - 6 for the ellipsoidal differential approximation. The results include the height correction to the assumed earth radius. The errors are of the same order of magnitude as the spherical approximation, except at high latitudes where they can be much worse, but vary greatly for a given latitude depending on azimuth. These results can be better understood by comparing the spherical radius A used in these tables with the terms R and N used in the more exact ellipsoidal differential correction, as shown in Table A - 1. The assumed radius A is less than R at the poles, and greater than R at the equator. Therefore the latitude term of the equation gives too small a result at the poles, and too large at the equator. On the other hand, A is always smaller than N, but A deviates more at the poles and less at the equator. Therefore, the longitude component is always too small, but less so at the equator. Close to the pole, the effect of A being too small partly corrects for the overestimation of the longitude component that results from the failure of the assumption of a linear coordinate system.

Table A - 7. Example of Errors in Spherical Differential Approximation with No Longitude Difference

Aircraft 1 altitude = 40,000 ft Aircraft 2 altitude = 30,000 ft Aircraft 2 latitude = Aircraft 1 latitude + 0.25 deg Aircraft 2 longitude = Aircraft 1 longitude			
Own latitude (deg)	Delta longitude (deg)	True slant range (NM)	Differential slant range – true slant range (m)
89	0.000	15.192	-136
80	0.000	15.188	-128
70	0.000	15.175	-104
60	0.000	15.154	-67
50	0.000	15.130	-21
40	0.000	15.104	27
30	0.000	15.079	73
20	0.000	15.059	110
10	0.000	15.046	134
0	0.000	15.042	142
-10	0.000	15.046	134
-20	0.000	15.059	110
-30	0.000	15.079	74
-40	0.000	15.103	28
-50	0.000	15.129	-20
-60	0.000	15.154	-65
-70	0.000	15.174	-103
-80	0.000	15.187	-127
-89	0.000	15.192	-136

Table A - 8. Example of Errors in Spherical Differential Approximation with No Latitude Difference

Aircraft 1 altitude = 40,000 ft Aircraft 2 altitude = 30,000 ft Aircraft 2 latitude = Aircraft 1 latitude Aircraft 2 longitude = Aircraft 1 longitude + Delta longitude			
Own latitude (deg)	Delta longitude (deg)	True slant range (NM)	Differential slant range – true slant range (m)
89	14.325	15.153	-64
80	1.440	15.190	-132
70	0.731	15.186	-125
60	0.500	15.179	-113
50	0.389	15.171	-97
40	0.326	15.162	-81
30	0.289	15.154	-66
20	0.266	15.148	-54
10	0.254	15.143	-46
0	0.250	15.142	-43
-10	0.254	15.143	-46
-20	0.266	15.148	-54
-30	0.289	15.154	-66
-40	0.326	15.162	-81
-50	0.389	15.171	-97
-60	0.500	15.179	-113
-70	0.731	15.186	-125
-80	1.440	15.190	-132
-89	14.325	15.153	-64

Table A - 9. Example of Errors in Spherical Differential Approximation with Combined Latitude, Longitude and Height Differences

Aircraft 1 altitude = 40,000 ft Aircraft 2 altitude = 30,000 ft Aircraft 2 latitude = Aircraft 1 latitude + 0.175 deg Aircraft 2 longitude = Aircraft 1 longitude + Delta longitude			
Own latitude (deg)	Delta longitude (deg)	True slant range (NM)	Differential slant range – true slant range (m)
89	10.027	14.368	1112
80	1.008	14.974	-10
70	0.512	14.998	-55
60	0.350	14.997	-52
50	0.272	14.987	-34
40	0.228	14.973	-9
30	0.202	14.960	15
20	0.186	14.949	35
10	0.178	14.943	47
0	0.175	14.942	49
-10	0.178	14.947	40
-20	0.186	14.958	20
-30	0.202	14.973	-8
-40	0.228	14.992	-44
-50	0.272	15.013	-83
-60	0.350	15.036	-125
-70	0.512	15.060	-170
-80	1.008	15.102	-248
-89	10.027	15.667	-1294

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Appendix B

Analysis of Validation/Revalidation Range Tolerance Error Budget

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B.1 Introduction

To get the benefit of hybrid surveillance, the errors under the control of hybrid surveillance should be minimized as much as practical to ensure that aircraft that could be validated as hybrid are validated. Some sources of error are outside the control of hybrid surveillance. These include:

- TCAS active surveillance range error.
- Intruder passive position sensor error.
- Intruder position message LSB.
- Uncompensated latency in the intruder position when received by TCAS.
- Own aircraft passive position sensor error.
- Uncompensated latency in own aircraft passive position when received by TCAS.

Errors that can be controlled to some degree by TCAS hybrid surveillance are referred to as *hybrid data processing errors*. These errors include:

- Differences in the time of applicability of the TCAS range measurement and the intruder position data once it is received by TCAS. Although this time difference cannot be eliminated, design options such as whether to use the TCAS crosslink will affect the size of the error.
- Differences in the time of applicability of the TCAS range measurement and own aircraft position data once it is received by TCAS. It is possible to time align this data by extrapolating or interpolating own aircraft position data and TCAS range data to a common time for the comparison. Own aircraft data can be extrapolated by own aircraft rates if available, and TCAS range can be extrapolated by TCAS range rate estimates if available.
- Approximations in calculating the slant range from own and intruder latitude, longitude and altitude that might be used to simplify processing (See **Appendix A**).

A 290 m validation range threshold was chosen based on the analysis shown in Table B-1. The 340 m revalidation threshold was made 50 m larger than the validation threshold in order to provide some hysteresis and so reduce the chance of an intruder near the threshold going to active surveillance because of small changes in the ranging errors. The following sections explain how the values in Table B-1 were estimated.

Table B - 1. Error Sources in the Hybrid Slant Range Calculation and Validation with TCAS Range

Errors Outside the Control of TCAS Hybrid Surveillance	
TCAS active surveillance range error, 95%	69 m
Passive surveillance intruder position sensor error, 95%	93 m
Intruder position message LSB	5 m
Uncompensated latency in intruder position when received by TCAS	185 m
Passive surveillance own position sensor error, 95%	93 m
Uncompensated latency in own aircraft position when received by TCAS	77 m
Total errors outside control of TCAS hybrid surveillance (assuming errors combine by root-sum-square)	250 m
Error budget for data processing by hybrid surveillance during validation	145 m
Resulting size of validation range tolerance (assuming errors combine by root-sum-square)	290 m (0.157 NM)
Revalidation range tolerance (validation range tolerance plus 50 m)	340 m (0.184 NM)

B.2 TCAS Active Surveillance Range Error

TCAS range accuracy is specified in Ref. A, §2.2.2.2.3, which requires that TCAS measure the range of Mode S targets with signal power at least 6 dB above MTL with no more than 125 ft (38.1 m) bias and 50 ft (15.24 m) rms jitter.

The 95% range error can be calculated from the bias and jitter using

$$95\% \text{ probability} = \text{bias} + 2\sigma = 125 \text{ ft} + 2*50 \text{ ft} = 225 \text{ ft } (69 \text{ m}) \qquad \text{(B2-1)}$$

B.3 Own and Intruder Position Sensor Error

14 CFR §91.227 requires that the NACp for all ADS-B Out units indicate a 95% accuracy of 0.05 NM or better. That corresponds to 93 m. That accuracy is assumed for both the intruder position sensor error and own position sensor error.

B.4 Intruder Message LSB

The intruder message LSB is specified in Ref. C, §A.1.4.2.3. The position squitter encoding using compact position reporting has a resolution of approximately 5.1 m.

B.5 Uncompensated Latency in Intruder Position When Received by TCAS

14 CFR §91.227 requires the uncompensated latency for all ADS-B Out units to be less than 0.6 s. At the maximum aircraft ground speed of 600 kt (309 m/s) assumed in the

TCAS design, that corresponds to a distance of 185 m. That is the worst-case position error that is possible for an intruder whose uncompensated latency satisfies the specification. That much range error would only be observed in a head-on encounter with the intruder having a ground speed of 600 kt. In addition to the range error being smaller at slower speeds, smaller values would apply if the intruder's relative heading was different from 180 degrees, with the intruder's velocity vector, and the position error due to uncompensated latency, being projected onto the line of sight between the two aircraft. Finally, 0.6 s is the maximum uncompensated latency that is allowed, and it can be expected that many actual values will be smaller than that.

The analysis in Table B-1 treats each of the errors as a normally distributed or Gaussian random variable. The magnitudes given in that table are treated as representing about two standard deviations of their respective distributions, so that 95% of all errors are smaller. They therefore combine by the square root of the sum of the squares procedure that applies to the standard deviations of all random variables, whether normally distributed or not. However, the 185 m worst-case range error due to uncompensated latency is an overestimate of the 95% value. If one knew both the distribution of relative headings and the distribution of uncompensated latencies over all intruders, one could calculate a value for two standard deviations of the overall distribution that was smaller than the worst-case of 185 m. However, the distribution of uncompensated latencies is unknown, and so a worst-case assumption would be needed there in any case, and one would have to assume something like a uniform distribution for the distribution of relative headings. It is much simpler to use the worst-case value as the two standard deviation value. It provides extra margin, and still allows the safety analysis in Appendix D to be carried through successfully.

B.6 Uncompensated Latency in Own Aircraft Passive Position When Received by TCAS

The uncompensated latency in the position report for own aircraft when reported to TCAS is assumed to be 0.25 s or less. Since that quantity is determined by systems outside the scope of this MOPS, no requirement for it can be stated in this MOPS, and it does not appear to be constrained by any other specifications. If the actual value in a proposed system will exceed the assumed value by a substantial amount under realistic operational loads, this analysis should be revisited. At the maximum aircraft ground speed of 600 kt assumed in the TCAS design an uncompensated latency of 0.25 s corresponds to a distance of 77 m. As with the intruder's uncompensated latency, the worst-case error is used as if it represents two standard deviations of the error distribution, even though it is an overestimate of that value.

B.7 Error Budget Allocated For Hybrid Surveillance Data Processing

The allocation of 145 m to hybrid surveillance data processing errors during validation is somewhat arbitrary. It is the same value that was used in the original DO-300. It was calculated there as the residual when errors outside the control of hybrid surveillance were subtracted from the 200 m validation range tolerance that had been a longstanding parameter of the hybrid surveillance design and that was mandated in the ICAO SARPS. In this revised analysis, it is simply assumed and added to the errors outside the control of TCAS hybrid surveillance to get a new value for the validation range tolerance.

B.8 Sample Allocation of Hybrid Data Processing Errors

The hybrid data processing error budget is 145 m (see Table B - 1). Table B - 2 shows some ways that the error budget could be allocated.

Table B - 2. Sample Allocation of Hybrid Data Processing Errors

Hybrid Data Processing Error	**Sample Allocations**		
Time Difference Between TCAS Active Range Measurement and Intruder Position Data	450 msec = 140 m	400 msec = 124 m	300 msec = 93 m
Time Difference Between TCAS Active Range Measurement and Own Aircraft Position Data	0 m (own aircraft data extrapolated)	200 msec = 62 m	100 msec = 31 m
Approximation in Calculating Slant Range from Position	0 m (perfect calculation)	0 m (perfect calculation)	95 m (spherical Earth approx. at 60 deg latitude)
Total (Assuming Errors Root Sum Square)	**140 m**	**140 m**	**136 m**

Appendix C

Analysis of the Impact of the Altitude Threshold (AMOD) on Transponder Utilization

The results of this appendix are applicable to a system compliant with RTCA DO-185B and the original version of RTCA DO-300. These results were not updated to reflect Change 2 to DO-185B nor the revisions contained within this specification.

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C.1 Introduction

Simulations were performed by Alion Science and Technology to determine the impact of AMOD defined in §2.2.6.1.4 and §2.2.7.1.2 on transponder utilization. This appendix documents those results.

C.2 Aircraft Deployments

Three different air space models were used representing Dallas Ft-Worth, the Los Angeles Basin, and Frankfurt (Table C - 1).

Table C - 1. Aircraft Deployment Scenarios

Scenario	Equipage		
	TCAS II and Mode S Transponder	Mode S Transponder Only	ATCRBS Transponder Only
Dallas-Forth Worth	81	5	52
Los Angeles Basin	83	29	362
Germany 2005	117	57	31

Note: *For the Germany 2005 scenario, 38 aircraft on the airport surface at Frankfurt have their Mode S transponders in operation and four of these aircraft have their TCAS II units in operation.*

C.2.1 Dallas-Forth Worth Aircraft Deployment

The Dallas-Fort Worth (DFW) aircraft deployment was constructed from recorded Automated Radar Terminal System (ARTS) III aircraft tracks provided by the FAA and contains 138 aircraft within 60 NM of DFW (Table C - 1). This aircraft deployment represents an unusually high density of TCAS II-equipped aircraft.

Several scans of the ARTS III radar track data were used to construct a record for each aircraft that included its initial location and velocity. The ARTS III data was examined to smooth out altitude anomalies and to fill in missing radar returns. The TCAS Signal Environment Model (SEM) uses an initial location along with a velocity vector for each aircraft. This approach was developed to use data available for the Los Angeles Basin scenario. For most radar tracks, the record identified the aircraft as general aviation or air transport. In constructing the scenario, the study assumed all air-transport aircraft would be equipped with TCAS II and most general aviation aircraft would be equipped with ATCRBS transponders. Five aircraft (most likely general aviation aircraft) were assumed to be equipped with Mode S transponders but not TCAS. For several aircraft, the ARTS III data did not provide the airline flight number or an assigned beacon or Mode A code. Aircraft above 16,000 ft altitude were assumed to be TCAS II equipped. For aircraft below 16,000 ft altitude, the aircraft speed or proximity to DFW (i.e., the appearance of taking off or landing) was used to identify aircraft likely to be TCAS II equipped. The remaining aircraft were assumed to be equipped with ATCRBS transponders.

C.2.2 Los Angeles Basin Aircraft Deployment

The hypothesized Los Angeles Basin air traffic model consists of 474 transponder-equipped aircraft within 60 NM of the Los Angeles International Airport (LAX) (Table C - 1). In this air deployment, 53 general-aviation aircraft are designated high-performance (multiple-engine) aircraft, 30 aircraft are air transport, and 29 of the remaining general aviation aircraft are designated as Mode S transponder equipped. The 30 air-transport and 53 high-performance general aviation aircraft are assumed to be equipped with TCAS II interrogators. The remaining 362 aircraft are modeled as equipped with ATCRBS transponders. The Los Angeles Basin air deployment produces an air traffic population with a density of 0.3 aircraft per square NM within 5 NM of any TCAS II-equipped aircraft (the maximum density for which TCAS was designed to operate).

C.2.3 Germany Scenario 2005 Aircraft Deployment

Scenario 2005 was developed by Germany in 2001 for studies of Identification Friend or Foe (IFF) and Secondary Surveillance Radar (SSR) performance. The United Kingdom and United States provided inputs to the scenario development and also reviewed the scenario. Scenario 2005 represents a projected picture of the air traffic and ground IFF/SSR deployments in Germany for the years 2005 to 2008. The airborne scenario contains a total of 900 transponder-equipped aircraft within 250 NM of Frankfurt Airport.

A portion of Scenario 2005 represents the Frankfurt airspace and has a high air-traffic density. Because Scenario 2005 has a large number of ground SSRs and military IFF interrogators contributing to the signal environment, the Frankfurt airspace with its high air-traffic density represents a severe test for SSR performance. Table C - 1 describes the number of aircraft in Scenario 2005 in the Frankfurt airspace (i.e., within 60 NM of the Frankfurt South SSR).

C.3 Results: Effect of AMOD on Transponder Utilization

Simulations were performed to determine the impact of changing the hybrid surveillance altitude threshold on the transponder utilization. The computer simulations were performed with a statistical TCAS model that used snapshots of the scenario to represent three minutes of time. Three aircraft deployments were used in the analysis: the Dallas-Fort Worth, the Los Angeles Basin, and Germany 2005. For this analysis, all UF=0 (correct address and incorrect address), Mode C-only interrogations (decoded as main beam or suppressions), and mutual suppressions were used to calculate the transponder utilization. Each of these signal events were assumed to occupy the transponder for a length of time within the limits of Ref. D. The precise numbers for the occupancy of each signal were based on transponder measurements performed by the DoD Joint Spectrum Center, QinetiQ, and EADS.

For the simulations, four different values of AMOD were used in the simulations (3000, 4500, 6000, and 10,000 ft). The slant range threshold or SMOD was set to 3 NM for each simulation. For comparison the transponder utilization where each TCAS used TCAS II Version 7 is also shown.

The transponder utilization charts (Figure C - 1, Figure C - 2 and Figure C - 3) show the amount of time the transponder is busy processing Mode C interrogations, Mode S interrogations, and mutual suppressions. For each simulation, the results are shown for

Mode S transponders on TCAS aircraft, for Mode S transponders where the aircraft had only the Mode S transponder, and for ATCRBS transponders where the aircraft had only the ATCRBS transponder. For each simulation, the mean transponder utilization is shown as is the transponder utilization for the transponder with the maximum transponder utilization.

C.3.1 Dallas-Forth Worth Air Deployment Results

For the simulation using TCAS II V7, Mode S tracking causes most of the transponder utilization (Figure C - 1). This is produced by a high density of TCAS II and Mode S equipped aircraft within 20 NM of the DFW control tower. For hybrid surveillance, increasing AMOD produces a small but steady increase in transponder utilization. Switching from TCAS II V7 to hybrid surveillance significantly reduces transponder utilization by reducing the time the transponder is occupied processing Mode S interrogations and the amount of time the transponder is mutually suppressed by its aircraft's TCAS.

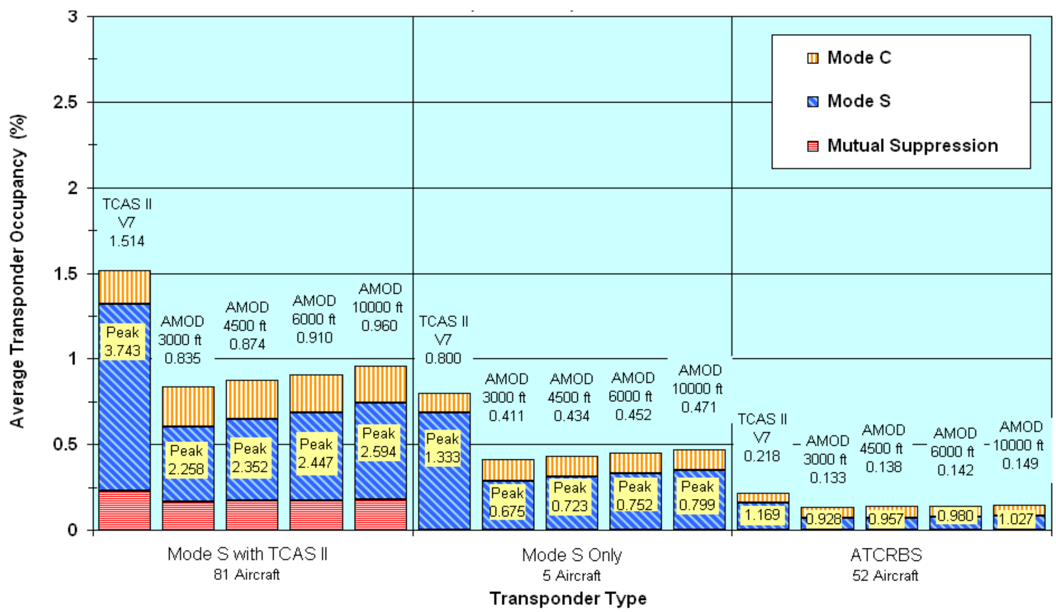

Figure C - 1. Dallas-Fort Worth Transponder Utilization

C.3.2 Los Angeles Basin Air Deployment Results

For the simulations using the Los Angeles Basin Air Deployment, hybrid surveillance provides a reduction in transponder utilization that is not as large as the reduction seen for the Dallas-Fort Worth Air Deployment (Figure C – 2). The reason is that for the Los Angeles Basin Air Deployment the TCAS equipped aircraft are spread more throughout the scenario. (The Los Angeles Basin has five airports which serve air carrier aircraft whereas, Dallas-Fort Worth has only two airports.) Also note that for the Los Angeles Basin Air Deployment, the Mode C tracking is much higher than was shown for Dallas-Fort Worth. This results from the large numbers of Mode C aircraft spread throughout the Los Angeles Basin Air Deployment. Comparing the effect of increasing AMOD on transponder utilization, the transponder utilization increases at a fairly small rate with increasing AMOD.

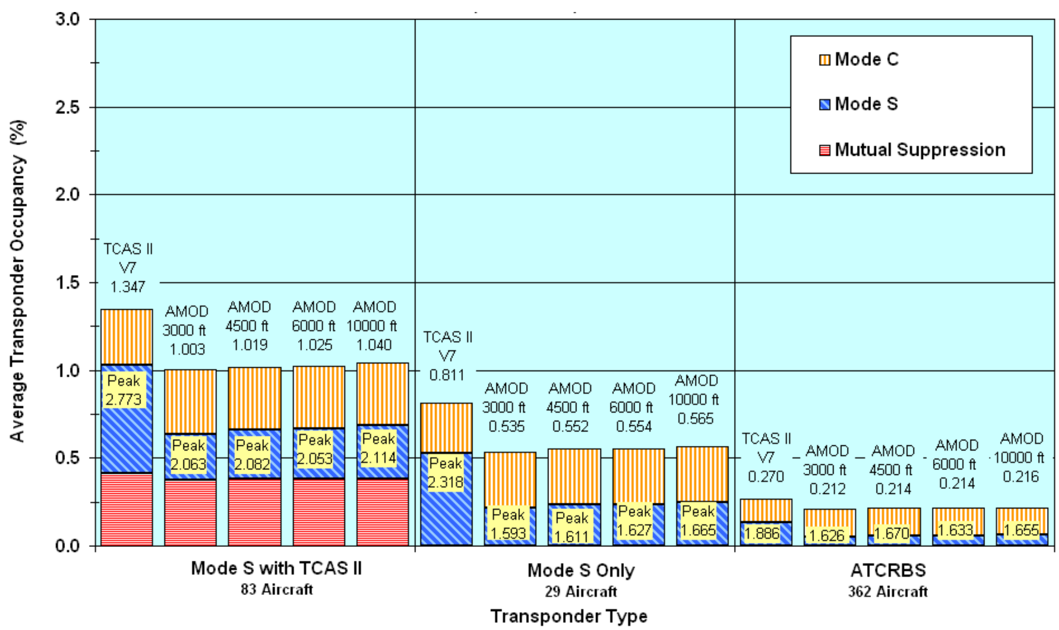

Figure C - 2. Los Angeles Basin Transponder Utilization

C.3.3 Germany 2005 Air Deployment Results

The German 2005 Air Deployment represents the air picture expected to be seen in Germany in the near future. The airspace near Frankfurt has a high density of TCAS equipped aircraft similar the Dallas-Fort Worth, but this air deployment also has a large number of high altitude (en route) air traffic that is not seen in the Dallas-Fort Worth or Los Angeles Basin air deployments. Consequently, the transponder utilization shown for the German air deployment is the highest of the three air deployments (Figure C - 3). The effect of implementing hybrid surveillance produces a significant reduction in transponder utilization. For Germany this reduction in transponder utilization exceeded 50 percent. When AMOD was increased the transponder utilization also showed a small increase.

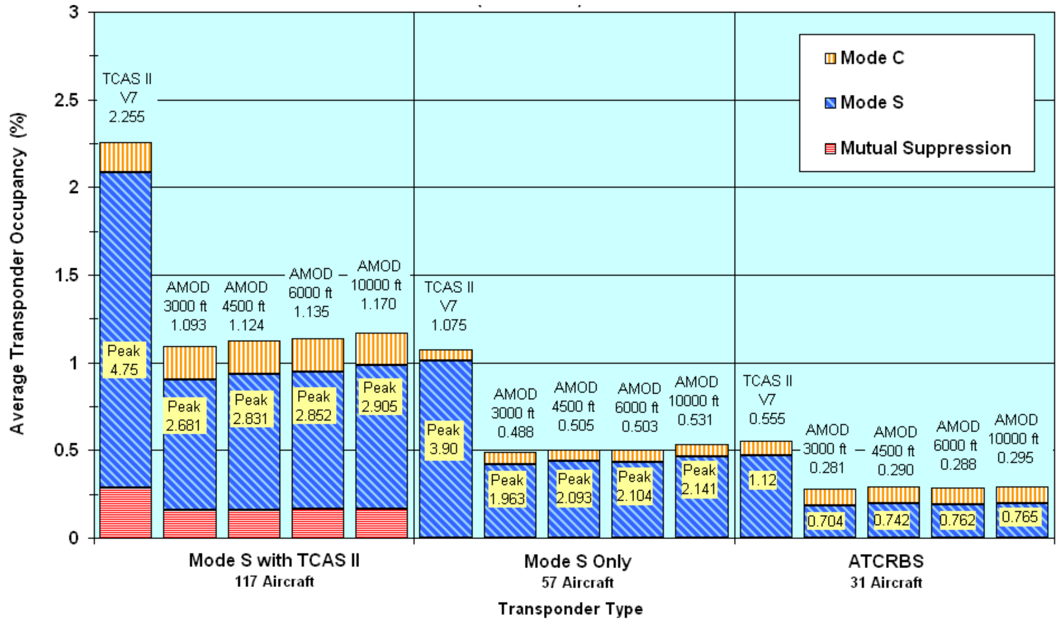

Figure C - 3. Germany 2005 Transponder Utilization

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Appendix D

Hybrid Surveillance Safety Analysis

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D.1 Safety Assessment Framework

This appendix describes the safety analysis supporting the requirements developed as part of the Minimum Operational Performance Standards for Traffic Alert and Collision Avoidance System II (TCAS II) hybrid surveillance. It includes the analysis methodology, a fault analysis, supporting analyses and simulations, and additional background on TCAS II functions that are important for understanding the implementation of hybrid surveillance.

D.1.1 Review of Hybrid Surveillance from a Safety Perspective

D.1.1.1 Operational Benefits

The major operational benefit of hybrid surveillance is reduced spectrum use. Frequency regulators and civil aviation authorities in congested airspace are concerned about increased use of the 1030/1090 MHz radio frequency bands used for transponder-based aircraft surveillance. Reducing active interrogations through the use of hybrid surveillance helps to ensure that transponder occupancy times will not increase to the point where there would be degradation in such surveillance.

A secondary benefit of hybrid surveillance is that the flight crew may see more targets on the TCAS display in congested traffic. TCAS performs interference limiting in congested airspace, which can have the effect of reducing the number of targets that are displayed. Reduced spectrum use lessens the need for TCAS to limit the surveillance targets.

D.1.1.2 Flight Crew Interface

The implementation of hybrid surveillance is transparent to the flight crew. All displays, control panels and procedures for using TCAS are the same with or without hybrid surveillance.

D.1.1.3 Airspace Impact

Hybrid surveillance has no adverse impact on the airspace. The implementation of hybrid surveillance is compatible with existing Mode S transponder output. If no targets qualify for passive surveillance, TCAS operates exactly as it does today. If some targets do qualify for passive surveillance, TCAS will reduce the number of active interrogations against those targets and reduce spectrum use.

D.1.1.4 Aircraft Impact

The existing antennas and wiring required for TCAS are not changed if hybrid surveillance is implemented. To take advantage of hybrid surveillance, an aircraft needs the ability to receive passive 1090 MHz squitters from other aircraft and the ability to provide own aircraft position to TCAS.

Passive squitters are received using the same antennas and receivers as non-hybrid TCAS. No wiring or antenna changes are required. Own aircraft position can be provided in different ways, depending on the avionics architecture. In most cases, own aircraft position will be provided using an existing ARINC 429 input bus on TCAS.

D.1.1.5 How Does Hybrid Surveillance Affect the Existing TCAS Collision Protection?

This appendix will demonstrate that hybrid surveillance does not compromise the existing TCAS collision protection. The requirements for hybrid surveillance were developed to ensure that TCAS performs its collision avoidance functions safely with or without hybrid surveillance enabled. Passive surveillance data is not used to detect threats or issue advisories. The passive-to-active-TCAS surveillance transition criteria ensure that active TCAS surveillance is available in time to detect threats and issue traffic advisories or resolution advisories.

D.1.2 Scope of Safety Assessment for Hybrid Surveillance

D.1.2.1 Typical Features of a Safety Assessment for Collision Avoidance Systems

Safety assessment of avionics can be quite involved. Airspace, aircraft and individual system impacts all need to be addressed. For collision avoidance systems, a safety assessment typically includes the following activities:

1. Develop a concept of operations that describes how the aircraft are expected to fly in the designated airspace.

2. Develop an encounter model that captures the expected encounter geometries and expected frequency of occurrence.

3. Compute risk ratios that look at the risk of collision with and without the collision avoidance system using a large number of simulated encounters. An alternative when considering changes to a collision avoidance system is to look at the risk of collision with the original collision avoidance system and the proposed changes to the collision avoidance system.

4. Develop a fault tree analysis or functional hazard analysis to identify events that could lead to a failure in the end-to-end collision avoidance process and estimate the absolute or relative system risk.

5. Simulate special encounters that could cause problems for the proposed system. This is important since the risk ratios calculated with a large number of encounters may obscure problems in special circumstances.

It is also important to show that the requirements developed for the proposed system or proposed modifications to an existing system are complete and correct.

D.1.2.2 Applicability of Existing TCAS Safety Assessments

A comprehensive safety assessment of TCAS II was published in 1983 (Ref. H). The study considered the principal TCAS failure mechanisms, including surveillance faults, bit errors in the altitude reply of the intruder's transponder, avionics failures and pilot errors. The faults of concern are those that result in a near mid-air collision (NMAC), because either:

- TCAS fails to produce adequate separation for two aircraft that already are on a near collision course; or

- TCAS advises a maneuver that induces an NMAC for two proximate aircraft that are not on a near collision course.

A comprehensive fault tree was developed for qualitative and quantitative analysis of all possible events that could lead to an NMAC. Two more recent safety studies related to TCAS include Ref. I and Ref. J.

Many pieces of the existing TCAS safety assessments and certification standards still apply with the proposed addition of hybrid surveillance. Specifically:

- Hybrid surveillance does not change how the flight crew uses TCAS. Therefore, there is no need to study the effect of human error or perform a mode confusion analysis.

- Hybrid surveillance does not change the type of aircraft that equip with TCAS or the way that they fly. Therefore, the same concept of operations and encounter models used for the original TCAS safety assessments apply.

- Hybrid surveillance does not change the antennas and wiring required for TCAS. Therefore, the existing certification standards for aircraft installation still apply. Any changes required on the aircraft to implement passive surveillance are already specified in Ref C.

- Hybrid surveillance does not change the collision avoidance functions (also called the collision avoidance system or CAS) within TCAS, including the aircraft tracking functions that are part of those collision avoidance functions, nor does it change the interface between the non-CAS surveillance functions (also called the surveillance system) and the collision avoidance functions.

- Hybrid surveillance <u>is</u> a change to the non-CAS surveillance system inside TCAS. However, it does not affect TCAS active surveillance; therefore the existing analysis of the surveillance faults and bit errors in the altitude reply of the intruder's transponder still holds.

Given those observations, this safety analysis will focus on the safety effects of the differences in the surveillance functions between TCAS without hybrid surveillance and TCAS with hybrid surveillance. The events in the fault tree in the original safety analysis that could be affected by those differences are those related to when and whether traffic advisories (TAs) or resolution advisories (RAs) are issued. Differences in the display of traffic prior to a TA or RA being issued are not a safety concern. The only display issues that are considered in the original safety analysis are those that occur once a TA or RA has been issued.

D.1.2.3 Approach for Hybrid Surveillance Safety Assessment

The safety assessment for hybrid surveillance serves multiple purposes. It is used to verify that minimum performance requirements are complete and that the collision avoidance protection of TCAS is not compromised. It was also used to support the development of some minimum requirements needed to mitigate the effect of potential fault conditions.

The safety assessment described in the rest of this appendix shows that hybrid surveillance does not compromise the safety of TCAS collision avoidance because:

- Advisories (Traffic Advisories, TAs, and Resolution Advisories, RAs) are never based on passive surveillance data. Tracks based on passive surveillance data are marked in such a manner that the CAS will not generate TAs and RAs for them. Advisories will be generated only for intruders under active surveillance. TCAS with hybrid surveillance will therefore retain its status as an independent safety system, and all previous safety studies of TCAS continue to apply unchanged. Tracks based on passive surveillance data may only be displayed on the pilot's traffic display for situational awareness.

- For normal (fault-free) operation, that is, when the position reports used for passive surveillance have the accuracy required under applicable standards and laws, intruders will be under active surveillance in sufficient time to issue advisories identical to those that would be issued by TCAS without hybrid surveillance, and will remain under active surveillance as long as a TA or RA persists. Simulation results show the largest variation in advisory time is 1 second, which is comparable to the variation that might occur between different vendor implementations of TCAS.
- For normal (fault free) operation, at the time of an advisory, the range, range rate, altitude, altitude rate, bearing, and bearing rate derived from active surveillance will be effectively identical to what would have been obtained if active surveillance had been maintained throughout. That ensures that TAs will have the same timing and that RAs will have the same timing, sense and strength as they would have had if hybrid surveillance was not being used.
- In the presence of faults in the position reports used for passive surveillance, the system safety is no worse than that of TCAS without hybrid surveillance. Either the fault condition affects TCAS without hybrid surveillance in the same manner as it does TCAS with hybrid surveillance, or mechanisms are in place to prevent the fault from affecting the outcome, or it is demonstrated that although the fault could degrade surveillance in TCAS with hybrid surveillance, the risk ratio is not affected.

The safety assessment is organized as follows:

- §D.2 provides some additional background on how TCAS processes surveillance information and performs collision avoidance. It also provides more detail on the requirements that ensure the transition from passive to active surveillance.

- §D.3 is the fault analysis. It systematically reviews all of the faults that could cause a missed or misleading TA or RA and either points to the requirement that ensures that the fault condition cannot occur, or demonstrates that TCAS without hybrid surveillance implemented would also have a missed or misleading TA or RA, or demonstrates that despite the difference in TA or RA timing and content the TCAS risk ratio is not affected.

- §D.4 contains more detail on three analyses and simulations that support the fault analysis in §D.3.

D.2 Background on TCAS and Hybrid Surveillance Implementation

§D.2.1 provides some necessary background on TCAS II. The remainder of §D.2 provides additional background on the surveillance features of TCAS with hybrid surveillance (also called hybrid TCAS below) that are different from those of TCAS without hybrid surveillance (also called non-hybrid TCAS below). Those differences are what drive the safety analysis, and this background is useful for understanding the fault analysis in §D.3 and supporting simulation analysis in §D.4.

D.2.1 TCAS

TCAS uses active interrogation of air traffic control transponders to track the slant range, bearing and altitude of nearby aircraft. Slant range and altitude are used to determine if the nearby aircraft pose a collision threat. Bearing is used to provide a pilot situation display, as well as to assist in detecting when an intruder will have a large enough horizontal miss distance that no collision avoidance advisory is needed. Two types of collision avoidance advisories are issued. A Traffic Advisory (TA) warns the flight crew of a potential threat but no avoidance maneuver is recommended. A Resolution Advisory (RA) provides the flight crew with a proposed climb or descend maneuver that the pilot flies manually. A TA is typically provided 10 to 15 seconds before an RA.

D.2.1.1 TA and RA Advisory Criteria

TAs and RAs are issued based on simultaneously satisfying both a range criterion and an altitude criterion. The equations for the modified tau range criterion and the altitude criterion are shown in Table D-1. The range criterion for TAs and RAs takes the same form, but with different parameter values. Those parameter values are shown in Table D-2, which was adapted from Ref. A, Table 2-13. TCAS computes a projected earliest time of closest approach that incorporates the possibility of lateral acceleration by the intruder as well as its slant range and range rate. This earliest time of closest approach is called modified tau to distinguish it from the simple range over range rate projection called tau, which is used as the latest time of closest approach. An absolute distance parameter called DMOD is used as an estimate of the lateral motion due to acceleration in calculating modified tau and also as an absolute distance threshold for issuing or maintaining TAs and RAs for intruders that are nearby, but that are diverging or that have very small closure rates.

Table D - 1. Collision Avoidance Advisory Criteria

Range Criterion	–(range – DMOD^2/range) / min(–6 kt, range rate) < tau threshold
Altitude Criterion	|altitude separation| < altitude threshold OR {altitude separation rate < -1ft/s AND – altitude separation / altitude separation rate < tau threshold}

Table D - 2. TCAS Advisory Parameters

Own Altitude (ft)	**Altitude Layer**	**Sensitivity Level**	**Tau Threshold** (sec)		**DMOD** (NM)		**Altitude Threshold** (ft)	
			TA	**RA**	**TA**	**RA**	**TA**	**RA**
< 1000	1	2	20	N/A	0.30	N/A	850	NA
1000 – 2350		3	25	15	0.33	0.20		600
2350 – 5000	2	4	30	20	0.48	0.35	850	600
5000 – 10000	3	5	40	25	0.75	0.55	850	600
10000 – 20000	4	6	45	30	1.00	0.80	850	600
20000 – 42000	5	7	48	35	1.30	1.10	850	700
> 42000	6						1200	800

The TA altitude criterion is satisfied if either the vertical separation between own aircraft and the intruder is less than a threshold, or else if their vertical separation is decreasing and the projected time to co-altitude is less than a threshold. The projected time to co-altitude is a simple vertical separation divided by vertical separation rate calculation, or altitude tau. The altitude criterion for RAs is more complex than that for TAs, and more complicated than shown in Table D-1, including calculations of the projected vertical separation at the time of closest approach. However, the TA altitude criterion, with appropriate parameter values for RAs, is a necessary but not sufficient condition for the RA altitude criterion. Therefore, comparing the TA and RA parameter values shown in Table D-2 is sufficient to show that the TA altitude criterion will always be satisfied prior to the RA altitude criterion. Since the objective of hybrid surveillance is to have intruders under active surveillance prior to any TA, they will then necessarily be under active surveillance prior to any RA.

The DMOD and tau threshold parameters in these equations vary with sensitivity level, which is primarily a function of altitude, but can also be affected by pilot control settings and other factors. RAs are inhibited in sensitivity level 2, so no parameters are shown for

RAs at that sensitivity level. The altitude threshold parameter is determined by the altitude layer setting, which depends only on the altitude of the TCAS aircraft. The definition of the altitude layers is simplified to show fixed boundaries; in reality hysteresis is provided to prevent rapid jumping between adjacent altitude layers when an aircraft is flying right at the boundary altitude. The altitude values shown are half way between the bottom altitude for the higher numbered layer and the top altitude for the lower numbered layer.

D.2.1.2 Surveillance System, Collision Avoidance System, and Their Interface

The two major subsystems within TCAS are the surveillance system and the collision avoidance system (Figure D - 1). The surveillance system interrogates aircraft transponders and processes the replies to provide range, bearing and altitude to the surveillance filters. The surveillance filters (also called trackers) smooth the measurements, estimate range rate and vertical rate, determine which tracks are valid, and establish the surveillance mode. If the surveillance system determines that an intruder's surveillance replies form a valid track, it then passes the position reports (but not the derived range rate and vertical rate) to the collision avoidance system. If the surveillance system determines that a track is no longer valid, it tells the collision avoidance system to drop that track. Valid tracks may be updated by active surveillance position reports once per second, in which case they are marked as NORMAL surveillance reports. However, for certain valid, active, but non-threatening tracks the surveillance system may only update their position every 5 seconds, in which case they are marked as being REDUCED surveillance reports. Under hybrid surveillance, the surveillance system is responsible for determining when a track should transition from passive surveillance to active surveillance and from active surveillance to passive surveillance, as well as between the two passive surveillance modes. Valid tracks under passive surveillance are reported to the collision avoidance functions as being REDUCED surveillance reports.

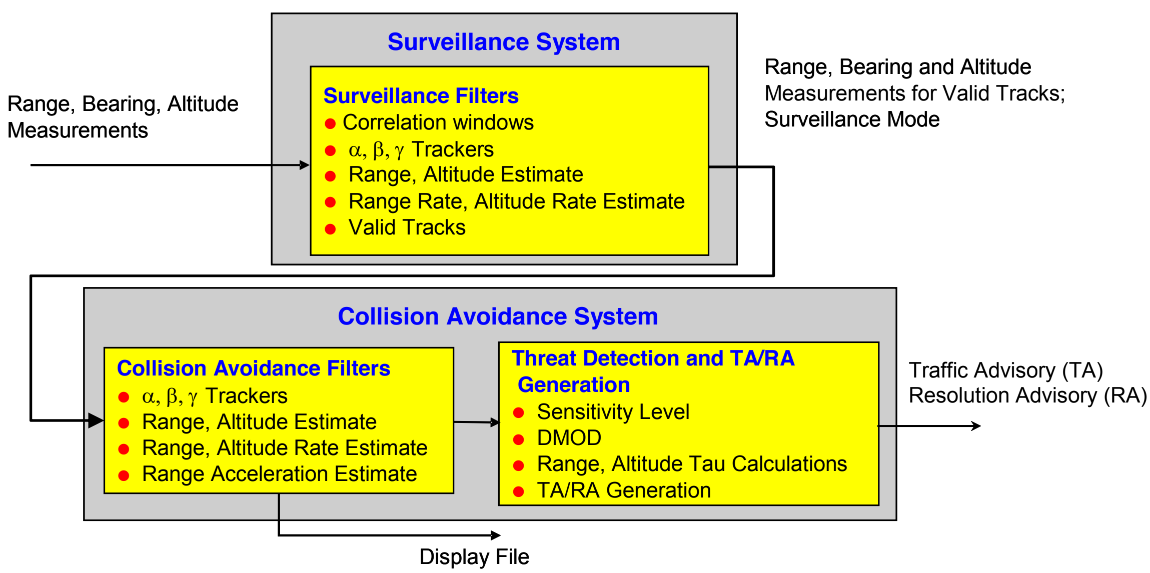

Figure D - 1. TCAS Surveillance and Collision Avoidance Systems

The collision avoidance system, like the surveillance system, filters the range, bearing and altitude measurements. However, the collision avoidance system only processes measurements for the valid tracks passed to it by the surveillance system. For valid tracks under either NORMAL or REDUCED surveillance the filtered range, bearing and altitude are output to the traffic display. However, the collision avoidance system will only generate TAs and RAs for valid tracks under NORMAL surveillance.

The distinction between NORMAL and REDUCED surveillance does not affect the collision avoidance system altitude tracking functions. They process both types of reports identically, and so there is no change in the altitude tracking when a track transitions from one mode to the other.

However, the collision avoidance system's range and bearing tracking functions are significantly affected by this distinction, as are the functions that generate TAs and RAs. The range and bearing tracking functions have a parameter called the range track firmness. The range track firmness for a given track is set to a value of zero whenever a REDUCED surveillance report is received for that track. The firmness is incremented by one at each NORMAL surveillance update with valid range data.

The range track firmness is used to select the tracker smoothing parameters. Under REDUCED surveillance and the resulting zero value for range track firmness, the result is that the track's range is simply updated to reflect the reported range, the range rate does not change (and so is zero for a track started under REDUCED surveillance, or otherwise holds the range rate estimate from the last NORMAL surveillance update) and the range acceleration is set to zero. If the surveillance subsequently transitions to NORMAL mode, the tracker gains selected by the range track firmness will have the same large values as if the track was just starting, and so, even if a residual range rate from a prior NORMAL surveillance period was being held, the range rate will be based only on active surveillance reports after two such reports are received. Range acceleration is not estimated until the tracker is considered fully initialized at a range track firmness of 8.

The range track firmness is also used to disable certain collision avoidance functions until the range track is considered to be sufficiently mature. A TA can be displayed after a single NORMAL surveillance report is received for an intruder. However, the intruder track will not have a valid range rate estimate until a second NORMAL surveillance report is received. Therefore a TA might not be issued until the second report if the TA depends on the range rate and not just the range. The range track firmness must reach a value of 3 before the collision avoidance system will display an RA for an intruder, The range track firmness must reach a value of 8 before horizontal miss distance filtering is enabled. Horizontal miss distance filtering inhibits unnecessary RAs if the projected horizontal miss distance is large enough. It does not apply to TAs.

The implementation of the collision avoidance system and associated filters is specified in Ref. B. Guidance is provided on the surveillance system's range filter implementation in Ref. A, but the specific implementation is dependent on the vendor.

D.2.2 Hybrid Surveillance Modes

The safety analysis for hybrid surveillance must distinguish three hybrid surveillance modes: active, validated passive and unvalidated passive. Active surveillance is considered the standard of truth, and is the only mode used by TCAS without hybrid surveillance. Active surveillance includes two sub-modes, NORMAL active surveillance with updates at 1-second intervals, and REDUCED active surveillance with updates at 5-second intervals. The distinction between those two sub-modes of active surveillance is not important to the safety analysis of hybrid surveillance. However, hybrid surveillance takes advantage of the different way that the collision avoidance system processes NORMAL and REDUCED surveillance reports.

Validated passive surveillance (also called hybrid surveillance) uses passive surveillance position reports to track intruders, but first validates the range, altitude and bearing provided by those passive position reports against an active surveillance position report. In addition, it revalidates those passive position reports by comparison with an active surveillance position report at intervals ranging from 10 to 60 seconds, depending on how much of a potential threat the intruder is. If the range computed from passive position reports is not within 290 m of the measured active range at the time of initial validation, or within 340 m of the measured active range at the time of revalidation, then that intruder's surveillance mode is switched to active surveillance.

Unvalidated passive surveillance (also called extended hybrid surveillance) is used for intruders that provide passive position reports and also report that their passive position reports meet certain quality criteria. Those intruders are acquired and tracked using passive position reports without any use of active position reports for validation purposes. However, if their reply power exceeds a threshold, which is 6 dBm higher than the receiver threshold used by standard TCAS, then their surveillance mode is switched to validated passive surveillance. If they fail a validation test at that transition, that will lead to a second transition to active surveillance.

During passive surveillance, passive range measurements are calculated based on ADS-B position reports from the intruder and position reports for own aircraft. The range and range rate estimates calculated for the intruder by the TCAS surveillance system are derived by tracking the passive range measurements over time, in the same manner as active range measurements are tracked by TCAS.

The barometric altitude data in the passive surveillance data is assumed to be identical to the barometric altitude data in active surveillance replies, because of the requirements in Refs. C and D. However, for those intruders under validated passive surveillance, the altitude data provided in their passive position reports is validated against the altitude provided in the active position reports at each validation and revalidation. No such altitude validation is performed for intruders under unvalidated passive surveillance.

D.2.3 Switching Between Hybrid Surveillance Modes

The transition from passive to active surveillance or vice versa is normally based on the range, range rate, relative altitude and relative altitude rate determined by the surveillance system. Table D-3 shows the relevant equations. The passive-to-active conditions, also called the hybrid threat criteria, are specified in §2.2.6.1.4, Active Surveillance Region. Both the range and altitude conditions must be true in order to trigger a passive-to-active transition from either the validated or unvalidated passive surveillance mode. §2.2.6.1.4 also specifies that the range rate must be estimated solely on the basis of passive position reports, in order to avoid possible range rate transients at transitions from active to passive surveillance. That means that, if the intruder was previously in the active surveillance mode, at least two passive position reports must be received before a transition back to active surveillance could take place.

Table D - 3. Surveillance Mode Transition Criteria

	Passive-to-Active (Hybrid Threat Criteria)	Active-to-Passive (Modified Hybrid Threat Criteria)
Range Criterion	– (range – 3.0 NM)/ min(–6 kt, range rate) ≤ 60 sec	– (range – 3.2 NM)/ min(–6 kt, range rate) ≥ 65 sec
Altitude Criterion	– (altitude separation – 4500 ft)/ min(–1 ft/s, altitude separation rate) ≤ 60 sec	– (altitude separation – 4900 ft)/ min(–1 ft/s, altitude separation rate) ≥ 65 sec

The active-to-passive conditions, also called the modified hybrid threat criteria, are specified in §2.2.7.1.2, Hybrid Surveillance Region. If either the range or the altitude condition is true, and if the intruder's passive position reports also pass a validation test, the surveillance mode will transition from active to validated passive surveillance. That paragraph also specifies that the range rate used in the range criterion must be based solely on active surveillance measurements, and that a range rate of -1200 knots should be assumed until that is true. Note that the numerical parameters in these equations are fixed and do not vary with sensitivity level, unlike the criteria for TCAS advisories shown in Tables D-1 and D-2.

Errors in range, range rate, altitude or altitude rate could lead to inappropriate surveillance mode transitions. Such errors could be due to differences between the passive and active range measurements, differences between the passive and active altitude measurements (however, a basic assumption of the design is that there is no such difference), or errors in the estimated rates provided by the surveillance trackers due to acceleration, jumps or noisiness of the basic range and altitude data.

In addition, a transition between the unvalidated passive surveillance mode and the validated passive surveillance mode can be triggered by a measurement of the intruder's reply power, used as a proxy for range. The expectation is that most intruders under unvalidated passive surveillance will transition to validated passive surveillance in that manner before they satisfy the conditions for active surveillance. However, if the reply power exceeds the specified threshold, it is also possible that the intruder may be closer in range than its passive range measurement indicates. The transition to validated passive surveillance results in validation or revalidation of the passive range. If the validation/revalidation test is passed, the intruder will remain in the validated passive surveillance state as long as its received power stays above the threshold. If the test fails, then the intruder is immediately placed under active surveillance.

D.2.4 Range Jumps and Range Rate Transients at Passive/Active Transitions

The intruder range determined by passive surveillance can differ significantly from the range measured under active surveillance, even when the passive range satisfies the revalidation requirements. Even larger range differences can occur due to a position reporting fault. During transitions from passive to active surveillance or vice versa there can be a significant jump in the apparent range of a track. Such large range jumps can lead to transients in the range rate computed by the surveillance system. Those range rate transients could lead to incorrect passive-to-active and active-to-passive surveillance mode transitions. This safety analysis will demonstrate that requirements are in place to mitigate the effects of such range rate transients in the surveillance system.

If such range rate transients were allowed to occur in the collision avoidance system, erroneous advisory decisions could be made. This safety analysis will demonstrate that requirements are in place to prevent such range rate transients in the collision avoidance system.

If the range jump at a passive-to-active or active-to-passive surveillance transition is large enough, the track might be dropped because the range does not fall within the required correlation window predicted from the last range and range rate estimates. Dropping tracks during such transitions is a safety concern for hybrid surveillance. This safety analysis will demonstrate that requirements are in place to ensure that track drops due to such range jumps are either prevented or their effects are mitigated.

D.2.5 Time Buffer for Passive-to-Active Surveillance Transitions

The safety objective for hybrid surveillance is to have an intruder under active surveillance prior to the time that either a Traffic Advisory (TA) or a Resolution Advisory (RA) is required, and to base those TAs and RAs entirely on active surveillance data with no residual effect from earlier passive surveillance data. Ideally, the active surveillance data should be tracked long enough prior to the TA or RA that the estimated range and range rate for the intruder are essentially identical to what they would have been if the intruder had always been tracked under active surveillance.

To help ensure those goals are achieved, it is desirable to start active surveillance several seconds before the time at which any advisory, TA or RA, should be generated. To accommodate encounters where the intruder is accelerating toward the TCAS aircraft, the transition to active surveillance should provide for such accelerated motion before the intruder crosses the TCAS advisory boundaries. A nominal range acceleration of 1/3 g or 11 ft/s^2 is assumed, as that is the acceleration that is used to derive the size of the DMOD parameter in the modified tau range criterion for threat declaration. The DMOD parameter is included in the threat declaration range test in order to address horizontal accelerations. A 1/3 g vertical acceleration is also assumed, as that is the altitude acceleration assumed by the collision avoidance functions when they model a pilot's response to an Increase Climb or Increase Descent RA, although in this case it is assigned to the combined acceleration of both aircraft. While larger accelerations are possible, they are uncommon, and ensuring that a transition to active surveillance was made sufficiently early to accommodate them would lead to a loss of some of the benefits of hybrid surveillance that is not justified. If such larger accelerations were encountered in operations, hybrid TCAS might generate its advisories slightly later than non-hybrid TCAS.

The size of the time buffer is determined by several factors. First, the collision avoidance range tracking function needs time to develop a good range and range rate estimate based solely on active surveillance reports. As discussed above, a TA can be issued on the first NORMAL surveillance report. However, the CAS tracking functions will not have a valid range rate estimate until at least two NORMAL surveillance reports have been received, so any TA issued on the first report will be based solely on the intruder's range. At least 3 NORMAL surveillance reports must be received before an RA will be generated for an intruder. The third NORMAL surveillance report will be received during the third update cycle, or about 3 seconds, after the decision to transition from passive to active surveillance. The CAS tracking functions must have received at least 8 NORMAL surveillance reports before the range tracking functions are considered to be fully initialized and to have a sufficiently accurate state estimate to perform horizontal miss distance filtering.

Next, there is the possibility that the track might be dropped during the transition from passive to active surveillance and restarted after 3 seconds, as required by §2.2.6.2, Active Surveillance Requirements. Therefore active surveillance reports might not actually begin until 3 seconds after the transition to active surveillance is started. However, §2.2.6.2, Table 1, clarifies that when the new track is presented to the CAS system, the three NORMAL surveillance updates that were used to initialize the track in the surveillance system will be reported to the collision avoidance system together in the same update cycle. Therefore the CAS track for that intruder will start with a firmness of 3 and with a valid range rate estimate no more than 3 update cycles after the update cycle in which the decision was made to transition that intruder to active surveillance. That is identical to what would happen if there was no track drop.

Combining the possibility of a track drop with the necessary initialization time for the collision avoidance tracking functions, the switch from passive to active surveillance must start at least 3 seconds before the intruder would qualify for either a TA or an RA. That ensures that, whether or not there is a track drop during the transition, the CAS system will have received 3 NORMAL range reports by the time a TA or RA should be issued. Better, but not essential, would be to start the transition at least 8 seconds before the intruder would qualify for an RA in order to allow for complete initialization of the CAS tracking functions.

D.3 Fault Analysis

D.3.1 Overview

The underlying premise of hybrid TCAS is that it cannot be less safe than non-hybrid TCAS. Ideally, TCAS should issue TAs and RAs at the same time and under the same conditions whether hybrid surveillance is implemented or not. The fault analysis in this section of the report lays out fault conditions that could cause hybrid TCAS to alert differently than non-hybrid TCAS. The analysis then either demonstrates that such faults are prevented, or mitigated, or have no effect on the overall TCAS risk ratio.

The fault analysis was developed with certain assumptions. These are:

- The requirements have been implemented correctly, since the implementation of the requirements is checked via testing (§2.4, Equipment Test Procedures; §3, Installed Equipment Performance). Thus, the major concerns are whether the requirements as defined are sufficient and whether bad input data could cause a fault.

- Hybrid surveillance does not degrade the performance of TCAS active surveillance. That is a requirement and is tested by ensuring that active surveillance performs as specified by the TCAS II performance standards (§2.2.1, General).

- The characteristics of active altitude and passive altitude are the same. The source of both is barometric altitude. For intruders under validated passive surveillance, any error in implementing passive altitude will be caught by the tight (100 ft) validation window and that intruder will be placed under active surveillance (§2.2.6.3, Validation of Airborne Position Message Data). However, there is no corresponding test for intruders under unvalidated hybrid surveillance.

D.3.2 High Level Fault Conditions

There are three high level ways in which hybrid TCAS could differ from non-hybrid TCAS in the timing of TAs and RAs and in the sense selection and strength selection for RAs. The first is if hybrid TCAS does not issue an advisory when non-hybrid TCAS does. The second is if hybrid TCAS issues an advisory when non-hybrid TCAS does, but issues a different advisory, for example a TA instead of an RA, or vice versa, or a different type of RA. Note that TAs are simply present or absent for an intruder, while there are a variety of different RAs that can be generated. The third is if hybrid TCAS issues an advisory when non-hybrid TCAS does not.

The level of concern is different for each of these categories, and within each the level of concern varies depending on the details of the timing and the advisory. If hybrid TCAS does not issue an advisory when non-hybrid TCAS initially does so, but does issue the advisory within a few seconds, that is of much less concern than a substantial delay in the advisory or failure to issue an advisory at all. A late TA or failure to issue a TA is of much less concern than a late RA or failure to issue an RA. In fact, the issuance of TAs was not generally considered in prior TCAS safety analyses. If hybrid TCAS issues a different advisory than non-hybrid TCAS that is of concern mainly if a TA is issued instead of an RA, or an inappropriate RA is issued, selected due to incorrect state estimates for the intruder in the hybrid TCAS system. Similarly, if hybrid TCAS issues an advisory when non-hybrid TCAS does not, that is of concern mainly if an inappropriate RA is issued due to erroneous state information. There is a secondary concern about nuisance alerts if hybrid TCAS frequently issues advisories when non-hybrid TCAS does not, or far in advance of when non-hybrid TCAS would issue an advisory.

One way that hybrid TCAS can fail to generate an advisory is if it does not have an intruder under active surveillance at the time that non-hybrid TCAS would issue an advisory. Hybrid TCAS is only able to issue advisories if the intruder is under active surveillance. If the intruder is not under active surveillance at the time an advisory should be generated, then either the advisory will be late or, if the condition persists, there will not be an advisory. There are two ways that hybrid TCAS might not have an intruder under active surveillance at the time that non-hybrid TCAS would generate an advisory. One is that hybrid TCAS does not have the intruder under surveillance at all, and the other is that hybrid TCAS has the intruder under passive surveillance.

Even if the intruder is under active surveillance, the state of the intruder's CAS track file in hybrid TCAS might differ in various ways from its state under non-hybrid TCAS. Because of that state difference hybrid TCAS might fail to generate an advisory when non-hybrid TCAS does, or might generate a different advisory, or might generate an advisory at a time that non-hybrid TCAS does not. The difference in the state of the intruder's CAS track file is due to the intruder being under active surveillance for a shorter time in hybrid TCAS, and will disappear once the intruder has been under active surveillance long enough for its CAS range track to be fully initialized.

The various conditions discussed above are summarized in Table D – 4. The table can be viewed as a tabular rather than graphical representation of an AND-OR fault tree. It can also be viewed as a representation of a logical expression consisting of a top-level OR of five terms represented by the columns under the OR. Each of those terms is an AND of two or more conditions. The conditions are listed in the leftmost column. T appears in a column for that condition if the condition must be true for the AND term represented by that column to be true. F appears in a column for a condition if the condition must be false for the AND term represented by that column to be true. If neither T nor F appears, the condition is not relevant to that column. Each of the five AND terms is numbered for easy reference in the text, if necessary.

Table D - 4. Hybrid TCAS Advisory Differs from Non-hybrid TCAS Advisory

		OR				
		1	2	3	4	5
Non-hybrid TCAS issues an advisory (the intruder is under active surveillance and satisfies the conditions for a TA or RA)	AND	T	T	F	T	T
Intruder under active surveillance by hybrid TCAS (§D.3.3)		T	T	T		
Hybrid TCAS does not issue an advisory when non-hybrid TCAS does (§D.3.3.1)		T				
Hybrid TCAS issues a different advisory than non-hybrid TCAS (§D.3.3.2)			T			
Hybrid TCAS issues an advisory when non-hybrid TCAS does not (§D.3.3.3)				T		
Intruder under passive surveillance by hybrid TCAS, so no advisory is possible (D.3.4)					T	
Intruder not under surveillance by hybrid TCAS, so no advisory is possible (D.3.5)						T

D.3.3 Intruder Under Active Surveillance By Hybrid TCAS

D.3.3.1 Hybrid TCAS Does Not Issue An Advisory When Non-Hybrid TCAS Does

When an intruder is under active surveillance hybrid TCAS can still fail to generate an advisory if the hybrid TCAS CAS range track for the intruder is not sufficiently mature. Once the intruder's CAS range track has received 8 NORMAL active surveillance updates it is considered fully initialized and the differences between hybrid TCAS and non-hybrid TCAS should be minimal.

One reason that hybrid TCAS can fail to generate an advisory for an intruder under active surveillance is that the collision avoidance functions will not generate an RA against an intruder unless at least 3 successive NORMAL active surveillance reports have been received for that intruder. A TA can be generated after only one NORMAL active surveillance report, but that TA would have to be based solely on the intruder's range, as no range rate estimate would be available until a second surveillance report was received. Therefore the TA might not appear until two reports have been received, if satisfying the TA criteria depends on having an accurate range rate.

Another reason that hybrid TCAS can fail to generate an advisory is if the intruder's range and range rate estimated by hybrid TCAS differ enough from those estimated by non-hybrid TCAS that the intruder does not satisfy the advisory criteria. While the CAS range tracking functions are not considered to be fully initialized, with their best range and range rate estimates, until 8 NORMAL active surveillance reports have been processed (more precisely, a range track firmness of 8 is reached), they are considered to be sufficiently initialized after 3 surveillance updates that RAs can be issued safely. See §D.3.3.5 for further discussion of the CAS range tracking.

Finally, as discussed in §D.4.1, Comparison of NORMAL/REDUCED Active Surveillance Regions with Passive/Active Surveillance Regions, in some regions of the range and range rate space, when an intruder transitions from passive to active surveillance it will be required to enter the REDUCED active surveillance state. That by itself is not an issue, as it would be in that state under non-hybrid TCAS also. However, the surveillance system's range trackers might have a range rate transient due to a jump in the intruder's apparent range at the transition from passive to active surveillance. If that transient has not died out sufficiently by the time the intruder crosses the boundary into the NORMAL active surveillance region, then that transition to NORMAL surveillance might be delayed. Even though the intruder is under active surveillance, it will be under REDUCED surveillance, and so the CAS will not generate TAs and RAs for it. While there are no specific requirements in this MOPS with respect to this possible problem, there are a number of other ways that range rate transients can cause difficulties, and so there is strong motivation for designing the surveillance system range trackers to suppress range rate transients at passive-to-active and active-to-passive surveillance transitions. The issue of range jumps and the resulting range rate transients at the passive-to-active transition is discussed more fully in §D.3.4.2.7, which in turn draws on the analysis of surveillance system range rate transients in §D.4.2.

In summary, if NORMAL active surveillance begins at least 3 seconds prior to the time that a TA should be issued, and 8 seconds prior to the time that an RA should be issued, and any surveillance system range rate transients resulting from the passive-to-active surveillance transition are suppressed, that TA or RA will not be delayed. If NORMAL active surveillance begins at least 3 seconds prior to the time that an RA should be issued, the only reason the RA might not be issued is if the CAS range and range rate, particularly the latter, have not yet converged to the correct values. It will be shown in §D.3.4, Intruder Under Passive Surveillance, that the 3-second time buffer is provided for TAs, and that the 8-second time buffer is provided for RAs, except in some cases where the passive range errors exceed the revalidation threshold, or when there is a single large jump in passive range at a critical time.

While altitude and altitude rate are important to the advisory criteria, they will not differ between hybrid and non-hybrid TCAS. See §D.3.3.4 for further discussion of the CAS altitude tracking. Therefore, any difference in advisory timing will be due to different values for range tau and modified range tau, and the resulting difference in the projected vertical separation during the interval of closest approach, also called the critical interval, that is defined by those two values.

D.3.3.2 Hybrid TCAS Issues A Different Advisory Than Non-Hybrid TCAS

A difference in the intruder range and range rate estimated by the CAS range tracker can lead to hybrid TCAS choosing a different advisory than non-hybrid TCAS. Again, the altitude and altitude rate estimates will not differ between hybrid TCAS and non-hybrid TCAS. Therefore, any difference in the advisory chosen will be due to different values for range tau and modified range tau and the resulting difference in the projected vertical separation during the time interval of closest approach that is defined by those two values.

If the CAS range tracker reaches a firmness of 8 (8 NORMAL active surveillance reports) and is therefore fully initialized, then it is assured that there will be no important difference between an RA issued by hybrid TCAS and one issued by non-hybrid TCAS. §D.3.4, Intruder Under Passive Surveillance, shows that the transition from passive to active surveillance will start early enough to ensure that the CAS range tracker is fully initialized prior to the time that any RA should be issued, under the normal condition that the intruder's passive range meets the revalidation criterion. If the passive range errors exceed the revalidation threshold, or if there is a single large jump in passive range at a critical time, then the CAS range tracker might not be fully initialized at the time an RA is issued.

D.3.3.3 Hybrid TCAS Issues An Advisory When Non-Hybrid TCAS Does Not

A difference in the intruder range and range rate estimated by the CAS range tracker is also one of the possible causes of hybrid TCAS issuing an advisory when non-hybrid TCAS does not. Again, the altitude and altitude rate estimates will not differ between hybrid TCAS and non-hybrid TCAS. Therefore, any difference in advisory timing will be due to different values for range tau and modified range tau, and the resulting difference in the projected vertical separation during the interval of closest approach that is defined by those two values.

The other possible cause for hybrid TCAS issuing an advisory, in particular issuing an RA, when non-hybrid TCAS does not, is the hybrid TCAS CAS range track not being mature enough to enable horizontal miss distance filtering. The horizontal miss distance function projects whether the intruder is likely to pass by the TCAS aircraft with a large horizontal miss distance, and inhibits RAs under that circumstance. Horizontal miss distance filtering is not enabled until the CAS range track for the intruder is considered fully initialized, which requires 8 active surveillance reports. If non-hybrid TCAS inhibits an RA due to the horizontal miss distance filtering function, but the intruder's CAS range track in hybrid TCAS is not sufficiently mature to enable the horizontal miss distance function, then hybrid TCAS will issue that RA.

§D.3.4, Intruder Under Passive Surveillance, shows that the transition from passive to active surveillance will start early enough to ensure that the CAS range tracker is fully initialized prior to the time that any RA might be issued, under the normal condition that the intruder's passive range meets the revalidation criterion. If the passive range errors exceed the revalidation threshold, or if there is a single large jump in passive range at a critical time, then the CAS range tracker might not be fully initialized at the time an RA is issued.

D.3.3.4 CAS Altitude and Altitude Rate Differences Between Hybrid TCAS and Non-hybrid TCAS

In summary, no such differences exist. First, it is a basic assumption of hybrid TCAS that the altitude reported in transponder replies to active interrogations is the same altitude that is reported in the position reports squittered by the same transponder. Various requirements of the Mode S transponder specification (Reference D) are designed to make the probability of any such difference extremely small. In addition, for intruders under validated passive surveillance, that assumption is verified during the validation/revalidation process. Because there is no difference between the active and passive altitude reports, there is no concern about transient altitude rate behavior when switching between passive and active surveillance or vice versa.

Second, the CAS altitude tracking functions are unaffected by the distinction between NORMAL and REDUCED surveillance reports. Therefore the altitude updates received during REDUCED surveillance update the altitude tracks just as they would under NORMAL surveillance, and there is no discontinuity in behavior or resetting of the altitude tracker at transitions between REDUCED and NORMAL surveillance, or vice versa. Other state variables related to altitude, such as altitude tracker firmness (a measure of the confidence in the altitude and altitude rate estimates) and the inner and outer altitude rate bounds that are used in low firmness conditions and in certain other situations, will also have the same values in hybrid TCAS and non-hybrid TCAS.

D.3.3.5 CAS Range and Range Rate Differences Between Hybrid TCAS and Non-hybrid TCAS

In the CAS range trackers, the intruder bearing measurements provided by the surveillance system are combined with the range measurements as part of the overall process of generating a horizontal miss distance estimate for the intruder as well as range and range rate estimates. The CAS tracking functions comprise three different range trackers (see Ref. B, §2.2.4.1.9, Horizontal_Miss_Distance_RA_Filter). One is a so-called Cartesian tracker that is used solely to detect horizontal maneuvers by either the intruder or the TCAS aircraft. Another is a parabolic tracker that is used both to detect maneuvers and to estimate horizontal miss distance by, in effect, fitting a parabola to the range values. The third is a range-bearing tracker that also both detects maneuvers and provides a second estimate of horizontal miss distance. Only this third tracker uses the bearing measurements provided by the surveillance system.

One way that the CAS range track for an intruder under hybrid TCAS might be substantially different from the track for the same intruder under non-hybrid TCAS is if hybrid TCAS was permitted to use passive surveillance data to generate advisories (that is, if passive surveillance reports were passed as NORMAL surveillance reports rather than as REDUCED surveillance reports). The passive range is allowed to differ from the active range by up to 340 meters even for intruder and TCAS position measurements that fully meet the ADS-B specifications. Also, the positions are allowed to vary from report to report over a larger distance than active range measurements, which increases the noisiness of the range rate estimate. Finally, use of the reported passive position would make TCAS entirely dependent on the accuracy of the reported data, and so increase the likelihood of a common mode failure where bad reported position data both leads to the situation where the two aircraft are too close together and prevents TCAS from detecting the problem.

To avoid all these concerns, it is critical to the safety of hybrid TCAS that both TAs and RAs, especially the latter, be generated only on the basis of independent range measurements made using TCAS active interrogations.

As described in §D.2.1.2, when an intruder is under REDUCED surveillance, and therefore when it is under passive surveillance, the CAS range tracker tracks only the last reported range. The range rate is held fixed at zero if the track has been under REDUCED surveillance since it was started, or it is held fixed at the last range rate estimate made under NORMAL surveillance if it was under NORMAL surveillance prior to entering the REDUCED surveillance state. Range acceleration estimates are always set to zero under REDUCED surveillance, as is the range tracker firmness. Therefore, when NORMAL surveillance commences, other than possibly a non-zero initial range rate value, the range tracker starts up just as it would for a new track. The tracker gains are initially set very high, so that the reported range is accepted without smoothing, and the first two range measurements are used to develop a new range rate estimate that completely replaces any leftover range rate value, whether zero or non-zero.

This procedure has been part of the CAS range trackers since the distinction between NORMAL and REDUCED surveillance was introduced along with the reduced 0.2 Hz rate of active surveillance for non-threatening intruders. It ensures that there is no range rate or range acceleration transient due to switching from passive to active surveillance.

The range, range rate, range acceleration, range firmness, and other range-related state variables can be different between hybrid TCAS and non-hybrid TCAS during the first 8 NORMAL track updates after the surveillance mode transitions from passive to active surveillance, although the differences will get smaller after each update. After 8 NORMAL surveillance updates the hybrid TCAS range track for the intruder is marked as fully initialized, and its state will be essentially the same as the range track for that same intruder under non-hybrid TCAS that was maintained under NORMAL surveillance since the intruder was detected.

The above analysis showing that the CAS range filter performance will not affect advisory times significantly was verified by simulating the TCAS collision avoidance functions and studying the advisory times with and without hybrid surveillance implemented for some representative co-altitude scenarios. §D.4.3 provides more details on the simulation and the simulation results. Both non-accelerating and accelerating scenarios were considered. Table D - 5 shows the TA and RA times for a range of head-on encounter scenarios with range jumps as large as 3000 ft at the passive-to-active surveillance transition, which occurs at T=60 seconds. The advisory times are identical.

Similar results were obtained for some representative co-altitude scenarios where two aircraft turn toward each other. The advisory times were within 1 second. They differed slightly since some of the range filter parameters are reset at the passive-to-active surveillance transition and the aircraft are accelerating. A 1-second difference in advisory times is similar to the difference in advisory times that might exist between two different manufacturer's TCAS implementations, and therefore is acceptable for a hybrid surveillance implementation.

Table D - 5. TA and RA Timing For Head-On Co-altitude Scenarios

Range Rate (ft/s)	Active Surveillance Only			Passive to Active Surveillance Range Jump at T=60 seconds											
				+3000 ft		+1500 ft		+600 ft		-600 ft		-1500 ft		-3000 ft	
	TA	RA	T_{CPA}	TA	RA	TA	RA	TA	RA	TA	RA	TA	RA	TA	RA
-1200	73	86	122	73	86	73	86	73	86	73	86	73	86	73	86
-1000	73	86	122	73	86	73	86	73	86	73	86	73	86	73	86
-470	73	86	125	73	86	73	86	73	86	73	86	73	86	73	86
-360	72	85	127	72	85	72	85	72	85	72	85	72	85	72	85

D.3.4 Intruder Under Passive Surveillance by Hybrid TCAS

This section analyzes the conditions that might lead to an intruder being under passive surveillance at the time that non-hybrid TCAS would issue a TA or RA. The conditions that must be considered are summarized in Table D-6.

If the intruder is under passive surveillance rather than active surveillance, it must be due to one of the following conditions. If the intruder is under validated passive surveillance, it satisfied the revalidation criteria at its last revalidation, and either its altitude and altitude rate or its range and range rate do not satisfy the passive-to-active or hybrid threat criteria. The hybrid threat criteria are given in Table D-3. If the intruder is under unvalidated passive surveillance, its received power level is below the threshold for transition to validated passive surveillance, and either its altitude and altitude rate or its range and range rate do not satisfy the hybrid threat criteria. The question is then whether an intruder can satisfy these passive surveillance conditions and also be in a state where non-hybrid TCAS would issue an advisory based on active surveillance measurements.

A final possibility, represented by columns 5 and 6 in Table D-6, is that the intruder transitions to active surveillance but quickly transitions back to validated passive surveillance, and continues to alternate between those two surveillance modes, unable to stay in the active surveillance mode. That requires that the intruder pass a validation test before it can return to validated passive surveillance from active surveillance. Then, the active-to-passive or modified hybrid threat criteria shown in Table D-3 must be satisfied while under active surveillance at essentially the same time that the passive-to-active transition criteria in Table D-3 are satisfied while under passive surveillance. That in turn requires that either the two sets of criteria can be satisfied simultaneously by the same values (a design error), or that the active surveillance values differ from the passive surveillance values in such a way as to allow both sets of criteria to be satisfied.

Table D - 6. Intruder Under Passive Surveillance by Hybrid TCAS

		OR					
		1	2	3	4	5	6
Intruder under validated passive surveillance	AND	T	T			T	T
Intruder under unvalidated passive surveillance				T	T		
Intruder passed last validation/revalidation test		T	T			T	T
Intruder received reply power less than threshold for transition to active surveillance				T	T		
Intruder's passive vertical separation and vertical separation rate satisfy passive-to-active transition criteria (§D.3.4.1)		F		F		T	T
Intruder's passive range and range rate satisfy passive-to-active transition criteria (§D.3.4.2)			F		F	T	T
Intruder's active vertical separation and vertical separation rate satisfy active-to-passive transition criteria (§D.3.4.1)						T	
Intruder's active range and range rate satisfy active-to-passive transition criteria (§D.3.4.2)							T

D.3.4.1 Analysis of Vertical Separation and Vertical Separation Rate Transition Criteria

The intruder's relative altitude with respect to the TCAS aircraft and the rate of change in that relative altitude are important factors in calculating TCAS advisories. Thus, if there were differences between hybrid TCAS and non-hybrid TCAS in the source of own aircraft altitude or in the tracking of own aircraft altitude and altitude rate, there could be a possibility of different advisories. However, both systems use identical interfaces and algorithms for obtaining and processing own aircraft altitude.

It is a basic assumption of the hybrid surveillance safety analysis that the altitude that an intruder's transponder would report at any given time in response to an active interrogation is identical to the altitude that it would squitter at that same time as part of its ADS-B position broadcasts. The altitude tracking performed by the TCAS surveillance system is the same for both altitude sources. Altitude tracking is performed differently for intruders reporting altitude in 25 ft increments than it is for intruders reporting altitude in 100 ft increments, but for a given intruder the altitude and altitude rate estimates will be the same whether it is under active surveillance, validated passive surveillance, or unvalidated passive surveillance. Thus, there is no issue of differences between the active and passive altitudes and altitude rates, or any issue of possible transient altitude rates or correlation failures during the transitions between active and passive surveillance, as there is with the range reports.

D.3.4.1.1 Analysis of Passive-to-Active Transition Time Buffer in Vertical Separation

The criteria for transitioning from passive to active surveillance and vice versa include conditions that are based on both altitude and altitude rate, as discussed in §D.2.3. If those altitude conditions are not designed properly they could prevent the timely transition from passive to active surveillance or they could allow inappropriate transitions from active to passive surveillance. One concern is that it must not be possible to simultaneously satisfy both the passive-to-active and the active-to-passive transition conditions with the same values for altitude separation and altitude separation rate. It can be seen by inspection of Table D-3 that is not possible. Since the active and passive altitudes and altitude rates are identical, that ensures that the condition summarized by column 5 in Table D-5 cannot be true because the two conflicting altitude tests cannot simultaneously be true. If it was possible to satisfy column 5 of Table D-6, then the intruder's surveillance mode could oscillate between the validated passive state and the active state.

Another concern is that the passive-to-active transition must occur prior to the time that the intruder would qualify for a TCAS advisory, or else the intruder would be under passive surveillance at the time the advisory should be generated, and hybrid TCAS will not generate an advisory for an intruder under passive surveillance. In addition, for reasons discussed in §D.2.5, it is desirable to have the transition to active surveillance start at least 3 seconds prior to the time of any advisory in order to provide sufficient time for the CAS range trackers to properly initialize and enable advisory generation. A lead time of 8 seconds is desirable prior to an RA in order to ensure that the horizontal miss distance filtering is enabled prior to the RA threshold being crossed.

Figure D-2 provides an easy way to evaluate whether those conditions are satisfied. The vertical axis represents the rate of change in vertical separation in feet per second, with negative values representing reduction in vertical separation. The horizontal axis represents the vertical separation in feet. The curve furthest to the lower left of Figure D-2 is a plot of the altitude criterion for a TA at altitude layer 6, sensitivity level 7, as shown in Tables D-1 and D-2. Since there is only a single hybrid surveillance passive-to-active altitude criterion, which does not vary with altitude layer or sensitivity level, it is only necessary to demonstrate that it gives a sufficient transition buffer time against the "largest" TA altitude boundary, the one furthest from the origin in vertical separation. All other TA altitude boundaries are to the left of the curve shown, and so if the passive-to-active transition begins early enough for that curve, it will provide an even larger time buffer for the TA altitude boundaries at other altitude layers and sensitivity levels. Similarly, all RA altitude boundaries are to the left of this TA boundary.

The next curve above and to the right of the TA curve is the locus of points from which that TA curve could be reached within 3 seconds assuming that there is an acceleration that is increasing the rate of closure at 1/3 g or 11 ft/s^2. That corresponds to the vertical acceleration that TCAS assumes for the pilot response to an Increase Climb or Increase Descent RA, although in this case it is allocated to the combined vertical acceleration of both the intruder and the TCAS aircraft. If the vertical separation is increasing faster than about 10 ft/s (600 ft/min) that acceleration is not enough to overcome that vertical divergence and put any intruder that starts outside the TA region inside the TA region within 3 seconds, and therefore the 3-second time buffer curve merges with the TA boundary curve.

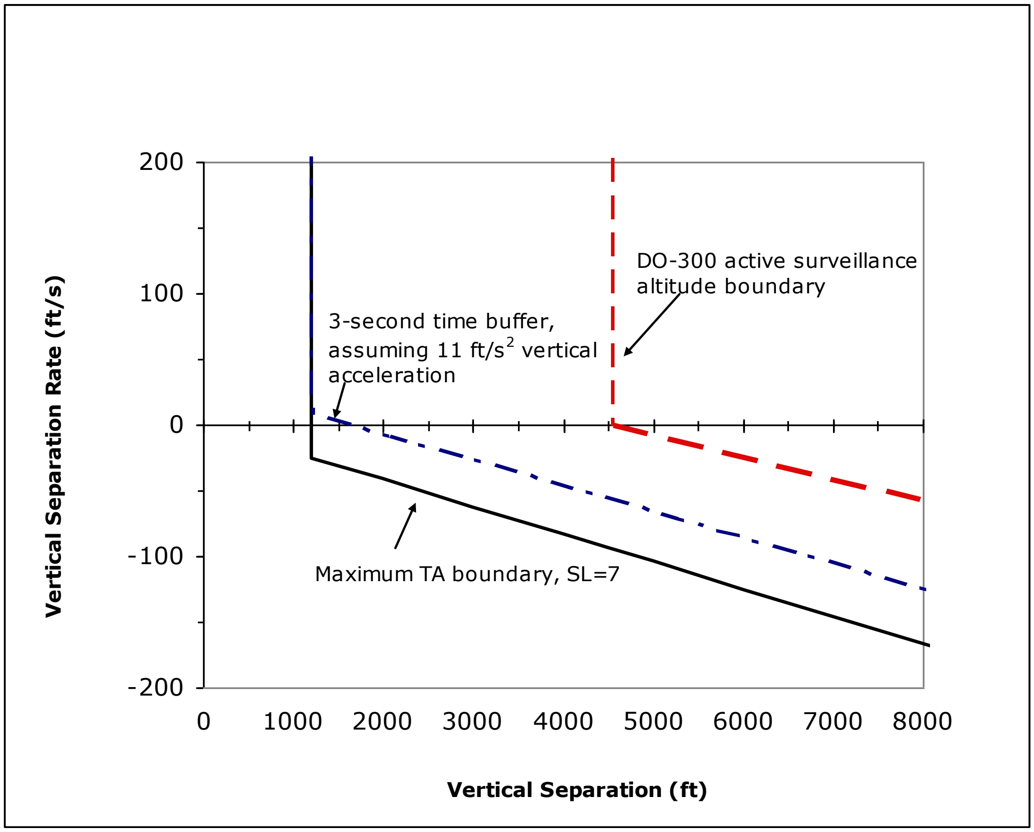

Figure D - 2. TA Active Surveillance Time Buffer In Altitude

The curve furthest to the upper right plots the altitude criterion for the passive-to-active surveillance transition, as given in Table D-3. It can be seen that the altitude condition for transitioning from passive to active surveillance will be satisfied much more than 3 seconds prior to any TA, even under the assumed worst-case acceleration of 11 ft/s^2. While not shown, the same approach can be used to show that at least an 8-second time buffer prior to a TA is provided under that acceleration. A similar analysis, also not shown, using the RA altitude boundary for the left-most curve, demonstrates that there will be at least a 10-second time buffer prior to any RA under that same worst-case acceleration.

Note that for vertical separation there is no concern about any errors in estimating the intruder's altitude or altitude rate, because the same values are used both to decide when to transition to active surveillance and when to issue a TA or an RA. Unlike the range values, there is no possible offset between the altitude and altitude rates computed under passive and active surveillance that would affect those two decisions differently. It is true that the TCAS altitude rate estimate can lag the true altitude rate substantially during vertical accelerations, particularly when altitude reports are quantized to 100 ft, and particularly when accelerating from level flight. However, that lag affects the passive-to-active transition decision and the decision to display advisories equally, potentially delaying both.

D.3.4.1.2 Simulation Results

Simulation of the TCAS collision avoidance algorithms for selected vertical scenarios confirms that the distance-based vertical separation criterion is sufficient. §D.4.3.5 describes three very aggressive vertical maneuver scenarios that were simulated, starting with a vertical separation of 3200 ft. For all scenarios, TCAS had sufficient time to alert.

D.3.4.2 Analysis of Range and Range Rate Transition Criteria

D.3.4.2.1 Overview of Passive Range and Range Rate Estimates

The range test used to determine when surveillance of an intruder will transition from passive to active surveillance is given in Table D-3. It depends on both the range and range rate that are estimated by the surveillance system using passive surveillance. Errors in the passive surveillance range and range rate estimates for the intruder, by which is meant differences from the range and range rate that would be estimated under active surveillance, will affect when the intruder passes that range test. If those errors are large enough and of the right sign, they can delay the transition to active surveillance beyond the safety margin provided by the range test, resulting in delayed advisories.

For intruders under validated passive surveillance, the passive range error is constrained by the validation process, in which a passive range measurement is compared against an active range measurement from a TCAS surveillance interrogation. The allowed difference is 290 meters upon first acquiring active surveillance on the intruder and 340 meters on subsequent revalidation tests. Revalidation tests are conducted at intervals ranging from 10 seconds to 60 seconds depending on the vertical separation, vertical separation rate, range and range rate of the intruder.

For intruders under unvalidated passive surveillance, there is no equivalent test that tightly constrains the range error. However, those intruders have reported to TCAS that their passive position reports have been certified to meet certain quality metrics. Those quality metrics in turn guarantee that the position reports from those intruders, under nominal fault-free conditions, will also meet the validation and revalidation requirements that are applied to intruders under validated passive surveillance. A test of their received power is used to detect gross violations of that guarantee.

An additional constraint on passive range errors is that a new passive range measurement must fall within a range correlation window centered about the predicted range of the intruder at the time of that passive range report; otherwise the track will not be updated. That predicted range is determined from the estimated range and range rate determined after the previous passive range report. The track will be dropped if this correlation failure persists. Those requirements are specified in §2.2.7.3, Track Updates Using Airborne Position Messages and §2.2.7.4, Tracking in the Absence of Airborne Position Messages.

D.3.4.2.2 Required Range and Range Rate Accuracy

Figure D–3 allows one to better understand the range and range rate accuracy required in order to achieve the goal of providing at least a 3-second time buffer between the time that the transition to active surveillance is triggered and the time that a TA should be issued. Four curves are shown on a graph of range rate versus range. The curve closest to the lower left of the graph is the range/range rate boundary for issuing a TA at altitude layer 6 and sensitivity level 7. The TA boundaries for lower altitude layers and sensitivity levels would be to the left of that curve, as would the RA boundaries for all altitude layers and sensitivity levels. The passive to-active surveillance transition should begin at least 3 seconds prior to the intruder arriving at that maximum TA boundary for the reasons described in §D.2.5.

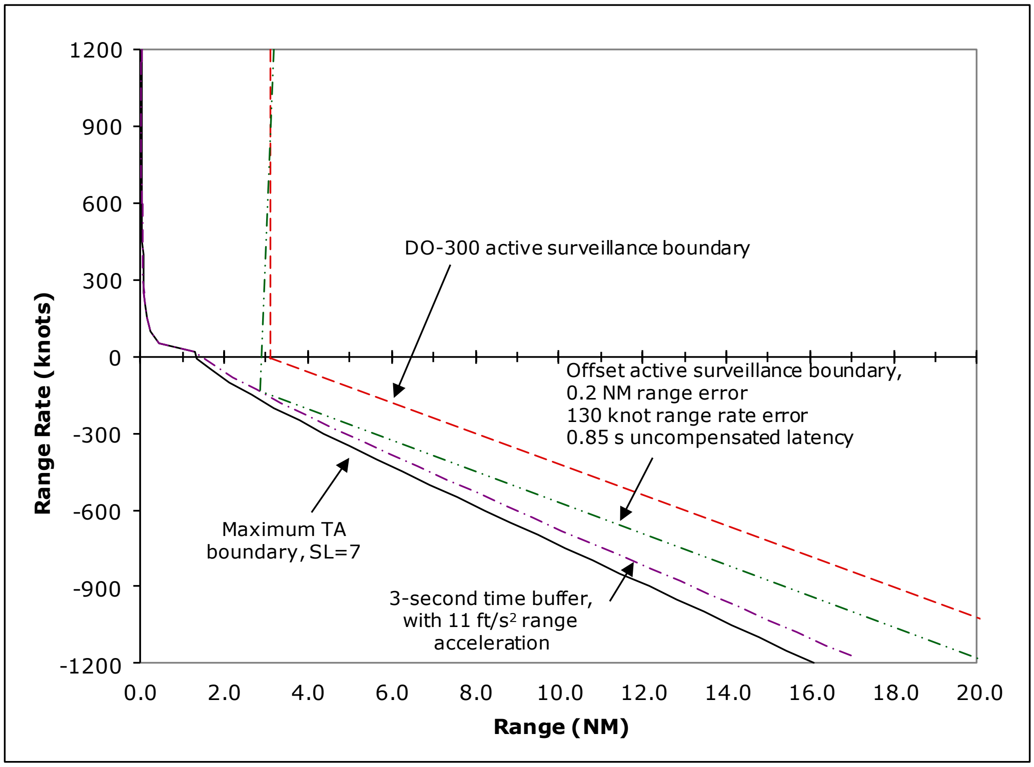

Figure D - 3. Range and Range Rate Accuracy Required for a 3-Second TA Time Buffer with (1/3)g Acceleration

The next curve above and to the right of the TA boundary curve is the locus of points from which an intruder could cross the TA boundary within 3 seconds assuming a range acceleration of 11 ft/s^2.

The curve closest to the upper right of the chart is the passive-to-active surveillance boundary in range and range rate, also called the hybrid surveillance boundary, as given in Table D-3. The range tau equation calculates the time-to-go, or range tau, required to reach a range of 3 NM, assuming the range rate remains constant. The curve shown is the locus of points from which a range of 3 NM can be reached in 60 seconds, the range tau criterion for transitioning to active surveillance. For all positive (diverging) range rates and for negative range rates more positive than -6 kt, the range tau equation uses a range rate of -6 kt instead of the true range rate, and that gives a fixed range boundary of 3.1 NM.

To determine how much error is allowed in the range and range rate values, one can shift the active surveillance boundary to the left (for range errors) and down (for range rate errors), representing respectively an intruder that is reporting a larger range than its true range and for which the estimated range rate is greater (more positive) than its true range rate. The shifted curve then represents where the intruder will really be, in terms of its active surveillance range and range rate, when it satisfies the passive-to-active range condition.

Figure D–3 shows an offset active surveillance boundary curve calculated for a fixed component of range error of 0.2 NM (370 meters), a range-rate-dependent range error that is due to 0.85 seconds of uncompensated latency (being the sum of a worst case uncompensated latency of 0.6 seconds for the intruder and 0.25 seconds for the TCAS aircraft), and a range rate error of 130 knots. It is the uncompensated latency that changes the slope of the vertical part of the curve. It also modifies the slope of the lower part of the curve, but that is less obvious visually. The knee in the shifted curve just touches the 3-second time buffer curve at 2.87 NM and -136 kt. Figure D–4 shows the critical region of the chart in greater detail.

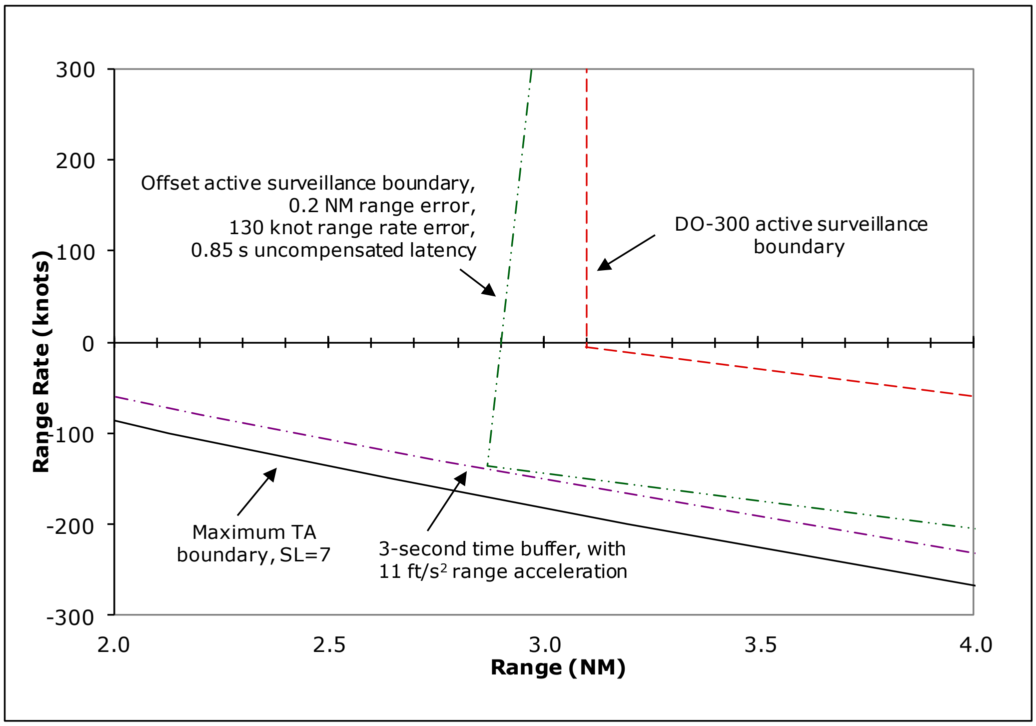

Figure D - 4. Detail of the Critical Point of Figure D-3

It can be seen that the most critical point is at the knee in the active surveillance boundary where the intruder is closing at -6 kt and reaches the 3.1 NM boundary, corresponding to the knee in the offset curve at -136 kt and 2.87 NM. Also, it can be seen that some tradeoff is possible between the allowed range error and the allowed range rate error (assuming for the moment that these are independent, which might not be the case if the range rate is derived from successive passive range measurements). If there were no error in the range rate, a range error of more than 1.6 NM could be tolerated without risking violation of the 3-second buffer. On the other hand, if there were no range error, a range rate error of about 159 knots could be tolerated.

The next two figures show how accurate the passive range and range rate must be in order to provide the desirable, but not essential, 8-second time buffer before the time that an RA should be issued, as described in §D.2.5. Figure D–5 shows a graph that is comparable to Figure D–3. The difference is that the lower-left curve is the range boundary for an RA, instead of a TA, at altitude layer 6 and sensitivity level 7. The next curve to the right is the locus of points from which that RA boundary can be reached within 8 seconds assuming an acceleration of -11 ft/s^2. The upper right curve is the same passive-to-active transition range boundary shown previously, and the curve to its left is offset by an assumed range and range rate error of 0.2 NM and 145 knots plus the additional range rate dependent range error due to 0.85 seconds of uncompensated latency. Figure D–6 shows the detail of the critical region, comparable to Figure D–4. It can be seen that an error of 0.2 NM in range and 145 knots in range rate will still trigger the transition to active surveillance at least 8 seconds before an RA should be issued. Smaller errors, especially smaller range rate errors, will provide a longer time buffer.

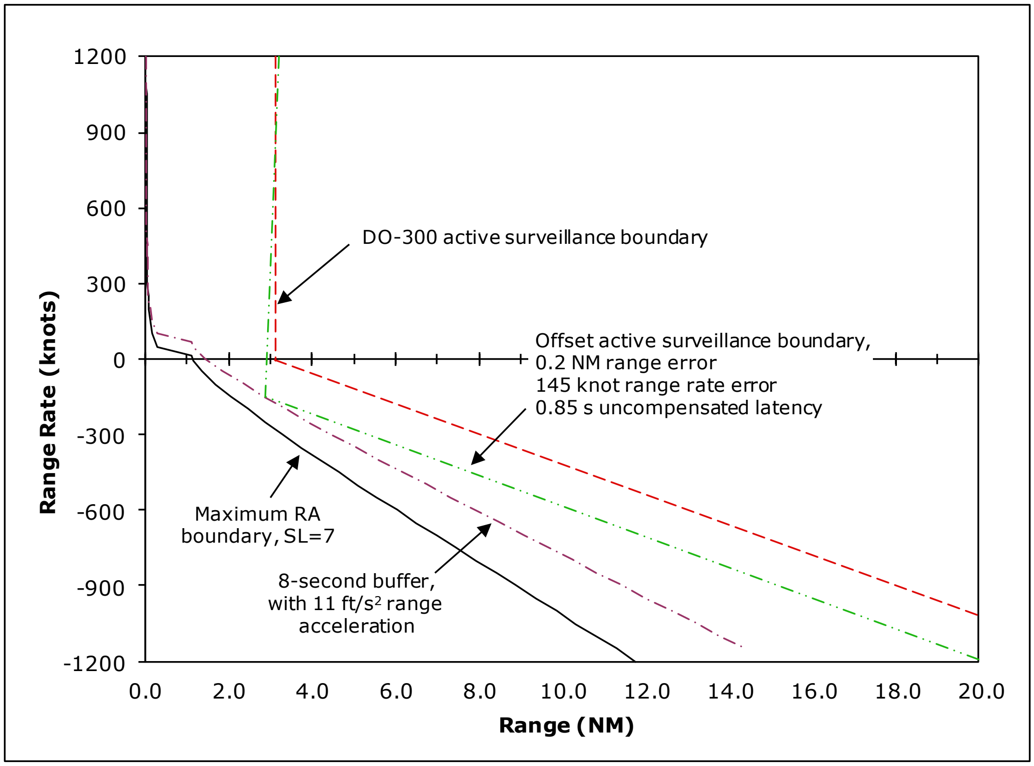

Figure D - 5. Range and Range Rate Accuracy Required for 8-Second RA Time Buffer with (1/3)g Acceleration

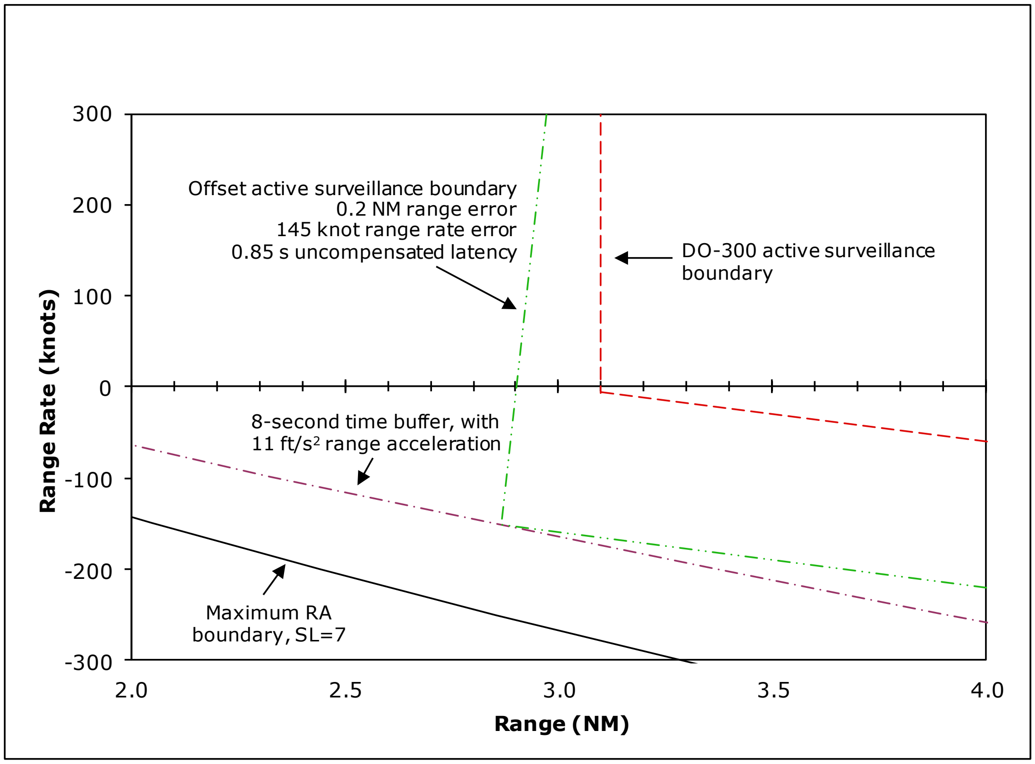

Figure D - 6. Detail of the Critical Point of Figure D-5

D.3.4.2.3 Passive Range Accuracy

This analysis applies to passive range estimates made during steady-state tracking of successive nominal passive range reports. Non-nominal position reports, where the range error exceeds the revalidation threshold, are analyzed in §D.3.4.2.9 and §D.3.4.2.10.

The most critical point for range and range rate accuracy is where the knee in the offset passive-to-active boundary curve touches the 3-second TA time buffer curve and the 8-second RA time buffer curve. At the point where the offset curve touches the TA time buffer curve it has a range error of 0.23 NM or 426 m, including 0.03 NM or 56 m due to uncompensated latency. At the point where the offset curve touches the RA time buffer curve it has a range error of 0.24 NM or 444 m, including 0.04 NM or 74 m due to uncompensated latency. The 340 m revalidation threshold satisfies the 426 m requirement with 86 m to spare, and the 444 m requirement with 104 m to spare.

D.3.4.2.4 Passive Range Rate Accuracy Estimate

This analysis applies to range rate estimates made during steady-state tracking of successive nominal passive range reports, that is, reports that have a range error smaller than the revalidation threshold. Large range rate transients under passive surveillance due to single, possibly large, jumps in the reported passive range are analyzed in §D.3.4.2.6.

The passive range rate is derived by tracking successive passive range measurements. While ADS-B reports do provide ground velocity information, TCAS passive surveillance currently does not attempt to combine that with own aircraft ground velocity information and the relative position of the intruder to derive the range rate. Instead, it is much simpler to use the existing TCAS surveillance functions and simply track the passive range measurements in the same manner as active range measurements.

The accuracy of the estimated range rate, derived by tracking the passive range reports, must be assessed without specific knowledge of the tracking algorithms, as the TCAS surveillance system range tracker is specified in detail only as an example for guidance purposes, and manufacturers are free to implement other designs as long as the overall TCAS MOPS tests are met. In addition, the statistical properties of the passive range reports are different enough from those of the active surveillance reports, primarily in the potentially much larger report-to-report variance of the passive range reports, that it might be appropriate to use different smoothing parameters for active and passive surveillance.

In its most basic form, estimating the range rate involves taking the range difference between two passive range measurements and dividing by their time difference. Any constant bias in the range is removed in taking the range difference, and so the error in the range rate is only affected by the update-to-update variations of the passive range error about that constant bias. For a given intruder, much of the passive range error is expected to be a constant bias. In particular, for a given intruder, most of the range error due to the uncompensated latency of both the intruder and own aircraft position reports is expected to be constant, and so will have no effect on the range rate estimate.

Current standards do not impose a limitation on the report-to-report variation in uncompensated latency for either ADS-B position reports from intruders or for own aircraft position data. That variation is determined by systems outside the scope of this MOPS and so this MOPS is unable to establish such requirements. This analysis will assume that the uncompensated latency for both the intruder's and own aircraft's position reports remains within 50 ms of the average value with 95% probability under realistic operational conditions (for example, if there is a data concentrator or data bus between the GPS unit and the TCAS unit, and it is shared with other data sources and sinks, those other devices are loading the data concentrator or data bus at their normal operational loads). While that value for the uncompensated latency variation does not have a major effect on the results reported here, in comparison to other much larger sources of variation, if it is determined that a proposed system differs substantially from that assumption, then this analysis should be revisited. At the maximum aircraft ground speed of 600 kt (309 m/s) assumed in the TCAS design, 50 ms corresponds to a distance variation of 16 m. Table D–7, adapted from Table B–1 in Appendix B, summarizes the sources of report-to-report variation for passive range measurements.

Table D - 7. Sources of Variation in a Single Passive Range Measurement

Passive surveillance intruder position sensor error, 95%	93 m
Intruder position message LSB	5 m
Variation in uncompensated latency in intruder position when received by TCAS, 95%	16 m
Passive surveillance own position sensor error, 95%	93 m
Variation in uncompensated latency in own aircraft position when received by TCAS, 95%	16 m
Variation in a single passive range measurement, 95% (assuming the above sources of variation combine by root-sum-square)	134 m

If a single passive range measurement has a 95% probability of being within 134 m of the average, then the range difference calculated from two successive passive range measurements will have a 95% probability of being within $\sqrt{2} \cdot 134 = 190$ m of the true difference. If those two measurements are 1 second apart, and assuming that time measurement errors can be ignored, that gives a range rate variation of 190 m/s or 369 kt, 95%, not sufficiently accurate to ensure the desired TA and RA time buffers are provided. However, if those measurements were separated by 3 seconds, as would be the case after 4 position reports, then the range rate variation would drop to 123 kt, achieving the needed accuracy to provide both the 3-second TA time buffer and the 8-second RA time buffer. That result assumes unaccelerated motion, but even if the intruder were accelerating at (1/3)g or 11 ft/s^2, this simple 2-point range rate estimator would achieve the desired accuracy after 4 seconds, or 5 position reports. To see that, observe that the range rate would only change by about 44 ft/s or 26 kt during that time. The 2-point estimator would estimate the average range rate during that interval to an accuracy of 92 kt and would have about 13 kt additional error (half the total change in range rate) due to the acceleration, giving a total error of 105 kt, 95%. Therefore, even a very basic range tracker should be able to achieve the necessary range rate accuracy, with 95% probability, within 4 seconds after the initial position measurement, even in the presence of range acceleration.

D.3.4.2.5 Expected Operational Range Rate Accuracy

The previous section takes a pessimistic approach to estimating the range rate accuracy. In particular, the use in Table D-7 of 93 m, 95%, as the possible report-to-report variation in the position error is pessimistic. That is the position error permitted by the ADS-B standards (Ref. C) and the United States ADS-B mandate (14 CFR §91.227). The model used in the previous section to derive the range rate accuracy in effect assumes that each position measurement is a sample of a normal or Gaussian position error distribution with a standard deviation of approximately 93/2 = 46.5 m. Therefore the individual measurement errors can jump around by fairly large distances. That is called an uncorrelated model, that is, there is no correlation between the successive position errors, and successive position samples jump all over the allowed distribution. However, GPS errors, inertial navigation system errors, and probably most other potential sources for ADS-B position reports, are correlated from update to update, rather than uncorrelated. A simple model for correlated samples is that the initial sample is drawn from the normal distribution described above, with a standard deviation of 46.5 m, but subsequent samples are random offsets from the previous sample, a so-called random walk, with the those random offsets being drawn from a distribution with a much smaller standard deviation than 93/2 m. The effect is an overall error that relatively slowly drifts around within the

93 m, 95%, error containment circle, rather than jumping rapidly all over it. There may be occasional larger jumps, for example, when the GPS satellite constellation visible to the GPS receiver changes. The standard deviation of the error in range rate is proportional to the standard deviation of the random update-to-update differences, and so is much smaller than estimated in §D.3.4.2.4. Range rate accuracy more on the order of tens of knots should be easily achieved. That appears to be supported by operational data, and is also consistent with the 10 m/s or 19 kt ADS-B horizontal velocity error mandated as the minimum required accuracy for future ADS-B systems. More accurate passive range rate values lead to larger time buffers between the decision to transition to active surveillance, based on passive surveillance, and the decision to issue an advisory, based on active surveillance.

D.3.4.2.6 Range Jumps Under Passive Surveillance

§D.4.2 presents an analysis of the effects of range jumps of various sizes on the filtered range and range rate estimates, and the resulting effect on the range tau values used in the hybrid surveillance (passive-to-active) and the modified hybrid surveillance (active-to-passive) conditions shown in Table D-3.

This section discusses single range jumps within the maximum error of 340 m allowed by revalidation that might occur while the intruder is under passive surveillance. One scenario that might lead to such jumps is if the range error was slowly drifting as in the correlated error model discussed in §D.3.4.2.5 and then there was a change in the satellite constellation being used to derive the position, leading to a sudden large change in the passive range error, but remaining within the revalidation error tolerance. Random jumps in range that occur at every position report are treated statistically in the analysis of passive range rate accuracy in §D.3.4.2.4. Singular jumps in range that go outside the revalidation error limit will cause effects similar to those discussed here, but with a larger maximum range rate error. However, unless corrected quickly, they will lead eventually to a failure to revalidate (for intruders under validated passive surveillance), or failure to correlate the range report with the track, and either a dropped track or a transition to active surveillance. Those larger range jumps are discussed in §D.3.4.2.9 and §D.3.4.2.10.

The worst case jump in passive range that is possible while still revalidating is a 680 m (2231 ft) jump. Over a 1 second interval, a jump that large could cause an unfiltered range rate error of 2231 ft/s. §D.4.2 analyzes the response of a typical surveillance filter to such range jumps. It will attenuate the peak of the range rate transient by about one-fourth to about 558 ft/s (330 kt). The range rate transient from a large range jump will take about 10 seconds to dissipate and return to the correct value. It will take about 6 seconds for the filter to reduce the error to about 1/3 of the peak value, or, for the worst-case 680 m jump, to 110 kt.

As also discussed in §D.4.2, the range and range rate errors from a range jump lead to an error in the passive-to-active range tau calculation. In the case of a jump to a larger range, the range tau becomes much too large shortly after the range jump occurs and does not settle back to the true value for 10 seconds. In the case of a jump to a smaller range, the range tau becomes much too small before returning to the true value. The magnitude of the error in range tau depends on the range and the direction of the range jump as well as the magnitude of the range jump, being greater at shorter ranges than at longer ranges, and greater for jumps to larger range than for jumps to shorter range.

If the intruder appears to jump toward the TCAS aircraft, the range rate will appear to be smaller than it is (larger closure rate or reduced divergence rate), and that could result in an earlier transition from passive to active surveillance than might otherwise occur. That is safe and will not cause a missed TCAS advisory.

If the intruder appears to jump away from the TCAS aircraft, the range rate will look larger than it is (smaller closure rate or divergence in range). That could cause a delay in initiating the transition from passive to active surveillance until the range rate error is reduced to the 130 kt value required to provide the desired time buffer. As noted above, that would take about 6 seconds. If such a jump occurred just before the transition to active surveillance should occur, and while the intruder was accelerating toward the TCAS aircraft, it could delay a TA against the intruder. It would not delay any RA, but the CAS range trackers might not be fully initialized at the time of the RA.

D.3.4.2.7 Range Jumps During Transitions from Passive to Active Surveillance

§D.4.2 presents an analysis of the effects of range jumps of various sizes on the filtered range and range rate estimates, and the resulting effect on the range tau values used in the hybrid surveillance (passive-to-active) and the modified hybrid surveillance (active-to-passive) conditions shown in Table D-3.

Under normal conditions, the range jump at the transition from passive to active surveillance will be less than or equal to the 340 m revalidation tolerance. However, hybrid TCAS also transitions an intruder to active surveillance if there is a revalidation failure under validated passive surveillance, or if an initial validation test fails during a transition from unvalidated to validated passive surveillance, or if there is a loss of valid updating passive replies. Under those circumstances much larger range jumps might occur. Range jumps can be either toward the TCAS aircraft or away from the TCAS aircraft.

One potential effect of a difference between the active and passive range is oscillation between the passive and active surveillance modes. If the active and passive ranges were the same that would not be possible, as the range test for the passive-to-active transition and the range test for the active-to-passive transition (Table D-3) cannot both be satisfied by the same range and range rate values. However, if the active range is greater than the passive range, and that range difference also causes a range rate transient in the surveillance range filter that makes it appear that the intruder's rate of closure has slowed, then the condition for returning to passive surveillance might become true shortly after transitioning from passive to active surveillance.

Figure D-17 in §D.4.2.3 illustrates the performance of a representative surveillance filter when the range jumps +1400 ft. A 340 m (1115 ft) range jump would be considered within the normal operational range, and 1400 ft is only slightly larger. Nothing special is done to reinitialize any of the filter parameters when the jump occurs. The passive range has a -1400 ft error, that is, under passive surveillance the target appears 1400 ft closer than it is. The system transitions from passive to active surveillance and the range jumps +1400 ft. The surveillance range tracker follows the jump well. The surveillance range rate filter significantly overestimates the range rate for about 10 seconds. The true range rate is -1200 ft/s, while the filtered range rate increases to about -900 ft/s, an error of 300 ft/s or almost 180 kt.

Figure D-18 in §D.4.2.3 translates the filtered range and range rate errors into an error in the modified hybrid range threat calculation for the active-to-passive transition. The modified hybrid range tau is significantly overestimated due to the filtered range rate errors. The true value is 60 seconds after the transition, while the value calculated with the filtered range and range rate increases to about 78 seconds shortly after the transition. The error in the modified hybrid range tau could cause the system to incorrectly transition to passive surveillance, since it appears to be greater than 65 seconds.

To prevent an incorrect transition to passive surveillance based on a jump in range and incorrect range rate data, §2.2.7.1.2, Hybrid Surveillance Region, only permits the transition to occur if the range rate calculation is based completely on active data, with no residual effects from prior tracking of passive range data. Until a range rate based on active data is available, §2.2.7.1.2 requires a default range rate of -1200 kt to be used.

A range jump in either direction could lead to a correlation failure if the first active report falls outside the correlation box centered at the predicted range calculated using range and range rate values based on passive surveillance. Furthermore, even if the initial active surveillance report falls inside the correlation box the jump in apparent range could lead to a large range rate transient. Such a range rate transient, if large enough, could potentially cause a correlation failure on a subsequent update cycle when it is used to calculate the projected range for the correlation box for that update cycle. That, in turn, could cause the intruder's track to be dropped a few seconds after the start of active surveillance.

§2.2.6.2 requires that a track not be dropped due to nominal range jumps at the transition from passive to active surveillance. That discussion emphasizes the size of the correlation window needed in order that the initial active range report be accepted. However, system designers must also address the possibility of subsequent correlation failures due to range rate transients. Measures that prevent range rate transients at the transition from passive to active surveillance would address both this potential problem and the potential problem described above of immediately transitioning back to passive surveillance. One way that range rate transients can be eliminated is similar to the approach taken in the CAS range tracker, in effect restarting the surveillance system's range tracker with the first active surveillance report, except that the range rate calculated under passive surveillance is retained until it can be replaced after the second active surveillance report is received.

D.3.4.2.8 Range Jumps During Transitions from Active to Passive Surveillance Mode

§D.4.2 presents an analysis of the effects of range jumps of various sizes on the filtered range and range rate estimates, and the resulting effect on the range tau values used in the hybrid surveillance (passive-to-active) and the modified hybrid surveillance (active-to-passive) conditions shown in Table D-3.

The size of range jumps at the transition from active to passive surveillance is constrained by the requirement in §2.2.6.1.2, Active to Hybrid Surveillance Transition, that passive surveillance reports satisfy the 290 m range validation criterion before such a transition is permitted. However, range jumps of that magnitude are allowed, and can be either toward or away from the TCAS aircraft. As discussed in §D.4.2.3, a jump of 290 m (951 ft) can result in a range rate transient peaking at about 290/4 = 72.5 m/s (238 ft/s, 141 kt), although the exact value will depend on the details of the range filter design. That is a small range rate transient, and its effects might be minimal. It is less than the 145 kt range rate error that would still provide an 8-second time buffer prior to an RA, and only slightly larger than the 130 kt error that would still provide a 3-second time buffer prior to a TA. Nevertheless, requirements are in place to prevent this transient from causing any undesirable effects.

If the range jump is toward the TCAS aircraft, it would result in a range rate transient that makes it appear the intruder is diverging more slowly in range, or converging faster, than it really is. That could potentially incorrectly trigger the hybrid surveillance (passive-to-active) range tau condition. However, §2.2.6.1.4, Active Surveillance Region, requires that any decision to transition to active surveillance using the hybrid surveillance range tau condition use range and range rate values calculated entirely from passive surveillance data, with no residual effect from any prior active surveillance tracking. That requirement will prevent such spurious transitions.

If the range jump is away from the TCAS aircraft, the resulting range rate transient will make it appear the intruder is closing in range more slowly, or diverging in range more quickly, than it really is. If the intruder is close to qualifying for active surveillance again, such a range rate error might also delay the return to active surveillance. A scenario where that sequence of surveillance mode transitions might occur would be if the intruder was closing fast enough to qualify for active surveillance, then slowed its closure rate enough to permit a transition to passive surveillance, and then increased its closure rate enough to require active surveillance again. A range rate transient at the transition to passive surveillance could potentially delay the subsequent transition to active surveillance.

As mentioned above, §2.2.6.1.4, Active Surveillance Region, requires that the use of the hybrid range tau condition be based solely on passive surveillance data. One way of satisfying that condition would be to allow time for the range rate transient from any range jump to die out. As shown in §D.4.2.3, that could take up to 10 seconds, too long a delay. Therefore, §2.2.6.1.4 also requires that a range and range rate based solely on passive surveillance be available within 5 seconds. That is the longest interval allowed between passive position reports, and applies to intruders that would normally be under 5-second updates, or REDUCED surveillance, if under active surveillance. §D.3.4.2.4 shows that two or more passive range reports over a time interval of 3 seconds or more will give sufficient range rate accuracy. Since the intruder starts the 5-second interval outside the modified hybrid surveillance (active-to-passive) boundary, which has a tau 5 seconds larger than the tau for the hybrid surveillance (passive-to-active) boundary, and a minimum range 0.2 NM larger, the additional 5-second delay should not impact the system's ability to provide a 3-second active surveillance time buffer prior to any TA.

Erroneous range rates due to range jumps in either direction can potentially lead to a later correlation failure when that erroneous range rate is used to project the position of the intruder at the next update cycle and the correlation box is centered at that incorrect location. In the case of active-to-passive transitions, the magnitude of the range rate transient is constrained as described above to about 141 kt. §2.2.6.2 requires that a track not be dropped due to nominal range jumps at the transition from passive to active surveillance. §2.2.7.3, Track Updates Using Airborne Position Messages, broadens that requirement to all surveillance mode transitions. Those discussions emphasize the size of the correlation window needed to ensure that the initial range report in the new surveillance mode is accepted. However, system designers must also address the possibility of subsequent correlation failures due to range rate transients. One way that can be accomplished is to eliminate the range rate transients, as discussed in the previous section.

D.3.4.2.9 Large Range Errors Under Validated Passive Surveillance

An intruder cannot enter into validated passive surveillance with a passive range error greater than 290 m. It cannot stay in the validated passive surveillance mode if the passive range error is greater than 340 m at the time of a revalidation test. Therefore any unsafe effects of large range errors must be due to large passive range errors that develop in the interval between revalidations. As discussed in Appendix E, intruders that are likely to meet the tests for a transition to active surveillance in less than 20 seconds are revalidated every 10 seconds. Larger revalidation intervals, up to 60 seconds, are used only when an intruder cannot penetrate the active surveillance region during that larger revalidation interval.

§D.3.4.2.2 showed that the passive range error must be less than 426 m in order to ensure that an adequate time buffer is provided prior to the time an advisory should be issued. Therefore, the only concern would be if the intruder crossed the passive-to-active boundary during the 10-second interval between revalidations and at the same time the range error grew larger than 426 m in such a manner as to make it appear that the intruder had not crossed that boundary.

In addition to revalidation, the other test that could detect a large passive range error, causing the track to be dropped, is the requirement in §2.2.7.3, Track Updates Using Airborne Position Messages, that passive position reports fall inside a correlation window that is centered on the predicted position of the intruder at the time of the report. That is the only mechanism that could potentially detect large range errors between revalidations. The size of the correlation window is unspecified. The window needs to be at least as large as the variation that might occur in a single passive range measurement, as calculated in Table D – 7 in §D.3.4.2.4. That table is appropriate rather than the revalidation tolerance calculated in Appendix B because the correlation window does not need to account for the constant portion of the discrepancy between the active and passive ranges. Table D – 7 shows that the size of the range correlation window must be at least ±134 m from the predicted position. In addition to that, the range rate estimate used to calculate the predicted position might have an error of ±130 kt if the parameters of the offset active surveillance boundary shown in §D.3.4.2.2 apply. That corresponds to ±67 m over a 1-second projection. Thus a correlation window of at least ±200 m seems necessary. Therefore, the intruder's passive range rate might be able to decelerate at 200 m/s^2 or 390 kt/s without causing a correlation failure. Larger correlation windows would permit even faster decelerations without a correlation failure. Thus, while the correlation requirement will prevent the surveillance system from accepting gross jumps in passive range, it appears it will not prevent penetration of the active surveillance boundary in certain cases, for example, an intruder whose reported position freezes while the true range keeps closing.

In summary, if a position error did occur between revalidations, just as the intruder was about to cross the active surveillance range boundary, and in such a manner that it did not violate the correlation requirement and also made it appear that the intruder was not crossing the active surveillance range boundary, then it might delay the transition to active surveillance by up to 10 seconds, until the next revalidation attempt. At the highest TCAS sensitivity level there is at least a 3-second time buffer between the transition to active surveillance and the time that a TA should be issued, and at least an 8-second time buffer before an RA should be issued, as discussed in §D.3.4.2.2. Larger time buffers are provided if the intruder's range rate estimate is more accurate. The worst-case 10-second delay in transitioning to active surveillance might delay or prevent a TA at that sensitivity level. It will delay an RA by at most a few seconds. At lower sensitivity levels such a delay will have less effect or no effect, as larger buffers are provided.

D.3.4.2.10 Large Range Errors Under Unvalidated Passive Surveillance

Unvalidated passive surveillance relies upon the intruder's own reported passive surveillance accuracy and certification status to assess whether the reported position is likely to be sufficiently accurate. If an intruder's reported position has a large error, in violation of its self-reported status, hybrid TCAS will not be able to immediately detect that. Therefore, a newly acquired intruder might be admitted to unvalidated passive surveillance with a large position error. Also, an intruder under unvalidated passive surveillance can develop a large position error without detection. The only constraint on the latter is the requirement in §2.2.7.3, Track Updates Using Airborne Position Messages, that position reports must fall within a correlation box centered on the predicted position of the track. As discussed in the previous section, that will detect certain large jumps in apparent range, but will not detect others because the correlation window needs to be fairly large.

The method provided for detecting large range errors resulting from such large position errors is measuring the received power level of the intruder's ADS-B position reports, as specified in §2.2.7.2.1, Persistence of Extended Hybrid Surveillance, §2.2.5.2, Acquisition of Extended Hybrid Surveillance Targets, and §2.2.5.2.4, Determination of Estimated Signal Strength. If the received power level exceeds the specified threshold, it indicates that the intruder is close enough to be of concern, and may be much closer than its passive range reports indicate. The intruder is then transitioned to hybrid surveillance (validated passive surveillance) and a validation test is performed. If that fails, as it will in the case of a large range error, then the intruder is placed under active surveillance.

The threshold power level is -68 dBm, as compared to the normal TCAS MTL of -74 dBm, except when the TCAS interference limiting function has raised the receiver MTL above -68 dBm, in which case the interference limiting threshold is used. Therefore, under circumstances where interference limiting has raised the TCAS MTL to -68 dBm or higher, both hybrid TCAS and non-hybrid TCAS will begin active surveillance on intruders at the same range, and there will be no difference in their safety due to unvalidated passive surveillance.

Received power level is an imprecise substitute for the active range measurements used under validated passive surveillance. The received power level can vary over a wide range of values even for an intruder at a fixed range. That is due to the antenna patterns on both the intruder and the TCAS aircraft, which may have deep nulls in various directions and peaks in other directions. Under some circumstances interference from reflections of the reply from surfaces such as lakes also has an effect. Also, replies sent from or received on a top-mounted antenna will generally have a different received power than those sent from or received on a bottom-mounted antenna, due again to different antenna patterns and interactions with the aircraft body.

As a result, the received power approach cannot ensure that hybrid TCAS generates RAs and TAs at the same time that non-hybrid TCAS would display them. Intruders under unvalidated passive surveillance that also have large position errors, making them appear much less threatening than they really are, might not be placed under active surveillance, and therefore might not trigger an RA, until they are much closer to the TCAS aircraft than they would be under non-hybrid TCAS. Therefore, a study was performed to determine the effect on the TCAS risk ratio of a delay in the start of active surveillance.

Risk ratio is a metric historically used to compare the safety performance of one collision avoidance system to another, or to flying without the use of a collision avoidance system. Using a large number of simulated encounter scenarios, the number of Near Mid-Air Collisions (NMACs) under the new system is counted, and divided by the number of NMACs under the old system, or without a collision avoidance system. An NMAC is defined as the two aircraft in the scenario approaching within 500 ft horizontally and 100 ft vertically. Risk ratios of less than one indicate improved performance, while risk ratios greater than one indicate that the new system provides degraded performance.

For this study, performed by MIT Lincoln Laboratory, the tools consisted of the U.S. correlated encounter model (Ref. N) as well as a fast-time framework used for Monte Carlo simulation of encounters sampled from the model. 500,000 encounters were simulated for each set of input conditions and the results were output in the form of risk ratios.

The study calculated TCAS risk ratio as a function of surveillance range, or the range at which a target track would first become available to the collision avoidance system. The surveillance range was varied from 0.5 NM to 14 NM, with increments of 0.5 NM between 0.5 NM and 4 NM and increments of 1 NM between 4 NM and 14 NM. 14 NM was chosen because it is the reliable surveillance range associated with a TCAS receiver sensitivity of -74 dBm, and the minimum guaranteed tracking range of aircraft in the TCAS design. Altering the receiver sensitivity to -68 dBm for extended hybrid surveillance (unvalidated passive surveillance) will result in an equivalently reliable surveillance range of approximately 7 NM. Comparing the risk ratios at 7 NM and 14 NM provides the worst case quantitative difference in safety of TCAS with respect to intruders that are under extended hybrid surveillance, but that have a position reporting failure such that they are much closer than their position report would indicate.

A surveillance range of 14 NM is only necessary for the highest closure rate encounters (1200 kt) for which TCAS guarantees protection. Those encounters can only happen at altitudes above 10,000 feet due to speed restrictions below 10,000 feet. Therefore, the results are separated by altitude layer. Two categories of equipage were simulated, TCAS/TCAS encounters and TCAS/Mode S encounters. TCAS/TCAS designates that both aircraft are TCAS equipped and TCAS/Mode S specifies that only one aircraft is TCAS equipped and the other is equipped with only a Mode S transponder. In addition, two pilot response models were used. Pilot response refers to the amount of time after an RA is given before the pilot begins to execute the evasive maneuver. 5 seconds is the TCAS standard model from the TCAS design specifications and 8 seconds is also a commonly accepted value for a slower pilot response.

The results are shown below in four figures. The TCAS/TCAS encounters with a 5-second pilot response show no degradation in risk ratio from 14 NM to 7 NM. For the 8-second pilot response there is a slight degradation from 14 NM to 7 NM, but only for the altitude layer above 18,000 feet; however, the change in risk ratio is minor and the impact on the safety of the system is negligible. The conclusion for the TCAS/Mode S encounters is similar. In both TCAS/Mode S cases there is a slight degradation in risk ratio from 14 NM to 7 NM for the altitude layer above 18,000 feet, but the impact on the safety of the system is negligible.

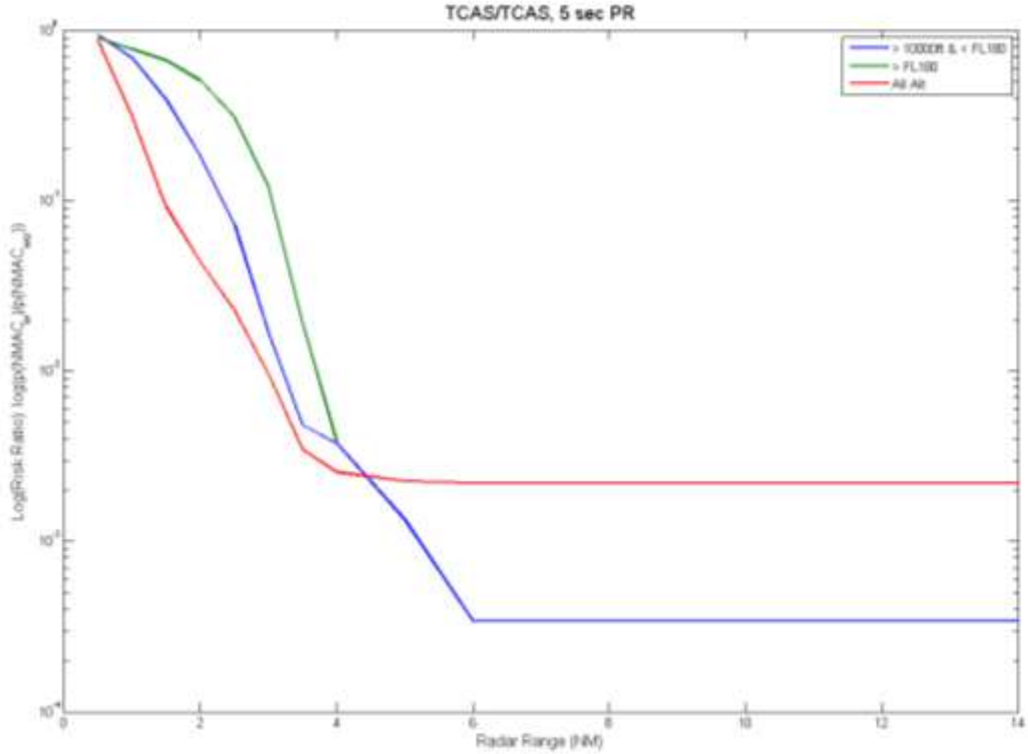

Figure D - 7. Risk Ratio as a Function of Maximum Active Surveillance Range, TCAS/TCAS Encounters, 5-second Pilot Response

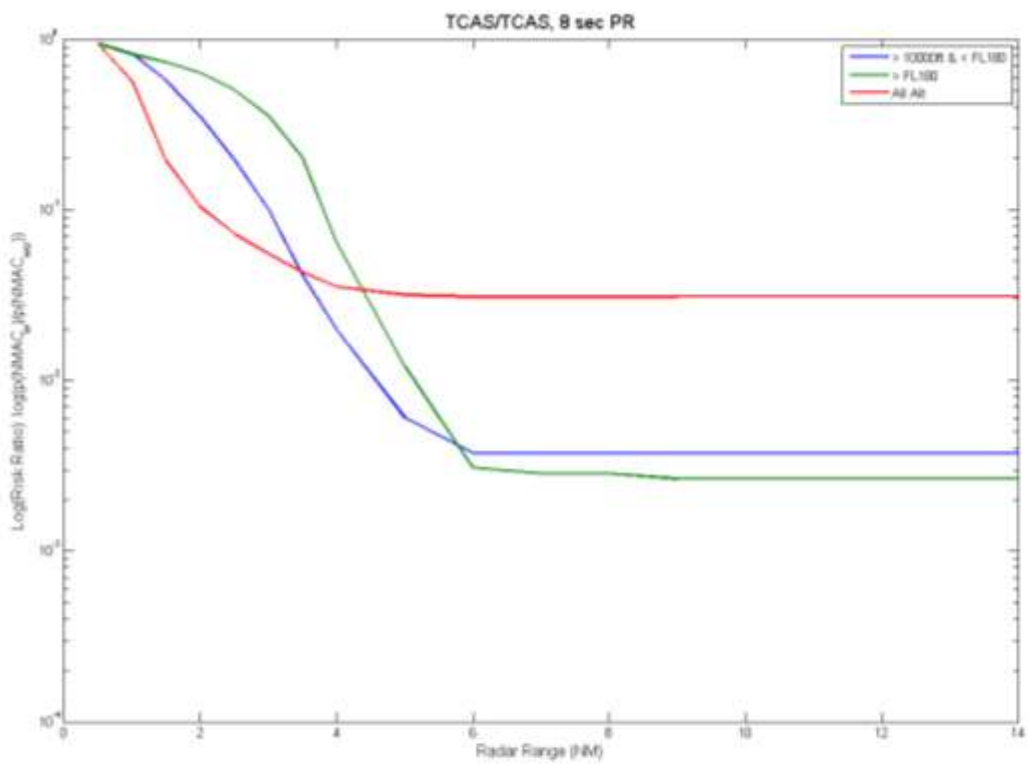

Figure D - 8. Risk Ratio as a Function of Maximum Active Surveillance Range, TCAS/TCAS Encounters, 8-second Pilot Response

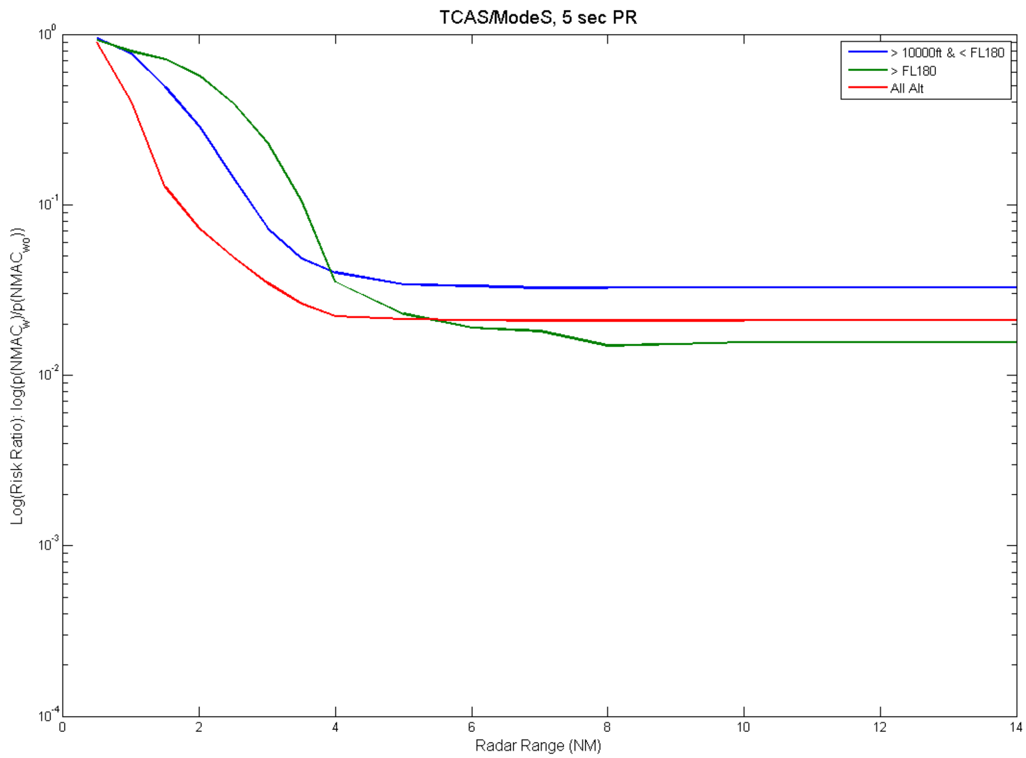

Figure D - 9. Risk Ratio as a Function of Maximum Active Surveillance Range, TCAS/Mode S Encounters, 5-second Pilot Response

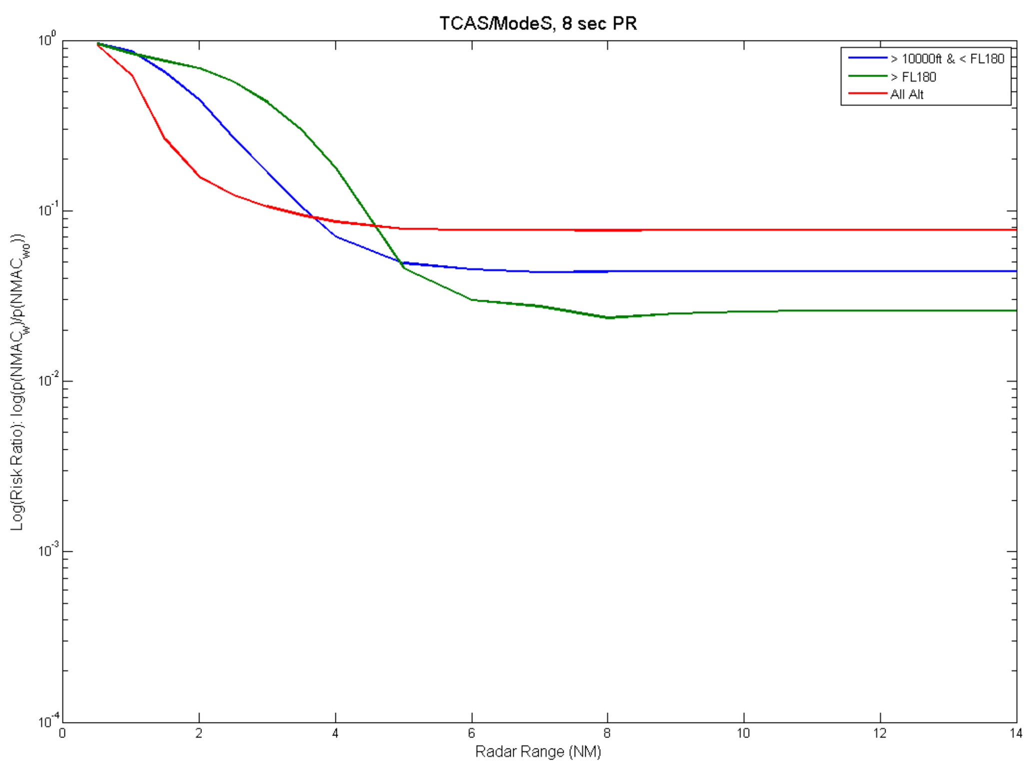

Figure D - 10. Risk Ratio as a Function of Maximum Active Surveillance Range, TCAS/Mode S Encounters, 8-second Pilot Response

A similar analysis was performed under the sponsorship of the European SESAR program (Ref. O). That study was based on a traffic model tuned to the European airspace, and looked at additional metrics in addition to the risk ratio, including the number of RAs, the number of sense reversals, the number of increase-rate RAs, the number of crossing RAs, and the fraction of encounters that failed to achieve the minimum desired separation (known as ALIM, and larger than the 100 ft vertical separation needed to avoid an NMAC), all as a function of the range at which active surveillance started. The results were similar to those described above. There was no increase in the risk ratio for surveillance ranges between 5 NM and 14 NM. Slight decreases in risk ratio were observed at altitudes above Flight Level 135 at ranges of 5 NM and 6 NM for a standard pilot response, and at 5-8 NM for a random range of pilot responses that models typically observed pilot response times. The number of RAs began to decline slightly at a range of 9 NM and more rapidly at shorter surveillance ranges. The other metrics began to shift slightly at 8 NM or 7 NM, with larger shifts at shorter ranges. The shifts consisted of a reduction in the percentage of crossing RAs and sense reversal RAs, and an increase in the percentage of RAs involving a rate increase. The conclusion was that there was no significant effect on TCAS safety at any altitude as long as active surveillance started at a range of 6 NM or greater.

Observe that these results make some of the other analyses in this Appendix moot. It appears not to matter very much from a safety perspective whether or not hybrid TCAS starts active surveillance early enough to issue an RA at the same time as non-hybrid TCAS, as long as the threat aircraft is under active surveillance by the time it reaches 7 NM range. It does make a difference for TAs, as such late RAs generally will not be preceded by a TA, but will be issued as soon as possible after active surveillance starts. However, hybrid TCAS only takes advantage of these results to address fault conditions that lead to large passive range errors under unvalidated passive surveillance.

D.3.5 Intruder Not Under Surveillance by Hybrid TCAS

There are three conditions under which hybrid TCAS will not have an intruder under surveillance. The first is that the intruder was never placed under surveillance. The second is if the intruder was under surveillance at some earlier time but surveillance was dropped because TCAS stopped receiving valid, correlating surveillance reports for that intruder. The third is if the intruder was under surveillance at some earlier time but surveillance was dropped because the track file was full and the intruder's track was dropped in order to provide space for a new intruder that is considered to be more of a threat. Table D-8 shows the various alternatives that must be considered.

Table D - 8. Intruder Not Under Surveillance By Hybrid TCAS

		OR							
		1	2	3	4	5	6	7	8
Intruder was never acquired by the surveillance system	AND	T	T						
Intruder was under active surveillance				T	T	T	T		
Intruder was under passive surveillance								T	T
Intruder track dropped due to lack of valid correlating surveillance reports				T	T			T	
Intruder track dropped because of track file overflow						T	T		T
Intruder is Mode C equipped		T		T		T			
Intruder is Mode S equipped			T		T		T	T	T

D.3.5.1 Mode C Intruder Track Acquisition, Maintenance and Termination

Hybrid TCAS performs surveillance of Mode C intruders identically to non-hybrid TCAS, and so Mode C tracks will be acquired, maintained and dropped identically by the two systems. Mode C intruders are always acquired and maintained by active interrogations. Therefore, the two systems will behave identically with respect to Mode C intruders. This addresses columns 1, 3 and 5 of Table D-8.

D.3.5.2 Mode S Intruder Track Never Acquired

The first way that hybrid TCAS can fail to have a Mode S intruder under surveillance is if the intruder was never placed under surveillance (Table D-8, column 2). Hybrid TCAS has two ways that a Mode S intruder can be placed under surveillance. One starts out in the same way that Mode S intruders are placed under surveillance by non-hybrid TCAS. The only difference is that the optional use of the Mode S Extended Squitter (Mode S Downlink Format DF-17) in non-hybrid TCAS is made mandatory in hybrid TCAS. This mode of acquisition requires at least two active interrogations of the intruder. Once the intruder is acquired in this manner, it may transition either to active surveillance or to validated passive surveillance, depending on whether various conditions are met. From validated passive surveillance the intruder may then transition to unvalidated passive surveillance under the appropriate conditions. However, no matter which surveillance mode it ends up in, it remains true that the initial detection and acquisition is identical to non-hybrid TCAS, and if a Mode S intruder is not acquired by hybrid TCAS it would also not be acquired by non-hybrid TCAS.

The second Mode S acquisition mode allowed by hybrid TCAS is not available in non-hybrid TCAS, and so can only increase the chance of acquiring an intruder in hybrid TCAS. It acquires certain Mode S intruders entirely passively by means of their Mode S Extended Squitters, or, equivalently, by means of ADS-B reports generated by appropriate receivers outside TCAS and reported to the TCAS unit. The position reports must meet certain quality and power level criteria before they can be used for passive acquisition.

For intruders that qualify for passive acquisition these two acquisition modes proceed in parallel. The intruder will initially be established as an active track if that detection and acquisition process proceeds faster, or it will initially be established as an unvalidated passive track if that detection and acquisition process proceeds more quickly. However, the passive acquisition process does not inhibit the active acquisition process until such time as the intruder is established under unvalidated passive surveillance. The passive acquisition procedure might acquire the intruder sooner than would be the case for non-hybrid TCAS under some circumstances, but if not, acquisition will be performed by a procedure identical to that used by non-hybrid TCAS.

D.3.5.3 Mode S Intruder Track Dropped Due To Loss Of Valid Correlating Position Reports

The second way that hybrid TCAS can fail to have a Mode S intruder under surveillance at the time that an advisory should be generated is if the intruder was under surveillance at some time but the track was dropped due to the loss of valid correlating surveillance reports (Table D-8, column 4 and column 7). Hybrid TCAS maintains active tracks in exactly the same manner as non-hybrid TCAS, so for Mode S tracks that have been under active surveillance throughout their lifetime, or for Mode S tracks that transitioned from passive to active surveillance and have been under active surveillance for more than a few seconds, the track drop behavior of the two systems will be identical. Therefore, differences between the hybrid and non-hybrid TCAS systems will occur only with respect to dropping intruder tracks that are under passive surveillance or that are in the process of transitioning from passive to active surveillance.

A dropped track in a threat or near-threat situation can affect the time at which a TA or RA is issued, since in a non-hybrid TCAS implementation it can take 10 seconds or more for a track to coast out and for a new surveillance track on the intruder to become established. The original safety assessment for TCAS included the effect of dropped and re-established tracks.

Mode S tracks can get dropped at the transition from passive to active surveillance if the active range measurements differ from the passive range reports by enough that they do not fall inside a correlation window. That correlation window is centered around the projected position of the track based on the prior (passive) range and range rate estimates. §2.2.6.2, Active Surveillance Requirements, specifies requirements that will prevent such correlation failures during the passive-to-active transition in the nominal case where the passive range is within the allowed revalidation tolerance. Therefore, such track drops are most likely to happen when there is some passive position reporting failure that results in passive range report errors larger than the normal revalidation tolerance.

In order to avoid a delay potentially as long as 10 seconds when a track is dropped and re-established during the transition to active surveillance, §2.2.6.2 also requires that active surveillance data be provided to the collision avoidance system within 3 seconds of the time that the decision to transition from active to passive surveillance was made, even in the event of such a track drop. §D.2.5, Time Buffer for Passive to Active Transitions, shows that requirement ensures that the collision avoidance system will be able to issue an RA 3 seconds after the decision to transition to active surveillance, whether or not a track drop occurs during that transition, and so the decision to make the transition to active surveillance must be made at least 3 seconds prior to the time that an RA could be issued. §D.3.4.1.1, Analysis of Passive-to-Active Transition Time Buffer in Vertical Separation, shows that an adequate time buffer is provided by the vertical separation condition for the passive-to-active surveillance transition. §D.3.4.2.2, Required Range and Range Rate Accuracy, demonstrates the range and range rate accuracy needed to ensure that an adequate time buffer is provided by the range condition for the passive-to-active surveillance transition. §D.3.4.2.3 and §D.3.4.2.4 show that passive range reports that meet the revalidation requirement will give the necessary range and range rate accuracy to provide the desired 3-second time buffer. Therefore, under normal circumstances, a Mode S intruder will be under active surveillance in time, and no delay of TAs or RAs will occur, even if a track drop occurs during the transition to active surveillance. §D.3.4.2.6 through §D.3.4.2.10 analyze what might happen in the event of sudden range jumps and large passive range errors. Under some circumstances a Mode S intruder might not be under active surveillance in time, resulting in a missing TA, the delay of a TA, or the delay of an RA. However, it is also shown that there is no significant effect on the TCAS risk ratio.

Another form of correlation failure can potentially occur soon after active surveillance starts, if the surveillance range tracker does not suppress range rate transients due to jumps in apparent range at the transition from passive to active surveillance. Such range rate transients will affect the projected range at the next TCAS update cycle, which is used as the center of the correlation box. Depending on the size of the range rate transient and the size of the correlation box, it could happen that the projected position is so far away from the true position that correlation failures occur for the second or subsequent active surveillance reports, until such time as the range rate transient dies down. If enough successive correlation failures occurred, the track might be dropped even though the initial active surveillance report was accepted and reported to the collision avoidance system.

Correlation failures can also occur while the intruder is under passive surveillance if there is a sudden jump in the reported position of either own aircraft or the intruder. Own position reports must be monitored per §2.2.10, Monitoring Requirements, and if they are determined to be invalid or unavailable, all passive surveillance tracks are transitioned to active surveillance. §2.2.7.4, Tracking In The Absence of Airborne Position Messages, covers all the possibilities for why a passive track might not be updated. In addition to correlation failures, there can also be circumstances where the intruder's passive position reports are received but contain invalid data, and where the intruder's passive position reports can cease. If passive position reports are being received from the intruder, but do not correlate in range or contain invalid data, the track is not dropped but instead transitions to active surveillance mode within either 1 second or 5 seconds depending on the surveillance update rate that the intruder would be under if it were under active surveillance. That may then lead to a track drop, if the active range does not match the passive range closely enough, as described above. However, if passive position reports cease for an intruder, then its passive surveillance track may be dropped, following the normal TCAS procedures for a track when surveillance reports cease. In most cases such track drops will occur because the intruder has flown out of range and so cannot be a threat. However, if the intruder is still close enough to be of interest to TCAS, and it is still generating standard All-Call squitters (DF=11), it will be reacquired by the normal acquisition process. If the intruder is not generating All-Call squitters, or its squitters are too low a power to be detected when they reach the TCAS aircraft, then the intruder would not be detected by non-hybrid TCAS either.

§D.4.1 discusses the relationship between regions of the airspace that are under 1-second versus 5-second active surveillance updates and regions that are under active versus passive surveillance.

D.3.5.4 Mode S Intruder Track Dropped Due To Track File Overflow

The third way that hybrid TCAS can fail to have a Mode S intruder under surveillance at the time that an advisory should be generated is if the intruder was under surveillance but the track was dropped due to a track file overflow (Table D-8, column 6 and column 8). That is, the track file was full, a new intruder track was acquired, and the older intruder track was dropped to provide a space in the track file for the new intruder. For Mode S tracks under active surveillance (Table D-8, column 6), hybrid surveillance and non-hybrid surveillance behave the same when a track file overflow occurs, dropping tracks at longer range in favor of new tracks at shorter range (Ref. A, §2.2.4.6.1.1, Surveillance Overload). Therefore the only difference between the two systems might be with respect to tracks under passive surveillance. No new requirements are stated for validated passive tracks, and so the default requirement of §2.2.1, General, applies, and they will be handled in the same manner as is required for non-hybrid TCAS. §2.2.7.3 Track Updates Using Airborne Position Messages, specifies the track overflow behavior for unvalidated passive tracks.

D.4 Supporting Analysis

The three analyses in this section of the report support the fault analysis described in §D.3 and the selection of some of the parameters in the minimum requirements for hybrid surveillance. The first analysis (§D.4.1) addresses the question of under what circumstances an intruder under passive surveillance must be updated at 1-second intervals. The second analysis (§D.4.2) addresses the transient effect of jumps in range on the surveillance system. The third analysis (§D.4.3) reports on a simulation study of the performance of the TCAS collision avoidance functions when an intruder tracked with passive surveillance transitions to active surveillance.

D.4.1 Comparison of NORMAL/REDUCED Active Surveillance Regions with Passive/Active Surveillance Regions

What intruders might satisfy the requirements to be under passive surveillance and also to be updated at a 1-second rate? Intruders that do not meet the range requirement for active surveillance also do not meet the range requirement for surveillance at the once per second rate. That can be seen in Figure D-11. The horizontal axis is range in nautical miles; the vertical axis is range rate in knots. The curve furthest to the left is the range condition boundary for triggering a TA at sensitivity level 7. The range condition boundaries for TAs at all other sensitivity levels, and for RAs at all levels, lie to the left of that curve. The curve furthest to the right is the range condition boundary for the passive-to-active surveillance mode change defined by this MOPS. The curve lying between those two is the range condition boundary for the transition between NORMAL active surveillance updated once per second and REDUCED active surveillance updated every 5 seconds, as defined in DO-185B, §2.2.4.6.2.2.3, Maintenance of Established Tracks. Although it may appear that the passive-to-active boundary and the normal/reduced boundary overlap on their vertical portions, in fact the vertical portion of the NORMAL/REDUCED boundary is at 3.05 NM range, while the vertical portion of the passive-to-active boundary is at 3.10 NM range, so the two curves are separated at all points. Since the curves are well separated at some points, in those regions intruders are required to transition from passive surveillance to REDUCED active surveillance at a 0.2 Hz rate.

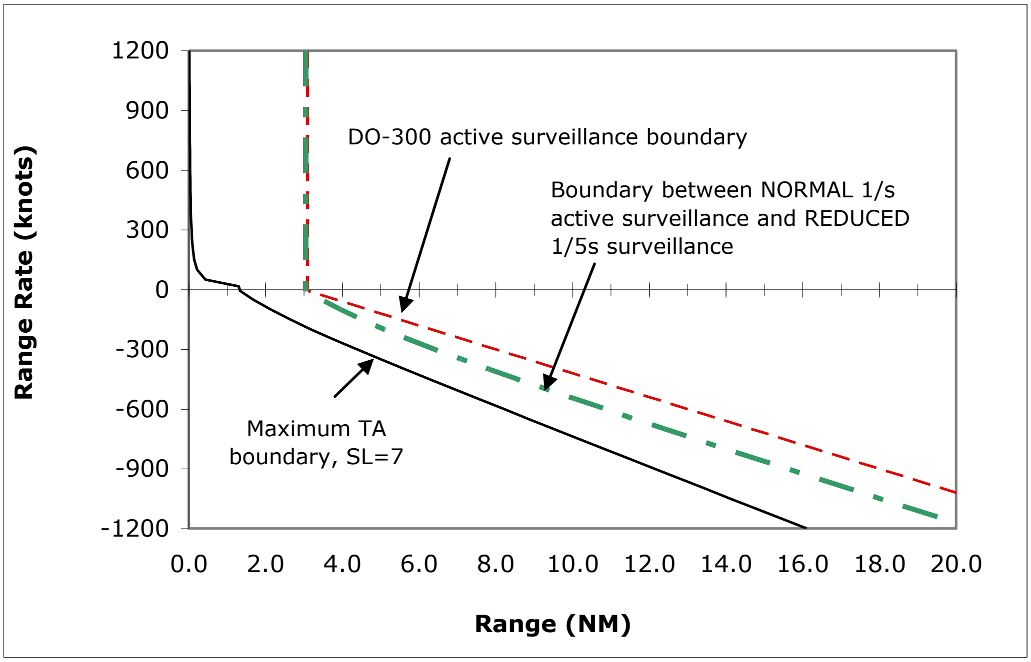

Figure D - 11. Normal/Reduced Surveillance Boundary Compared to Passive/Active Boundary and Maximum TA Boundary

However, a TCAS unit is not required to use reduced surveillance if it or the intruder is above 18,000 ft. Under that condition no requirement is specified, and so manufacturers are free to decide not to implement reduced surveillance. Above 18,000 ft, for those TCAS units that do not implement reduced surveillance above that altitude, there can be intruders that do not satisfy the range requirement for active surveillance and that also must be updated once per second.

In all TCAS implementations, below 18,000 ft, there also can be intruders under passive surveillance that must be updated once per second. The test for NORMAL/REDUCED surveillance does not have a vertical separation criterion, while the passive/active test does. Therefore, to be under passive surveillance and also in a region where updates must be provided every second, the intruder must satisfy the range criterion for NORMAL surveillance but not the altitude criterion for active surveillance. Thus, the intruder must have at least 4500 ft vertical separation from the TCAS aircraft, and, if it is closing vertically on the TCAS aircraft, it must be more than 60 seconds away from reaching 4500 ft vertical separation.

D.4.2 Transient Effect of Jumps in Range on the Surveillance System

D.4.2.1 Concerns

This section considers the effect of jumps in reported range such as those that might occur when the system transitions from passive to active surveillance or from active to passive surveillance. The concern is how the surveillance system's range tracking functions will respond to a single large jump in the intruder's reported range.

Range jumps will generally occur at the transitions from passive to active surveillance or vice versa because of the difference between the range measured by active interrogations and the range calculated from passive position reports. If there is some fault in the passive range, the difference between the active and passive range reports might be quite large, and a large range jump will occur at the transition from passive to active surveillance. Such large jumps are prevented on the transition from active to passive surveillance by the requirement that the passive range pass a validation test prior to making that transition. However, even if the passive range error is within the allowed revalidation error of 340 m, a substantial range rate transient can result.

The results here can also be applied to the case where a jump in the passive range occurs during passive surveillance. Such jumps might be due to such things as a change in the satellite configuration being used by the GPS unit that is providing position reports, resulting in a jump to a new range that is still within the 340 m revalidation limit, or might be due to some fault in the position reporting that results in a larger jump in passive range.

A sudden change in range affects not only the range but also the range rate estimation. The analysis quantifies the error in the range rate estimate due to a jump in range and translates that range rate error into the resulting error in the hybrid range tau and in the modified hybrid range tau. An error in the hybrid range tau could cause an erroneous (delayed, early, or inappropriate) transition from passive to active surveillance. An error in the modified hybrid range tau could cause an erroneous transition from active to passive surveillance.

D.4.2.2 Surveillance System Range Filter Implementation

The surveillance system's range filters are not specified to the same level of detail that the collision avoidance system's range filters are. The range filter that was used to evaluate the transient effect of range and range rate errors is based on a sample surveillance filter described in Ref. A, Appendix A.9. The filter is an α-β-γ tracker that predicts range and range rate with nominal steady state filter coefficients of $\alpha = 0.44$, $\beta = 0.114$ and $\gamma = 0.0120$.

Other surveillance filter implementations may give somewhat different results. However, the features of the transient response that are illustrated are likely to be a concern for many implementations, since they depend primarily on the structure of the filter.

The surveillance correlation windows were disabled so that a track would not be dropped due to a large range jump. The initial condition transients were allowed to settle before the range jumps were introduced.

D.4.2.3 Simulation Results

Both positive and negative range jumps of 660 ft (201 m), 1400 ft (427 m), and 3000 ft (914 m) were simulated at ranges of 15 NM and 4 NM and at range rates that corresponded to hybrid range tau values near 60 or 65 seconds. A sample of the results is presented in Figures D-12 through D-23 below. In addition to plots of the range and range rate estimates, the hybrid range tau is plotted in order to show the effect of the resulting range rate transients on the range criterion for transitioning from passive to active or active to passive surveillance.

The simulation results show that:

- As expected for a linear filter, the maximum deviation in range and range rate from the true values is proportional to the size of the range jump.

- The surveillance system range filter tracks the range jumps very well. The filtered range differs from the reported range by no more than about 1/10 the magnitude of the range jump (about 66 ft for the 660 ft range jumps, 140 ft for the 1400 ft range jumps, and 300 ft for the 3000 ft range jumps).

- The peak range rate deviations are slightly less than (range jump magnitude)/4 or slightly less than 660/4 = 165 ft/s = 98 kt, 1400/4 = 350 ft/s = 207 kt, and 3000/4 = 750 ft/s = 444 kt. (If the range jump is measured in feet, the range rate deviation calculated by the range-jump/4 approximation is in ft/s. If the range jump is measured in NM, the range rate deviation from that approximation is in NM/s, not in knots.)

- The filtered range rate returns to the true value 10 seconds after the range jump, although it then overshoots the true value. The transients die out completely after 25 seconds.

- The range rate deviation is reduced to 1/2 its peak value about 5 seconds after the range jump, to 1/3 its peak value about 6 seconds after the range jump, and to 1/4 its peak value about 7 seconds after the range jump.

- Range jumps of these magnitudes away from the TCAS aircraft cause a significant underestimate of the rate of closure in range, and therefore a significant overestimate of the range tau.

- Range jumps of these magnitudes toward the TCAS aircraft cause a significant overestimate of the rate of closure in range and therefore a significant underestimate of the range tau.

- The deviation in the range tau value is greater the closer the intruder is in range. For a given value of range tau, shorter range implies smaller range rate, and with smaller range and smaller range rate, the deviations in both range and range rate due to the range jump have a larger effect.

- For a given size of range jump, the deviation in the range tau is larger if the jump is away from the TCAS aircraft than it is if the jump is toward the TCAS aircraft.

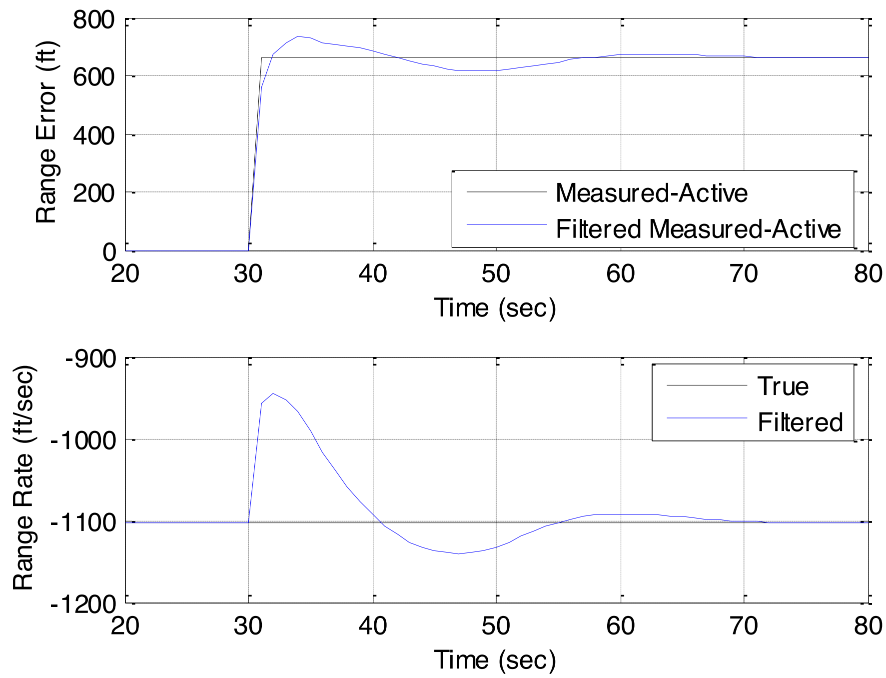

Figure D - 12. Representative Surveillance Filter Response to a +660 ft Jump in Range

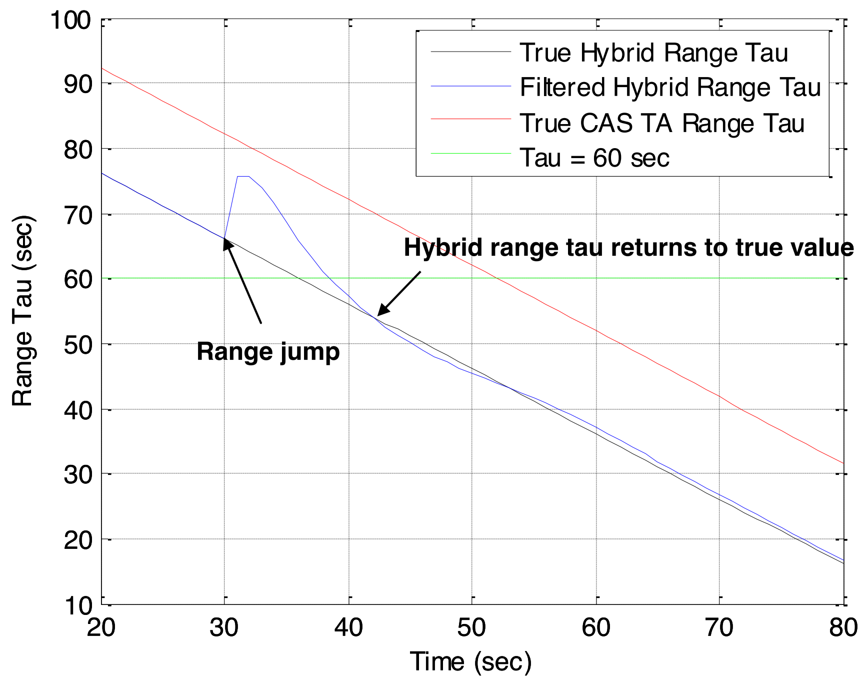

Figure D - 13. Error in Range Tau Due to a +660 ft Jump in Range at 15 NM

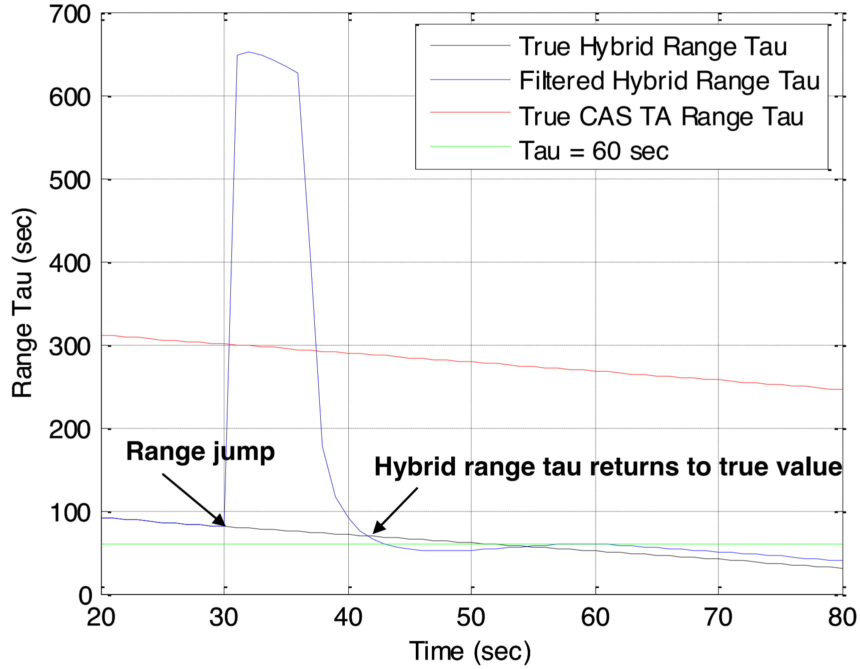

Figure D - 14. Error in Range Tau Due to a +660 ft Jump in Range at 4 NM

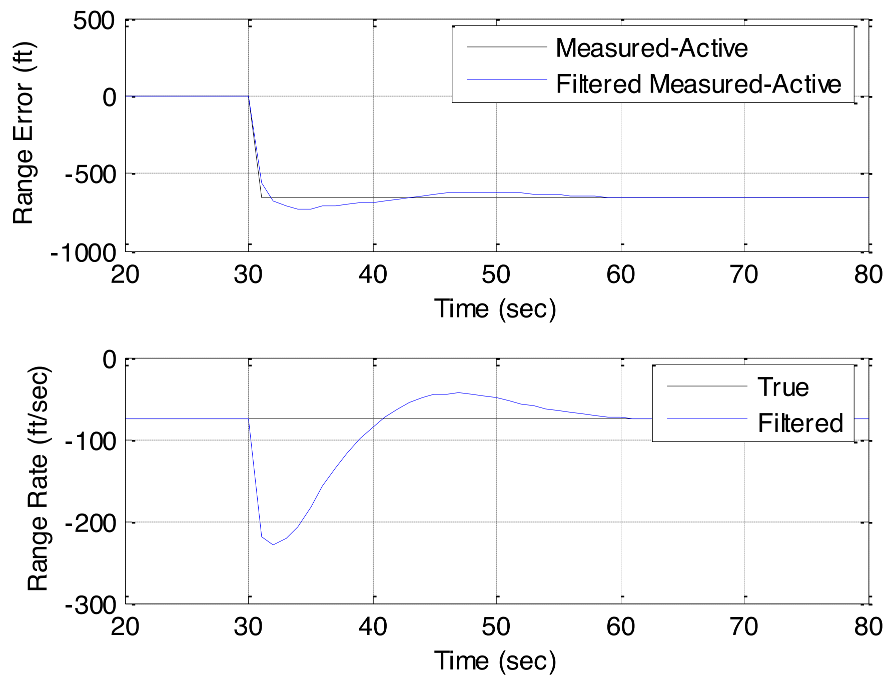

Figure D - 15. Representative Surveillance Filter Response to a -660 ft Jump in Range

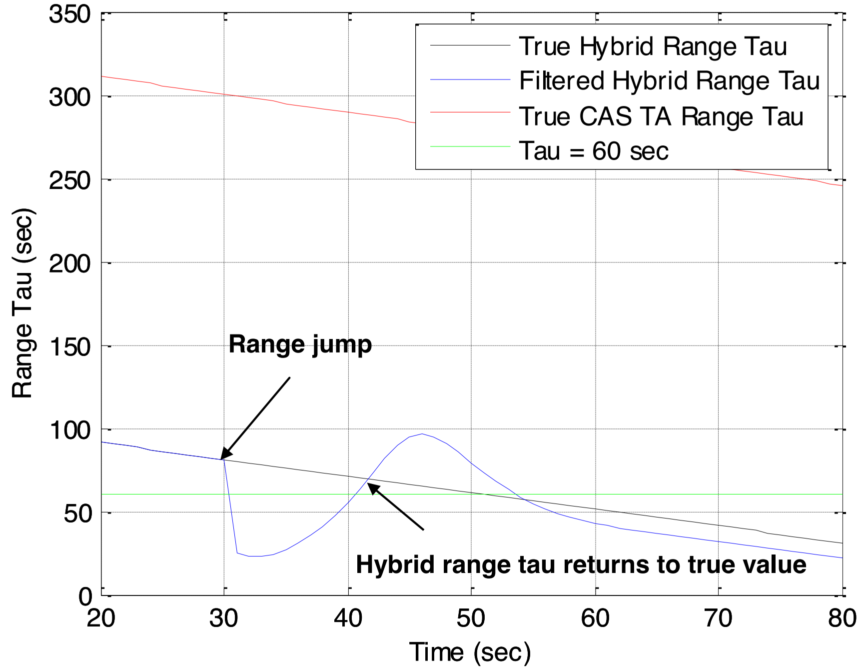

Figure D - 16. Error in Range Tau Due to a -660 ft Jump in Range at 4 NM

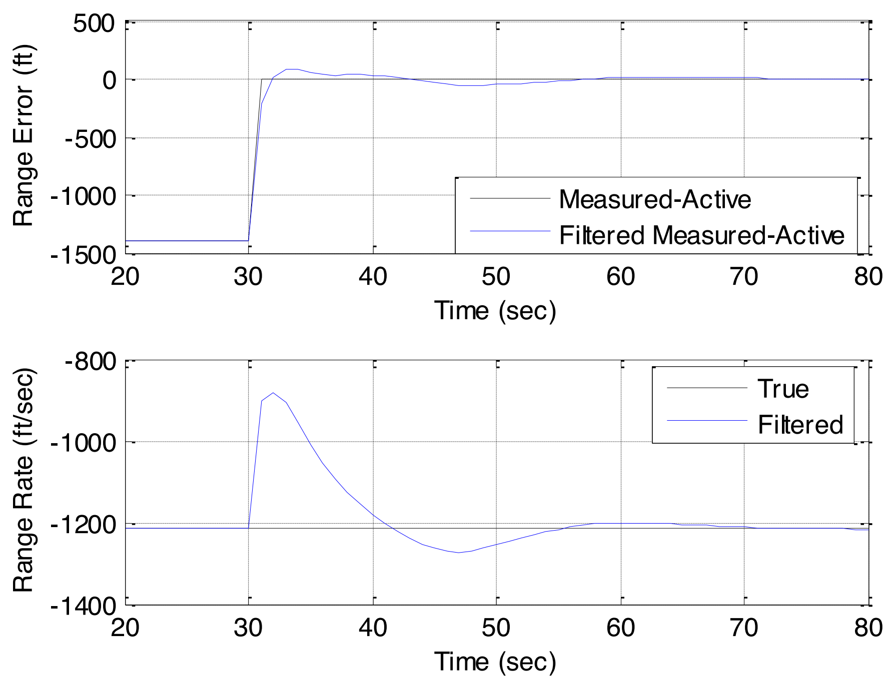

Figure D - 17. Representative Surveillance Filter Response to a +1400 ft Jump in Range

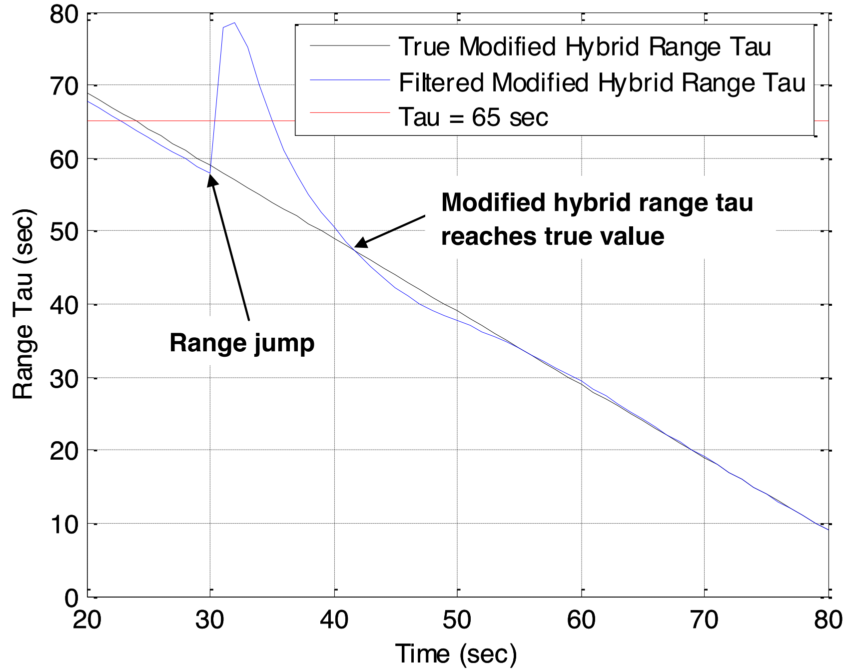

Figure D - 18. Error in Range Tau Due to a +1400 ft Jump in Range at 15 NM

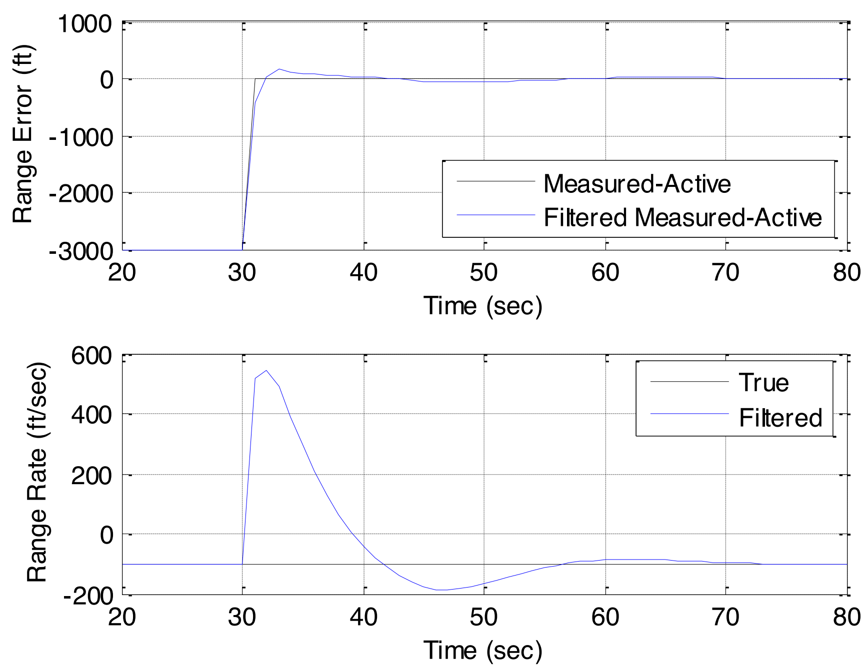

Figure D - 19. Representative Surveillance Filter Response to a +3000 ft Jump in Range

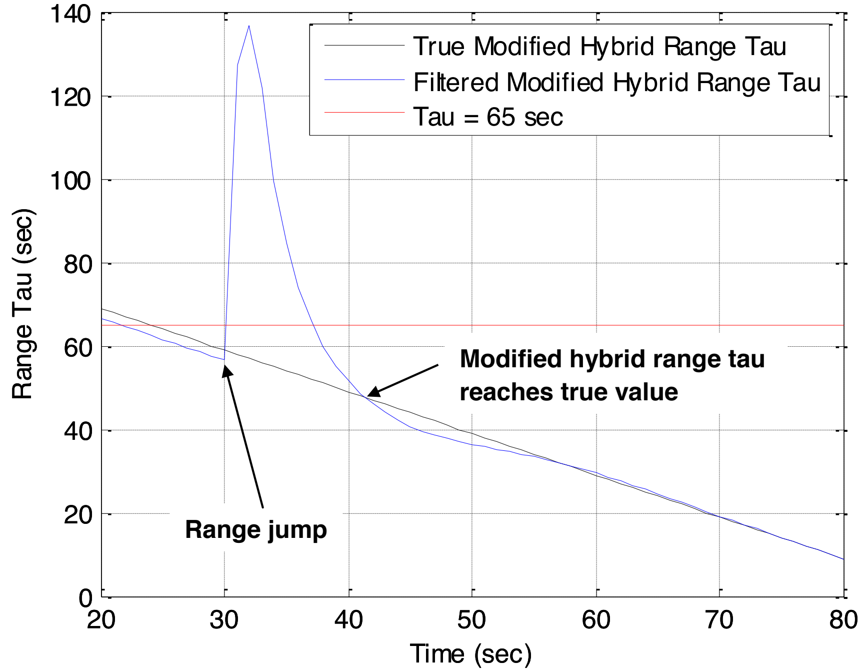

Figure D - 20. Error in Range Tau Due to a +3000 ft Jump in Range at 15 NM

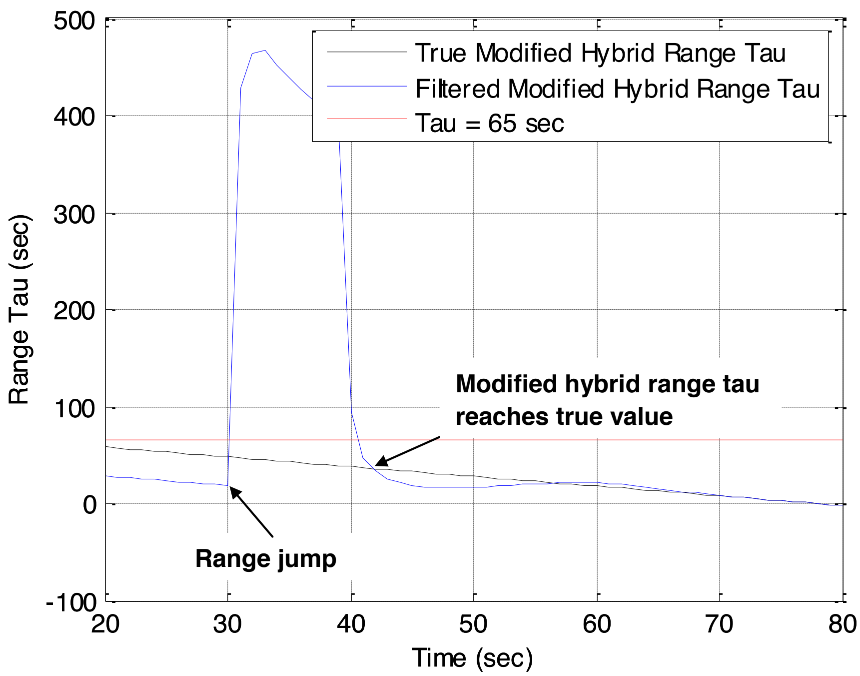

Figure D - 21. Error in Range Tau Due to a +3000 ft Jump in Range at 4 NM

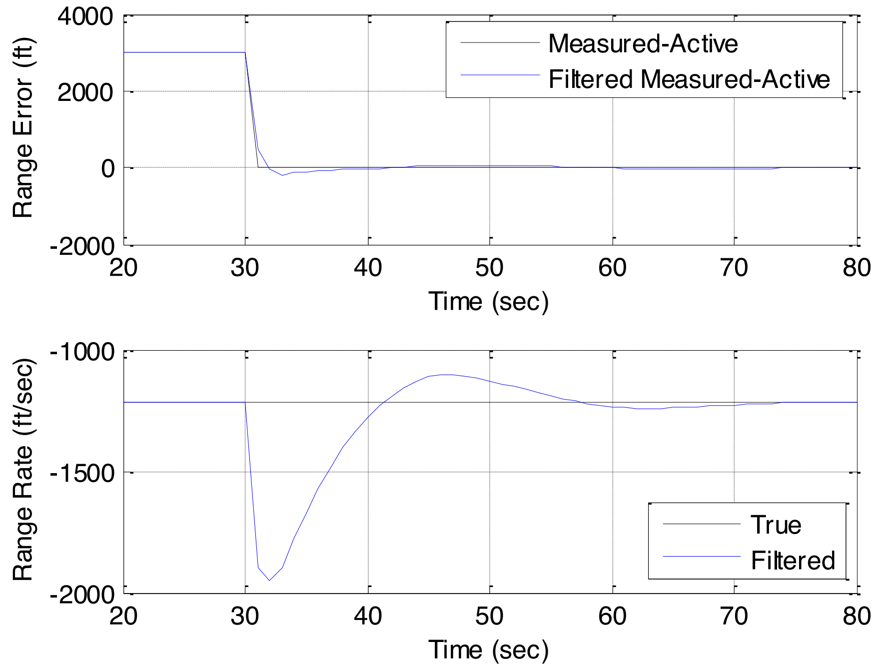

Figure D - 22. Representative Surveillance Filter Response to a -3000 ft Jump in Range

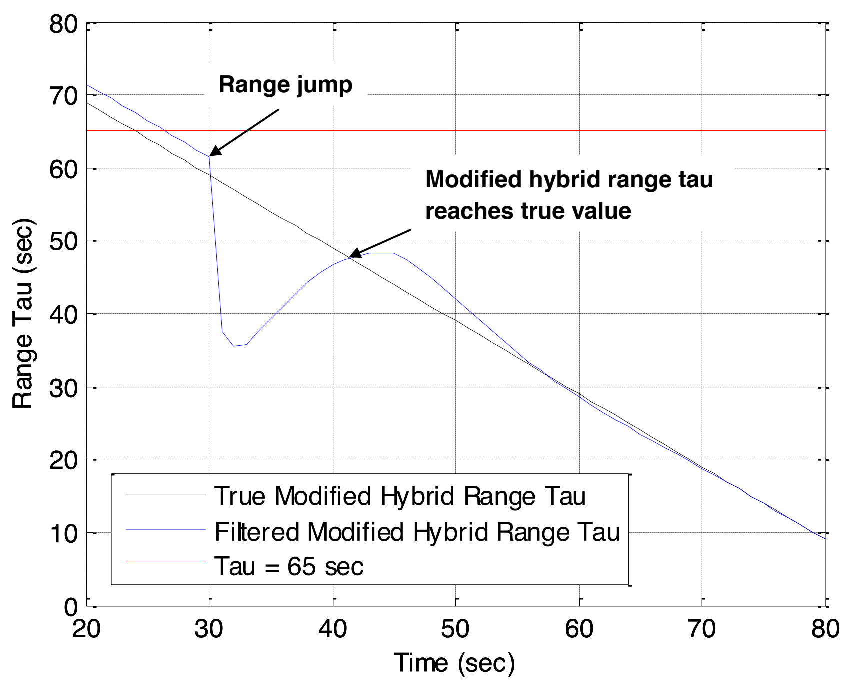

Figure D - 23. Error in Range Tau Due to a -3000 ft Jump in Range at 4 NM

D.4.3 Collision Avoidance Threat Detection After a Transition from Passive to Active Surveillance

D.4.3.1 Concerns

This section of the report provides some simulation results on the performance of the TCAS collision avoidance algorithms starting at the transition from passive to active surveillance. The results presented in the fault analysis in §D.3 were based on analyses of how the CAS range and altitude tracking functions are implemented, the time required to initialize those tracking functions once active surveillance started, and the expected response of those functions to potential large range jumps between the last passive range report and the first active range report. The purpose of the simulations presented here were to confirm that a faithful implementation of the CAS range and altitude tracking functions performed as expected.

The collision avoidance range filter performance is illustrated in §D.4.3.3 and §D.4.3.4 by looking at the performance of the collision avoidance algorithms for some co-altitude scenarios after a jump in range at the passive to active surveillance transition. §D.4.3.3 tests the CAS behavior under several non-accelerating, head-on encounters, with range jumps of various sizes and in both directions occurring at the start of active surveillance reports. §D.4.3.4 tests the CAS behavior under several scenarios where the TCAS and intruder aircraft are flying parallel at maximum speed, then turn sharply toward each other until they are converging head-on, with the transition to active surveillance occurring during the period of acceleration, and range jumps of various sizes, in both directions, occurring at the start of active surveillance. This is the most stringent acceleration case to stress the range-based threat detection and alerting.

Section §D.4.3.5 studies the performance of the TCAS collision avoidance algorithms for a vertically accelerating scenario where an intruder directly above own aircraft and traveling at the same speed starts an aggressive descent.

D.4.3.2 Collision Avoidance Algorithm Implementation

The simulations demonstrating the performance of the TCAS collision avoidance algorithms used the TCAS evaluation environment developed at MIT Lincoln Laboratory. Lincoln Laboratory has incorporated a TCAS vendor's code into a larger environment that includes the capability to set up encounter models and analyze performance (Figure D-24). The environment includes a visual acquisition and pilot model. It has been used for numerous evaluations of TCAS performance.

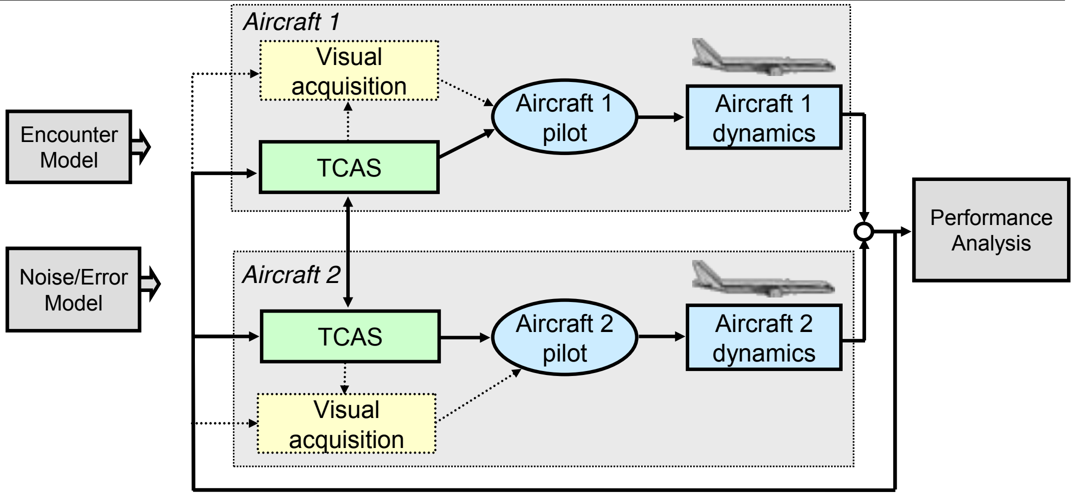

Figure D - 24. MIT Lincoln Laboratory TCAS Simulation Environment

D.4.3.3 Co-Altitude, Non-accelerating Scenarios

The co-altitude, non-accelerating scenarios demonstrate that jumps in range at the passive to active surveillance transition do not affect the time that a TA or RA is issued. The scenario conditions are:

- Both aircraft are level at flight level 220. This sets the TA tau threshold to 48 seconds before the closest point of approach, and the RA tau threshold to 35 seconds before the closest point of approach.

- The intruder is traveling head-on toward the TCAS aircraft at four different closure rates: 1200 ft/s (711 kt), 1000 ft/s (592 kt), 470 ft/s (278 kt), and 360 ft/s (213 kt).

- The passive to active surveillance transition occurs 60 seconds into the simulation and approximately 60 seconds before closest point of approach. That corresponds to ranges of 12 NM, 10 NM, 5 NM and 4 NM.

- At the passive to active surveillance transition, the range jumps ±660 ft, ±1500 ft or ±3000 ft.

Table D-9 compares the TA and RA times for the passive-to-active surveillance transition against advisory times when using active surveillance only. Time is measured from the start of the simulation, and the transition from passive to active surveillance occurs at T=60 seconds. The TA and RA times are the same for all scenarios, regardless of the size of the range jump at the transition point. That demonstrates that the collision avoidance function performance is not affected by range jumps when an intruder switches from passive to active surveillance.

Figure D-25 illustrates the collision avoidance range filter performance for a scenario with a 3000 ft range jump at the passive-to-active surveillance transition. The range filters track the new range within a couple of seconds.

Figure D-26 illustrates the collision avoidance range rate estimation for the same scenario. The range rate has a large jump for one point just after the transition and afterwards immediately tracks the true range rate. The lack of a persistent range rate transient in the CAS range filter performance is possible because of the features designed into the CAS range filters to address possible range jumps at the transition from REDUCED active surveillance to NORMAL active surveillance. Those features are described in §D.2.1.2, Surveillance System, Collision Avoidance System, and Their Interface.

Table D - 9. TA and RA Timing For Head-On Co-Altitude Scenarios

Range Rate (ft/s)	Active Surveillance Only			Passive to Active Surveillance Range Jump at T=60 seconds											
				+3000 ft		+1500 ft		+600 ft		-600 ft		-1500 ft		-3000 ft	
	TA	RA	T_{CPA}	TA	RA	TA	RA	TA	RA	TA	RA	TA	RA	TA	RA
-1200	73	86	122	73	86	73	86	73	86	73	86	73	86	73	86
-1000	73	86	122	73	86	73	86	73	86	73	86	73	86	73	86
-470	73	86	125	73	86	73	86	73	86	73	86	73	86	73	86
-360	72	85	127	72	85	72	85	72	85	72	85	72	85	72	85

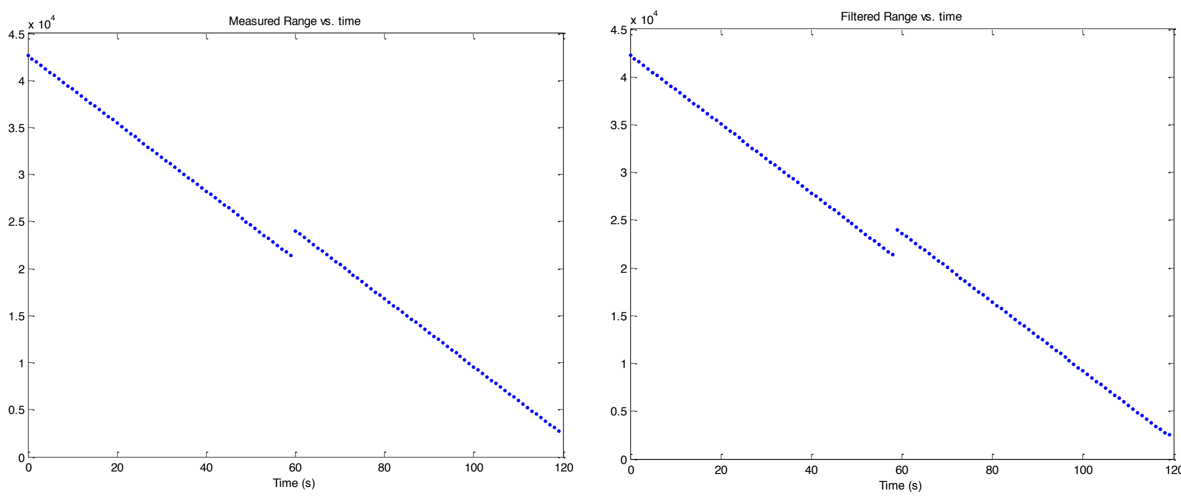

Figure D - 25. Example of Collision Avoidance Range Filter Tracking for 3000ft Range Jump

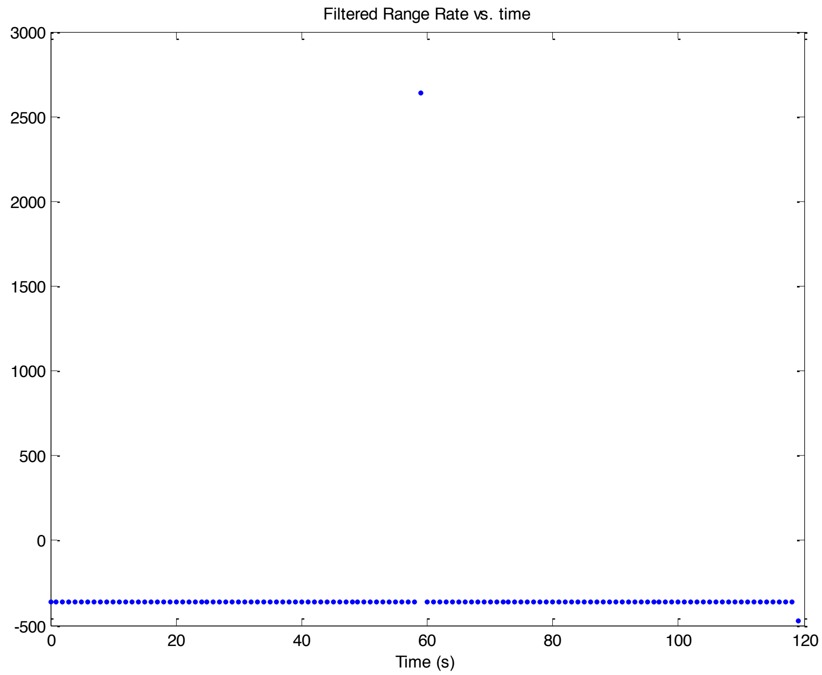

Figure D - 26. Example of Collision Avoidance Range Rate Tracking for 3000 ft Range Jump

D.4.3.4 Co-Altitude, Accelerating Scenarios

The co-altitude, accelerating scenarios demonstrate that jumps in range at the passive to active surveillance transition do not affect the time that a TA or RA is issued even with accelerations. The scenario conditions are:

- Both aircraft are level at flight level 220, flying parallel at 600 kt. The intruder is offset laterally by 10 NM.
- Both aircraft start to turn towards each other with a 60 degree bank angle (2 minute turn) and continue straight at one another once they have turned through 90 degrees.
- The passive to active surveillance transition occurs at T=60 seconds.
- At the passive to active surveillance transition, the range jumps ±660 ft, ±1500 ft or ±3000 ft.

Table D-10 shows the TA and RA times with and without hybrid surveillance implemented. Regardless of the size of the range jump at the transition point, the TA and RA times are the same for the passive-to-active surveillance transition. There is a 1-second difference between the advisory times for active surveillance only and a passive-to-active surveillance transition. The active surveillance TA and RA occur 1 second earlier. The difference is due to a small lag in estimating range rate due to the reset of the range filter parameters at the passive-to-active surveillance transition. The difference is not significant enough for the advisories to be misleading or for safety to be reduced.

Table D - 10. TA and RA Timing For Turning Co-altitude Scenarios

Active Surveillance Only			Passive to Active Surveillance Range Jump at T=60 seconds											
			+3000 ft		+1500 ft		+600 ft		-600 ft		-1500 ft		-3000 ft	
TA	RA	T_{CPA}	TA	RA	TA	RA	TA	RA	TA	RA	TA	RA	TA	RA
72	74	100	73	75	73	75	73	75	73	75	73	75	73	75

D.4.3.5 Aggressive Descending Intruder Scenarios

The descending intruder scenarios demonstrate that the hybrid surveillance vertical transition criteria are sufficient to ensure that TCAS will have time to alert. The scenario conditions are:

- The TCAS aircraft is initially level at flight level 220.
- The intruder aircraft is initially level at flight level 252, either directly overhead, or 5.75 NM in front of the TCAS aircraft and closing at 250 ft/s (148kt).
- There are two vertical profiles. At 60 seconds into the simulation, one of the following happens:
    - The intruder accelerates downward at 1.25 g to a maximum descent rate of 10,000 ft/min.
    - The TCAS aircraft accelerates upward at 0.5 g to a maximum climb rate of 10,000 ft/min, while at the same time the intruder accelerates downward at 0.5g to a maximum descent rate of 10,000 ft/min.
- The intruder is simulated with 25 ft and 100 ft altitude quantization.
- The TCAS aircraft is simulated with coarse and fine altitude.

The scenarios simulated are much more aggressive than those an aircraft would be expected to encounter. The TCAS safety studies typically use a worst case vertical maneuver where one aircraft climbs or descends with a 0.5 g acceleration and a maximum 4000 ft/min descent rate.

Simulation results showed that TCAS issued TAs and RAs at the same time, whether the intruder was only tracked actively or was tracked with passive surveillance and transitioned to active surveillance when the descent began. In some cases, this meant that no advisory was issued. Table D-11 shows the advisory times. The vertical maneuvers began when the simulation time was 60 seconds. Note that for the 1.25 g descent, TCAS issues a TA four seconds after the transition time.

The simulation did not consider the effect of a 3 second delay in establishing an active track. However, the vertical protection simulated was a 3200 ft altitude separation when the vertical maneuvers began. The vertical protection provided by the hybrid surveillance vertical transition criterion is 4500 ft – 100 ft altitude error = 4400 ft. It would take a 24000 ft/min altitude separation rate to cover 1200 ft in 3 seconds, which a much more aggressive descent than was studied. Therefore the hybrid surveillance vertical protection provided by AMOD = 4500 ft is sufficient.

Table D - 11. TA and RA Timing For Aggressive Descent Scenarios

Scenario	Passive to Active Surveillance Transition								
	Intruder 25 ft Altitude Encoding				Intruder 100 ft Altitude Encoding				Time to Co-Altitude (sec)
	Fine Altitude Tracking		Coarse Altitude Tracking		Fine Altitude Tracking		Coarse Altitude Tracking		
	TA	RA	TA	RA	TA	RA	TA	RA	
Intruder Overhead, 1.25 g Descent	68	70			64	68			80
Intruder In Front, 1.25 g Descent	None	None			75	None			80
Overhead Intruder, Coincident 0.5 g Decent and Ascent	64	66	64	66	65	66	65	66	75

D.5 Conclusions

The safety assessment described in this appendix shows that hybrid surveillance does not compromise the safety of TCAS collision avoidance because:

- Advisories (Traffic Advisories, TAs, and Resolution Advisories, RAs) are never based on passive surveillance data. Tracks based on passive surveillance data are marked in such a manner that the collision avoidance system will not generate TAs and RAs for them. Advisories will be generated only for intruders under active surveillance. TCAS with hybrid surveillance will therefore retain its status as an independent safety system, and all previous safety studies of TCAS continue to apply unchanged. Tracks based on passive surveillance data may only be displayed on the pilot's traffic display for situational awareness.

- For normal (fault-free) operation, that is, when the position reports used for passive surveillance have the accuracy required under applicable standards and laws, intruders will be under active surveillance in sufficient time to issue advisories identical to those that would be issued by TCAS without hybrid surveillance, and will remain under active surveillance as long as a TA or RA persists. Simulation results show the largest variation in advisory time is 1 second, which is comparable to the variation that might occur between different vendor implementations of TCAS.

- For normal (fault free) operation, at the time of an advisory, the range, range rate, altitude, altitude rate, bearing, and bearing rate derived from active surveillance will be effectively identical to what would have been obtained if active surveillance had been maintained throughout. That ensures that TAs will have the same timing and that RAs will have the same timing, sense and strength as they would have had if hybrid surveillance was not being used.

- In the presence of faults in the position reports used for passive surveillance, the system safety is no worse than that of TCAS without hybrid surveillance. Either the fault condition affects TCAS without hybrid surveillance in the same manner as it does TCAS with hybrid surveillance, or mechanisms are in place to prevent the fault from affecting the outcome, or it has been demonstrated that although the fault could degrade surveillance in TCAS with hybrid surveillance, the risk ratio is not affected.

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Appendix E

Variable Validation Intervals

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E.1 Derivation of the Revalidation Time Interval

This appendix provides the derivation for the equation and table in §2.2.7.5 (Revalidation) that are used to determine the time interval until the next revalidation attempt.

If the passive position reports remain reasonably close to the true position of the intruder, the normal case, then the transition to active surveillance will occur prior to the earliest possible time for a Traffic Advisory (TA) against the intruder. Any safety concerns for that condition are addressed by the safety analysis in DO-300, Appendix D. This analysis considers the case where, subsequent to a successful revalidation, the intruder accelerates toward the TCAS aircraft while at the same time its passive reports diverge from its true position in such a manner that they indicate that the intruder is less of a potential threat than it really is. The analysis assumes that nothing is known about the possible failure modes of the passive range reports, and so makes no assumption about how far they might deviate from the true position of the intruder. All that is known is that the last revalidation was successful, and so at that time the passive range was close to the active range. It is also assumed that, given a successful revalidation, the range rate estimated from previous passive position reports is roughly accurate. Finally, it is assumed that the TCAS aircraft and the intruder can accelerate toward each other at an acceleration of at most 1/3 g (11 ft/s^2). That limit on the acceleration sets a lower bound on how soon the intruder can physically satisfy the range tau requirements for the transition to active surveillance. If the next revalidation occurs at or prior to that lower bound, any divergence between the true and reported range will be caught before active surveillance is required. The 1/3 g value was chosen by the SC-147 Surveillance Working Group because that is the lateral acceleration assumed in the calculation of the TCAS threat detection parameter DMOD, which makes a similar worst-case acceleration argument.

Two models were examined for calculating the worst-case (shortest) time interval from the time of a successful validation until the intruder could pass the range and range rate condition for transition from passive to active surveillance. The simpler model assumes that the TCAS aircraft and the intruder can simply accelerate in range directly toward each other at a constant 11 ft/s^2, up to a maximum closing speed of 1200 knots. Such constant acceleration is not realistic in many aircraft geometries, as aircraft typically accelerate by turning rather than by substantial speed changes. However, when a more realistic model was evaluated that modeled both aircraft turning toward each other, each with a lateral acceleration of 11/2 ft/s^2 , identical results were obtained given the quantization used in the table. For assumed total accelerations on the order of 1 g (32 ft/s^2) (lateral accelerations of ½ g) the more complicated model allowed a few more cells of the range and range rate space to go 10 seconds longer between validations than the simpler model. However, for the 1/3 g (11 ft/s^2) acceleration assumption, the two models give identical results. For that reason, only the simpler model will be presented.

The model assumes that the estimated range and range rate at the time of successful revalidation, which are based upon passive reports, are accurate because of the successful validation. The range must be accurate within the validation tolerance or revalidation would not succeed and the track would transition to active surveillance. The argument for the range rate being accurate is more indirect. It is based on the likelihood that if the current passive range measurement is accurate, then the measurements in the recent past that primarily determine the range rate estimate are also likely to have been accurate. That is enforced to some degree by the requirement that a passive range report must fall within a correlation window centered about the predicted range of the track, where that predicted range is based on the previous range and range rate estimates. If a passive range report does not fall within the correlation window, the track will coast. If it coasts repeatedly, it will transition to active surveillance. Thus, there is a limit on how much the range reports are allowed to jump around from update to update.

It is assumed that the TCAS aircraft and the intruder can simply accelerate in range directly toward each other at a constant 11 ft/s^2, up to a maximum closing speed of 1200 knots. The range equation is then:

$$r(t) = r_0 + v_0 t_a + 0.5 a t_a^{\,2} + v_{max}(t - t_a)$$

where:
t is the time since the last validation (s),
r_0 is the range estimate at validation (ft),
v_0 is the range rate estimate at validation (ft/s),
a is the assumed acceleration, -11 ft/s^2,
v_{max} is the maximum assumed closure rate, -2025 ft/s (-1200 knots), and
$t_a = \min(t, (v_{max} - v_0)/a)$ is the length of the acceleration interval.

The corresponding velocity equation is:

$$v(t) = v_0 + a t_a$$

The range tau condition for transitioning to active surveillance is then:

$$tau(t) = -\frac{(r(t) - s_{mod})}{\min(v(t), v_{min})} \le t_{thr}$$

where:
s_{mod} is a range offset of 18228 ft (3 NM) that is used in the range condition for transition to active surveillance,
v_{min} is a minimum closure rate assumed in the tau calculation, -10.13 ft/s (-6 kt), and
t_{thr} is the range tau threshold value of 60 seconds for transitioning to active surveillance.

To create Table 2 in §2.2.7.5, $tau(t)$ was calculated at projection times t of 10, 20, 30, 40 and 60 seconds for values of r_0 of 3 through 30 NM in increments of 1 NM and for values of v_0 from -1200 to +1200 knots in increments of 100 knots. For each combination of r_0 and v_0 the longest of those projection times that resulted in a $tau(t)$ of greater than or equal to the 60 second threshold t_{thr} was entered into the corresponding table cell.

Each cell in the table represents a range of values for r_0 and v_0 that is 1 NM by 100 kts in size. Some cells in the table are such that all values for r_0 and v_0 in that cell satisfy the range tau condition for the transition to active surveillance. Those cells are marked with an ‘A’. Other cells contain both values that are within the active surveillance region and those that are not. However, there is no reason for the table to be accessed for range and range rate values that require a transition to active surveillance. The times in those cells are for the r_0 and v_0 values that fall outside the active surveillance region.

For some combinations of r_0 and v_0 near the boundary of the active surveillance region, the simple acceleration model shows that there is not even 10 seconds before the intruder might enter the active surveillance region. Rather than specify a variety of shorter revalidation intervals, which would lead to excessive interrogation rates, such table cells have been set to the minimum value of 10 seconds. An intruder that is in one of those cells at the last successful revalidation and whose passive position reports continue to be accurate, the normal case, will transition to active surveillance at the appropriate time. However, if that intruder has the kind of failure analyzed here, that failure will not be detected for 10 seconds, at the next revalidation attempt. The intruder will then be inside the nominal range and range rate boundary for the transition to active surveillance, but by at most 10 seconds. The safety consequences of this delay are analyzed in Appendix D, §D.3.4.2.9.

Instead of using a pre-calculated table of validation intervals as presented above, one might instead wish to calculate the maximum safe validation interval in real time. The necessary equations are derived below from the tau equation and the variable definitions used above, specifically:

$$tau(t) = -\frac{r_0 + v_0 t_a + 0.5 a t_a^2 + v_{max}(t - t_a) - s_{mod}}{\min(v_0 + a t_a, v_{min})} \le t_{thr}$$

where:

t is the time since the last successful validation (s),
r_0 is the range estimate at validation (ft),
v_0 is the range rate estimate at validation (ft/s),
a is the assumed acceleration, -11 ft/s^2,
v_{max} is the maximum assumed closure rate, -2025 ft/s (-1200 knots),
v_{min} is the minimum closure rate assumed in the tau calculation, -10.13 ft/s (-6 kt),
$t_a = \min(t, (v_{max} - v_0)/a)$ is the length of the acceleration interval in seconds,
s_{mod} is a range offset of 18228 ft (3 NM), and
t_{thr} is the range tau threshold value of 60 seconds for transitioning to active surveillance.

In principle, it is necessary to use multiple equations in the real time calculations because of the min() function used in the definitions of tau(t) and t_a. The timeline must be divided into two or three segments, depending on the initial range rate v_0. Within each of these time segments the results of the min() functions can be reduced to single values or expressions. The first time segment applies only if the initial range rate is more positive than v_{min} (-6 kt), so that the intruder is either moving away from the TCAS aircraft or converging more slowly than v_{min}, and covers the time interval during which the intruder accelerates toward the TCAS aircraft until it is converging at a rate of v_{min}. The second time segment applies from the time the intruder is converging at or faster than v_{min} until the time that the intruder has accelerated to the maximum closure rate of v_{max}. The third segment applies after the intruder has reached a closure rate of v_{max} and so has stopped accelerating. It is not known a priori which of these segments will contain the time when the condition tau(t) = 60 seconds is satisfied, although it will be shown below that the first time segment can be ignored, and that the third time segment applies only at large initial ranges r_0 and high initial closure rates v_0, resulting in most solutions falling during the second time segment. It will be argued that the equation for the second time segment can also be used for the third time segment without any loss of safety and very little increase in interrogations. Therefore, the final result is that only a single equation, for the second time segment, needs to be solved.

The first time segment is only applicable if $v_0 > v_{min}$. If the first time segment is applicable, it will end at time $t_1 = (v_{min} - v_0)/a$, the time it takes to accelerate from v_0 to v_{min}. During that time interval, the tau equation can be simplified by using the fixed constant closure rate of v_{min} (-6 kt) and by ignoring the term that calculates the range closure after the acceleration has stopped upon reaching the range rate v_{max}. The following simplified tau equation is the result:

$$tau(t) = -\frac{r_0 + v_0 t + 0.5at^2 - s_{mod}}{v_{min}}.$$

If $tau(t1) \leq t_{thr}$, then the maximum safe interval until the next validation falls somewhere during the first time segment. The appropriate time t can be found by solving the quadratic equation $tau(t) = t_{thr}$ for t, giving:

$$t = \frac{-v_0 \pm \sqrt{v_0^2 - 2a(r_0 + v_{min}t_{thr} - s_{mod})}}{a}.$$

That equation has two solutions, but only the more positive one (obtained when using the minus sign) is of interest. The other solution will give a negative value for t. [To see this, note that the expression ($r_0 + v_{min}t_{thr} - s_{mod}$) will always be positive in value, as otherwise the intruder would already satisfy the tau condition for active surveillance. Therefore the expression inside the square root will always give a positive value that is larger than v_0^2 and a positive real root that is larger than v_0.]

However, because of the small constant range rate v_{min} used in the tau equation during that first time segment, $tau(t) = 60$ can only occur during that first time segment for a very small range of initial conditions r_0 and v_0, such a small range that this version of the tau equation can be ignored for practical purposes.

In order to see why that is so, observe that the range versus time trajectory is a parabola opening downward with a fixed shape due to the fixed acceleration. Its location in range versus time space is determined by r_0 (the range at time 0) and v_0 (the slope at time 0). For $tau(t) = t_{thr}$ to hold, the range at time t must be $s_{mod} - v_{min}\, t_{thr} = 3.1$NM, and therefore $r_0 + v_0 t + 0.5at^2 = 3.1\text{NM}$. The initial range r_0 must be greater than 3.1 NM in order that the active interrogation conditions not apply at the time of validation. v_0 must be more positive than v_{min} in order for the first time segment to be applicable. For the same reason, the range rate at time t must not be more negative than v_{min}. Given those constraints, the largest possible r_0 occurs when $v_0 = 0$ (the top of the parabola is reached just at time 0) and the range rate just reaches v_{min} at the same time that $tau(t) = 60$ is satisfied. Since it takes only 0.92 seconds to accelerate to v_{min} at a = -11 ft/s^2, that gives a maximum r_0 that is only a few feet larger than the minimum value of 3.1 NM.

The maximum possible v_0 will occur when r_0 = 3.1 NM on the outbound leg of the parabola. Since the range trajectory is a parabola, when it reaches 3.1 NM and $tau(t) = t_{thr}$ is satisfied on the inbound leg, the range rate will be the negative of the initial range rate v_0. That cannot be more negative than v_{min}, or the conditions for the first time segment would no longer apply, and so v_0 cannot be greater than - v_{min} or +6 kt. At larger initial range rates, the range rate would become more negative than v_{min} before the tau condition is satisfied, and so the tau equation for the first time segment would not be applicable.

Since the first time segment will give a valid solution over such a narrow range of initial conditions, and since any such solution will give a safe validation interval much smaller than 10 seconds, the first time segment can be ignored in practice, as the tau equation for the second time segment, presented below, gives almost the same validation interval under those initial conditions. The two equations give identical results if the actual range rate just reaches v_{min} at the same time that $tau(t) = t_{thr}$. For example, for v_0 = +6 kt and r_0 = 3.1 NM, both equations give a solution of $t = t_1$ = 1.84 s.

The second time segment starts at t_1 and ends when the intruder reaches the maximum closure rate v_{max}, and so it ends at $t_2 = (v_{max} - v_0)/a$. During the second time segment the following simplified version of the equation for $tau(t)$ applies:

$$tau(t) = -\frac{r_0 + v_0 t + 0.5at^2 - s_{mod}}{v_0 + at}.$$

If $tau(t_2) \le t_{thr}$, then the maximum safe interval until the next validation falls somewhere during the second time segment. The appropriate time t can be found by solving the quadratic equation $tau(t) = t_{thr}$ for t, giving:

$$t = \frac{-(v_0 + at_{thr}) \pm \sqrt{(v_0 + at_{thr})^2 - 2a(r_0 + v_0 t_{thr} - s_{mod})}}{a}$$

Once again that gives two solutions but only the more positive one (obtained when using the minus sign) is of interest for the same reasons described above. One probably does not want to pre-test the condition $tau(t_2) \le t_{thr}$ but rather simply calculate t and determine if it falls between zero and t_2 in order to verify that it is a valid solution. If the solution does not fall within the second time segment and $t_2 \ge 60$ then the validation interval can be set to 60 seconds without further calculation.

During the third time segment, the intruder has reached the maximum closure rate and has stopped accelerating. The simplified equation for $tau(t)$ during the third time segment is:

$$tau\,(t) = -\frac{r_0 - (1/2a)(v_0 - v_{max})^2 + v_{max}\,t - s_{mod}}{v_{max}}\,.$$

Solving that version of the tau equation for $tau(t) = t_{thr}$ gives:

$$t = -\frac{r_0 - (1/2a)(v_0 - v_{max})^2 - s_{mod}}{v_{max}} - t_{thr}\,.$$

If a valid solution is not found in the first two time segments, then this equation provides the desired answer.

Note that since the intruder has a range greater than 3.1 NM (otherwise it would satisfy the conditions for active interrogation), if it has a range rate of greater than or equal to +300 kt, a validation interval of 60 seconds will always be chosen. That can be seen by solving for t using the equation for the second time segment with v_0 = +300 kt and r_0 = 3.1 NM, which gives a time of 62 seconds for the maximum safe interval between validations. Larger values of r_0 and v_0 will give larger safe intervals, all of which will be truncated to 60 seconds.

Given all the above, an algorithm for computing the validation interval given that the intruder does not satisfy the conditions for active interrogation might be:

1. If $v_0 \geq +300$ kt then set the validation interval to 60 seconds.

2. Otherwise, calculate $t_2 = (v_{max} - v_0)/a$ and

$$t = \frac{-(v_0 + at_{thr}) - \sqrt{(v_0 + at_{thr})^2 - 2a(r_0 + v_0 t_{thr} - s_{mod})}}{a}\,.$$

If $0 < t \leq t_2$ then t is a valid solution. It must be truncated to the next smaller integer number of seconds. If less than 10 seconds it must be set to the minimum validation interval of 10 seconds. If greater than 60 seconds it must be set to the maximum validation interval of 60 seconds. It could optionally be further quantized to the set of values 10, 20, 30, 40 and 60 seconds used in the table of validation intervals.

3. If, in step 2, $t > t_2$, but $t_2 \geq 60$, then the validation interval can be set to 60 seconds, as any valid solution for the third time segment must have a value greater than t_2.

4. If, in step 2, $t > t_2$, and $t_2 < 60$, then it is necessary to compute

$$t = -\frac{r_0 - (1/2a)(v_0 - v_{max})^2 - s_{mod}}{v_{max}} - t_{thr}$$

and that gives the correct solution for t. The resulting value must then be quantized to the appropriate integer value as described in step 2.

A calculation similar to that described above was carried out in Excel for each entry in a range versus range rate table like Table 2 above. The results were quantized to the values

10, 20, 30, 40 and 60 seconds used in that table. The resulting table was then compared to Table 2. The two tables were identical.

Another observation is that the equation in step 2 of the above procedure could also be used for the third time segment, ignoring the t_2 boundary. That would correspond to the assumption that the intruder's acceleration does not stop when the closure rate reaches 1200 kt, allowing the closure rate to grow larger than that. The resulting times will be smaller than the times calculated by the above procedure, and so will lead to shorter revalidation times. Hence, safety will not be compromised, but slightly higher interrogation rates will result. However, the equation in step 4 of the above procedure is only used for ten cells of Table 2 that represent intruders at ranges at or beyond 24 NM and with closure rates of 1000 kt or greater. In three of those cells the calculated safe revalidation intervals are 10 seconds or smaller, and so the minimum value of 10 seconds would be used, and the remaining cells have values less than 21 seconds. If the 10-20-30-40-60 second quantization scheme is used as in Table 2, eight of those cells are quantized to 10 seconds and the remaining two cells are set to 20 seconds. If the equation in step 2 is used instead, and the results are quantized as in Table 2, only the one cell at 30 NM and -1200 kt would change, from 20 seconds to 10 seconds. Therefore it is attractive to trade a very small increase in interrogation rates for a simplification that eliminates steps 3 and 4 of the above procedure. That additional simplification has been adopted in the equation presented in §2.2.7.5.

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Appendix F

1090 MHz Spectrum Reduction Analysis

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F.1 Introduction

The principle motivation for updating DO-300 to Version A was to modify the hybrid surveillance algorithms to reduce the TCAS use of the 1090 MHz channel. A number of algorithm changes were proposed by members of the SC-147 Surveillance Working Group (SWG). These proposed changes were evaluated using a Lincoln Laboratory TCAS surveillance simulation to understand the associated impact on the 1090 MHz channel. This appendix provides a high level description of the changes to the surveillance algorithms, the simulation used to evaluate these changes, and the results produced by the simulation.

F.2 Simulation and Input Data Set

A high fidelity TCAS surveillance simulation has been developed and updated over the last two decades to analyze the impact of changes to the TCAS surveillance algorithms. The simulation takes as input aircraft position tracks with associated transponder equipages (ie, ATCRBS, Mode S only, and Mode S with TCAS). The surveillance activity for each TCAS aircraft present in the dataset is simulated in one second intervals. The TCAS surveillance metrics of interest are output for each aircraft, such as number of interrogations and surveillance range for TCAS aircraft and reply rates and transponder utilization for victim transponders.

The most important area in which to analyze reduction in RF channel usage by TCAS is a dense terminal region. Hybrid surveillance can make the greatest impact here as this type of an environment would experience particularly high levels of RF interference. The analysis was therefore focused on the New York City area as this airspace has been noted as being one of the most dense aircraft environments in the country. An input data set was generated from radar tracks covering a circular area centered about the JFK radar with a radius of 120 NM. These radar tracks were taken from Sunday, November 29, 2009 between 17:00 and 18:00 EST as this hour was observed to be of particularly high Mode S density.

The following assumptions were made in the simulation for this analysis:

1. All TCAS in the simulated scenario are equipped with the surveillance modification under test
2. For the hybrid surveillance modifications, all Mode S aircraft are ADS-B equipped
3. TCAS does not perform altitude monitoring using DF=0 and DF=4 FRUIT messages (Ref. A, §2.2.4.6.2.2.1)
4. There is no upper limit on the number of aircraft TCAS instantaneously tracks
5. Information in airborne position messages (lat/lon/alt) is always valid and is always accurate
6. Own position information (lat/lon/alt) is always available and is always accurate
7. All Mode S aircraft with 1090ES are crosslink capable
8. Any aircraft marked as being non-crosslink capable is tracked actively

9. Aircraft on the ground at an airport are able to communicate with all other aircraft on the ground at the same airport

F.3 Evaluate Algorithm Changes

Many changes to the surveillance algorithms were proposed by members of the SWG. A number of these proposed changes were removed from consideration due to minimal impact on the 1090 MHz channel and/or difficulty to implement. The following subsections summarize those algorithm changes that were picked to be incorporated into Change 2 of DO-185B and Version A of DO-300.

F.3.1 Algorithm Changes to DO-185B

F.3.1.1 Reduced Surveillance Volume when Operating on Airport Surface

There were two parts that contributed to this algorithm change. First was a change that reduced the full TCAS interrogation power by 10 dB when TCAS is powered on. Prior to DO-185B Change 2, TCAS units were initialized to full interrogation power (maximum surveillance range) when TCAS was first powered-on. This initialization value lengthened the amount of time required for a newly powered-on TCAS in a busy environment to decrease its power, through interference limiting, to the proper level. For example, it would take a TCAS unit 104 seconds (13 steps × 8 seconds freeze time per step) to reach the maximum 13 dB on-ground attenuation in a busy terminal environment. While the TCAS unit was “frozen” between eight second steps, interrogations would have been sent to all aircraft within communication range, resulting in increased utilization of those aircraft’s transponders. The issue was exacerbated by the fact that aircraft powering on TCAS on the ground are usually located at the peak of local aircraft density (the busy airport surface).

The second part of this algorithm change was to reduce the relative altitude threshold for targets of interest while TCAS is operating on the ground. While it was intended for TCAS to be activated only immediately prior to taking the active runway, analysis of surveillance data had indicated that many aircraft were activating their TCAS well before reaching the active runway (Ref. M, Appendix B). Although RTCA DO-185B limits TCAS interrogation more significantly while own aircraft is on the ground than when airborne, even with severe interference limiting DO-185B requires a TCAS to interrogate aircraft that are within ±10,000 ft of own aircraft. Reduction of TCAS altitude surveillance volume to ±3000 ft while on the ground was found to reduce unnecessary interrogations while on the ground without significant loss of situational awareness.

F.3.1.2 Eliminating Range Monitoring Interrogations to On-Ground TCAS Aircraft when Own TCAS is on the Ground

The interference limiting algorithms described in DO-185B require that a TCAS unit adjust its receiver sensitivity and interrogation power level based upon, among other parameters, the number of other TCAS equipped aircraft within 3 and 6 NM (NTA3 and NTA6). A TCAS unit above 2000 ft AGL includes only airborne TCAS in the NTA3 and NTA6 values; a TCAS unit ≤ 2000 ft AGL includes both airborne and on-ground TCAS in the NTA3 and NTA6 values. TCAS typically determines these values by simply counting the number of TCAS equipped aircraft that are currently under track and within the specified range. However, DO-185B does not allow TCAS to actively track other aircraft on the ground. Therefore to include TCAS aircraft operating on the airport surface in the NTA3 and NTA6 calculations, a TCAS unit ≤ 2000 ft AGL is required to monitor other TCAS aircraft on the ground through an interrogation every 5 seconds. It was found that when own TCAS is on the ground, these monitoring interrogations for determining NTA3 and NTA6 were an unnecessary use of the RF spectrum as other interference limiting procedures exist to restrict interrogations by TCAS operating on the airport surface. This modification precludes TCAS operating on the airport surface from interrogating other TCAS operating on the airport surface.

F.3.2 Algorithm Changes to DO-300

F.3.2.1 Passively Monitor TCAS Aircraft when Below 2000 ft AGL

This algorithm change was based on the same principle described in §F.3.1.2 where DO-185B required TCAS below 2000 ft to interrogate other TCAS aircraft on the ground for the sole purpose of determining NTA3 and NTA6. With the change in §F.3.1.2, when own TCAS is on the ground, these interrogations were eliminated to reduce TCAS use of the 1090 MHz channel. However, a TCAS with Hybrid Surveillance could continue to monitor such targets through the passive reception of ADS-B messages. Therefore a change was made to the TCAS Hybrid Surveillance algorithms such that monitoring interrogations for the calculation of NTA3 and NTA6 would be replaced with the passive monitoring of these targets.

F.3.2.2 Two Validation Attempts

To ensure that a target would always be tracked actively prior to an alert, the original version of DO-300 required that any failure to validate a passive track would require an immediate transition to active tracking. The cause for such a failure could include TCAS not receiving a reply to the validation interrogation. Since failing to receive a reply to an interrogation attempt is not uncommon, it was observed that this safeguard could prematurely and undesirably require TCAS to transition a valid passive target to active tracking. To avoid passive tracks unnecessarily transitioning to active tracking, the validation algorithms were changed such that the transition to active tracking would only occur if validation replies were not received for multiple consecutive surveillance cycles. The simulation performed for this analysis assumed that this transition would occur after two consecutive surveillance cycles; however the requirement specified in §2.2.7.5 of this document allows validation to be attempted in up to five consecutive surveillance cycles.

F.3.2.3 Variable Validation Rate

The original version of DO-300 required that all passively tracked targets have their ADS-B position information periodically validated with a TCAS interrogation. The requirements were that an ADS-B equipped target close in either range or altitude (but not both) be validated once every 10 seconds while a target neither close in range nor altitude be validated once every 60 seconds. It was determined that a reduction in TCAS use of the 1090 MHz channel could be achieved by simply modifying these validation rates. New logic to determine the validation rate for a passive track was developed to still remain within the constraints of the existing DO-300 safety study.

Notionally, this new logic is the following: if an ADS-B equipped target is close in both altitude and range, the target should be tracked with active surveillance (i.e. only use TCAS active interrogations to calculate the relative position of the target). If the target is not close in altitude, then the target should be validated once every 60 seconds. If the target is close in altitude but not range, the target should be validated at a rate between 10 and 60 seconds with this variable rate based on a 'worst case' calculation. This calculation is considered 'worst case' as it assumes the other aircraft will accelerate toward own ship with the TCAS MOPS defined maximum for combined acceleration of 1/3 g. The variable validation rate is given in this document as both an equation and a table in §2.2.7.5.

F.3.2.4 Use of Short Replies for Validation

With the original version of DO-300, validation was performed using crosslink interrogations which elicited replies containing the ADS-B position of the target aircraft. This allowed for a very straightforward validation technique as the ADS-B position information included in the reply could be directly compared with slant range and bearing derived from the active interrogation; i.e., no interpolation or time alignment of passive and active position was necessary. While this validation technique was simple to implement, it had a negative side effect from the point of view of 1090 MHz channel use.

The reply elicited by a crosslink interrogation is twice the length of a reply to a standard TCAS interrogation. Therefore the use of crosslink interrogations for validation purposes negated some of the benefit yielded by hybrid surveillance. It was determined that a reduction in 1090 MHz channel use could be achieved by requiring TCAS to perform validation using standard interrogations which elicit replies that are half the length of those from crosslink interrogations. The additional processing required to perform this alternative validation technique (i.e., extrapolation for time alignment) was determined to be negligible.

F.3.2.5 Extended Hybrid Surveillance

The original version of DO-300 contained two requirements that were eliminated in DO-300A. The first was that a TCAS with Hybrid Surveillance had to acquire a target with the procedure described in DO-185B (i.e., acquisition using active interrogations) before that target could be tracked passively. The second was that all passive tracks were required to be validated with a periodic interrogation. It was determined that a reduction in the TCAS use of the 1090 MHz channel could be accomplished by relaxing these requirements for target aircraft that are considered non-threatening and reporting high quality ADS-B information.

This surveillance algorithm change was achieved by allowing a TCAS with Hybrid Surveillance to passively acquire and track qualified ADS-B equipped target aircraft without validation. Surveillance of such aircraft was governed by rules that became known as Extended Hybrid Surveillance. In the most basic sense, a target aircraft would qualify for Extended Hybrid Surveillance if it was reporting high quality ADS-B information and its squitters were received at a power level below -68 dBm. Since received power level can be considered a rough surrogate for range, this change allowed for distant ADS-B equipped targets to be acquired passively without any interrogations. Furthermore, this change eliminated the need to periodically validate ADS-B equipped aircraft that were far away and non-threatening.

F.3.2.6 Passive Only Surveillance on the Ground

As noted in §F.3.1.2, data collections showed that many more TCAS were operating on the airport surface than previously expected. While the algorithm changes described in

§F.3.1.1, §F.3.1.2 and §F.3.2.1 reduced the number of interrogations used by TCAS when on the ground, it was recognized that a TCAS with Hybrid Surveillance could eliminate most interrogations by performing only passive surveillance on targets that are reporting high quality ADS-B information. Prior to DO-300A, the TCAS Hybrid Surveillance requirements did not distinguish between airborne operation and operation on the ground. While this modification to the Hybrid Surveillance MOPS was evaluated in simulation as an independent change, it was considered part of Extended Hybrid Surveillance during the MOPS modification process due to a large similarity in the requirements.

F.4 Results

The surveillance algorithm changes described in §F.3 were evaluated using the simulation described in §F.2. These algorithm changes were compared against two baseline scenarios to understand the relative impact on the 1090 MHz channel. The first baseline scenario assumed all TCAS aircraft were equipped with a DO-185B compliant unit while the second baseline assumed all TCAS aircraft were equipped with a DO-300 compliant unit.

The metric chosen to understand the impact of each algorithm change was the 1090 MHz Receiver Occupancy. This metric describes the percentage of time a receiver with a minimum triggering level (MTL) of -74 dBm is occupied due to the decoding of TCAS generated replies. The calculation is performed through the summation of relevant replies received multiplied by the length of the reply. For example, if an antenna received 100 short reply messages (each 64 μs in length) and 50 long reply message (each 120 μs in length) the 1090 MHz Receiver Occupancy would be (100*0.000064) + (50*0.000120) = 1.24%.

Within the simulation, the 1090 MHz TCAS Receiver Occupancy was calculated for those TCAS aircraft that were less than 30 NM from the JFK sensor. This metric was then averaged over all such TCAS aircraft and over the entire hour of the input data set. This averaging resulted in one value of 1090 MHz Receiver Occupancy for the scenario under consideration. Results were then compared against the baseline cases to highlight the relative reduction in 1090 MHz Receiver Occupancy. The relative reduction provided by each surveillance algorithm change is provided in the second and third columns of Table F-1. As an example, Table F-1 indicates that Extended Hybrid Surveillance provided a 26% reduction in 1090 MHz Receiver Occupancy when compared against a baseline of DO-185B (column 2, row 9) and an 11% reduction when compared against the original version of DO-300 (column 3, row 9).

As it was understood that multiple surveillance algorithm changes would be reflected in the final version of DO-300A, several combinations of algorithm changes were also examined. The bottom two rows of Table F-1 are the relative reduction in 1090 MHz Receiver Occupancy provided by a combination of multiple surveillance algorithm changes. The algorithm changes included in each group are indicated by shaded cells. As an example, Group A included the two modifications that were specific to DO-185B. This group provided a 24% reduction in 1090 MHz Receiver Occupancy when compared against a baseline of DO-185B.

Column H of Table F-1 most closely represents the modifications that were included in Version A of DO-300. This column and the requirements in this document differ in only two manners. First, the modification of "Passively Monitor TCAS Aircraft when Below 2000 ft AGL (§F.3.2.1)" was not included in Version A of DO-300. However, the majority of this modification is captured in "Eliminate Range Monitoring Interrogations to TCAS Aircraft when on the Ground (§F.3.1.2)" which is included in the updated version of DO-185. Second, as explained in §F.3.2.2, the modification of "Two Validation Attempts (§F.3.2.2)" was simulated differently than the text drafted for Version A of DO-300. These two differences between column H and requirements specified in Version A of DO-300 are considered to be insignificant with regard to the TCAS use of the 1090 MHz channel.

Table F - 1. Simulated Reduction in 1090 MHz Receiver Occupancy

Algorithm Change	% 1090 MHz Interference Reduction		Group A	Group B	Group C	Group D	Group E	Group F	Group G	Group H
	Vs DO-185B	Vs DO-300								
Reduced Surveillance Volume when Operating on Airport Surface (§F.3.1.1)	10%	NA								
Eliminate Range Monitoring Interrogations to TCAS Aircraft when on the Ground (§F.3.1.2)	14%	NA								
Original DO-300	17%	NA								
Passively Monitor TCAS Aircraft when Below 2000 ft AGL (§F.3.2.1)	36%	23%								
Two Validation Attempts (§F.3.2.2)	19%	2%								
Variable Validation Rate (§F.3.2.3)	30%	16%								
Use of Short Replies for Validation (§F.3.2.4)	34%	20%								
Extended Hybrid Surveillance (§F.3.2.5)	26%	11%								
Passive Only Surveillance on the Ground (§F.3.2.6)	49%	38%								

% Reduction in 1090 MHz Interference Relative to DO-185B			24%	68%	66%	71%	88%	83%	83%	89%
% Reduction in 1090 MHz Interference Relative to DO-300			NA	62%	59%	66%	86%	79%	80%	87%

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