Performance objectives and functional requirements for the use of improved hybrid surveillance in European environment

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Abstract

Effective use of the 1090 MHz frequency is one of the key challenges for future ATM. In European environment, Mode S replies triggered by TCAS interrogations represent currently about half of all Mode S transmissions on this channel and several methods (hybrid surveillance, interference limiting algorithms) to optimize this type of communication were already introduced in the past. Further space for improvements was identified recently, in particular, in the context of widespread deployment of ADS-B ensured through planned ADS-B Out mandate. It is expected that the considered TCAS II changes could reduce TCAS interrogations on the 1090 MHZ frequency by up to 80%, and the related MOPS is currently under development in the EUROCAE WG75/RTCA SC147 (to be published as RTCA DO-300A update). This SESAR 9.47 deliverable provides description of the proposed TCAS enhancements in terms of functional requirements and will be used as a baseline for development and validation of these advanced TCAS capabilities in SESAR.

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Executive summary

Effective use of the 1090 MHz frequency is one of the key challenges for future ATM where the communication on this channel (currently used mostly by Mode A/C and Mode S SSR and TCAS) will be further increased through extensive use of ADS-B. TCAS interrogations represent currently about half of all transmissions on this channel and several methods (hybrid surveillance, interference limiting algorithms) how to optimize this type of communication were already introduced in the past. Since that further space for improvements was identified, in particular, in the context of future availability of ADS-B reports from surrounding traffic (ensured through planned ADS-B Out mandate) and the related MOPS is currently under development in the EUROCAE WG75/RTCA SC147 (to be published as RTCA DO-300A update). It is expected that the proposed TCAS II changes could reduce TCAS interrogations by up to 80% (based on simulations using the US data).

The key proposed TCAS enhancement is a capability to track a target (which does not represent a threat from TCAS perspective) using the position information provided in its ADS-B reports rather than by requesting and tracking its transponder replies. Although this approach allows to reduce or even to eliminate active TCAS interrogations, it also introduces a new potential failure mode due to reliance of own system on the position information provided by the intruder's avionics. This requires understanding of potential operational impacts and a definition of the adequate mitigation means. For hybrid surveillance (RTCA DO-300), this aspect is handled through cross-check of ADS-B based (passive) tracking values with intruder's location determined using active interrogations with reduced frequency. Newly proposed extended hybrid surveillance (RTCA DO-300A draft) will allow eliminate active interrogations for targets qualified according the accuracy and integrity parameters included in their ADS-B reports (version 2) and by monitoring Mode-S squitter signal strength as an additional mitigation mean independent of ADS-B content.

This document provides description of the proposed TCAS enhancements in terms of functional requirements and it will be used as a baseline for development and validation of these advanced TCAS II capabilities in the SESAR 9.47 project. In addition, an analysis of potential operational impacts of wrong ADS-B data on TCAS performance is analyzed through encounter-based methodology.

1 Purpose of This Document

This document describes TCAS II changes (considering version 7.1 as a baseline) proposed in the current draft of RTCA DO-300A (Minimum Operational Performance Standards (MOPS) for Traffic Alert and Collision Avoidance System II (TCAS II) Hybrid Surveillance). The aim is not to duplicate this document but to provide a functional analysis of the proposed capabilities in the way (and level of detail) suitable for understanding the behaviour of such new system in different types of environment. The document will be primary used as a basis for planning of the validation activities targeting the European environment and, together with MOPS, as a reference for testing system development. As the DO-300A MOPS is not frozen at the moment of this document delivery, an update may be required in the future to reflect its final version (which will be also used as a basis for system development planned in SESAR 9.47).

The surveillance modifications covered within this document are voluntarily limited to DO-300A and do not cover surveillance modifications independently proposed to RTCA DO-185B (see Section 4.5 for more information).

1.1 Structure of the document

This document is organized in the following way:

- Conceptual description of hybrid surveillance capabilities is provided in Chapter 2.
- Functional requirements for hybrid surveillance are defined in Chapter 3
- European operational context and associated needs are described in Chapter 4.
- Finally, Appendix A contains the results of supporting operational study investigating potential impact of the new operational hazard associated with purely passive surveillance.

1.2 Glossary of terms

Active tracking – surveillance method where the tracking data about a target are obtained through interrogation of its transponder and subsequent analysis of transmission characteristics (delay, incoming direction) of its reply.

Passive tracking – surveillance method where the tracking data about a target are obtained using position from its ADS-B reports together with own position provided by onboard navigation.

Active surveillance – a type of surveillance including active tracking.

Extended hybrid surveillance - a type of surveillance including passive tracking of target based on ADS-B and own position data when target's ADS-B data and own position data are of sufficient quality. This assessment is based on data quality indicators provided together with target's/own position information.

Hybrid surveillance – a type of surveillance including passive tracking of target based on ADS-B and own position data when the quality of tracking parameters is controlled through regular cross-check with data obtained via active surveillance method.

Qualified position data – position data are considered qualified (for extended hybrid surveillance) when their data quality indicators meet the applicable performance requirements.

Tracking data/parameters – this term is used within this document to represent the basic output of the TCAS Surveillance function concerning a given target: its slant range, bearing and altitude.

Validated tracking data/parameters – tracking data are considered validated (for hybrid surveillance) when the differences between values obtained via passive and active surveillance do not exceed predefined thresholds.

1.3 Acronyms and Terminology

Term	Definition
A/C	Aircraft
ACAS	Airborne Collision Avoidance System
ADD	Architecture Definition Document
ADS-B	Automatic Dependent Surveillance - Broadcast
ALIM	Altitude Limit
ATCRBS	Air Traffic Control Radar Beacon System
ATM	Air Traffic Management
CAS	Collision Avoidance System
CPA	Closest Point of Approach
DF	Downlink Format (Mode S)
DOD	Detailed Operational Description
E-ATMS	European Air Traffic Management System
EHS	Enhanced Surveillance (Mode S)
ELS	Elementary Surveillance (Mode S)
FL	Flight Level
HMD	Horizontal Miss Distance
ICAO	International Civil Aviation Organisation
IRS	Interface Requirements Specification
INTEROP	Interoperability Requirements
MOPS	Minimum Operational Performance Standard
MTL	Minimum Trigger Level
MTOM	Maximum Take-Off Mass
NACp	Navigation Accuracy Category for Position
NIC	Navigation Integrity Category
NM	Nautical Mile

Term	Definition
NUCp	Navigation Uncertainty Category for Position
OSED	Operational Service and Environment Definition
RF	Radio Frequency
RL	Reply Length (Mode S)
RTCA	RTCA Inc
SDA	System Design Assurance
SESAR	Single European Sky ATM Research Programme
SESAR Programme	The programme which defines the Research and Development activities and Projects for the SJU.
SIL	Source Integrity Level
SJU	SESAR Joint Undertaking (Agency of the European Commission)
SJU Work Programme	The programme which addresses all activities of the SESAR Joint Undertaking Agency.
SPR	Safety and Performance Requirements
SSR	Secondary Surveillance Radar
SWG	Surveillance Working Group (RTCA)
TCAS	Traffic Collision Avoidance System
TMA	Terminal Manoeuvring Area
TS	Technical Specification
TAD	Technical Architecture Description
UF	Uplink Format (Mode S)
VMD	Vertical Miss Distance

2 General Functional Block Description

As stated in RTCA DO-300: **“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 safety and effectiveness of the TCAS.”**

The original hybrid surveillance MOPS (RTCA DO-300 – published in December 2006) allows to use ADS-B position data for tracking a target provided that such passive tracking data are regularly validated against data obtained via active interrogation method. The achievable reduction of 1090 MHz interference with such capability (based on the simulations performed within RTCA SC147 working group) seems to be about 17% with respect to the pure TCAS II version 7.1. This document is based on the planned DO-300A MOPS (currently under development, DO-300A Draft 0.5a used) which goes beyond DO-300 by proposing (in addition to some changes to the DO-300 hybrid surveillance tracking) an extended hybrid surveillance method allowing purely passive tracking (without any active interrogation) for targets which meets a set of predefined criteria. Performed simulations (using the US data) suggest that the potential reduction of 1090 MHz interference with such approach can be up to 80% with respect to the 7.1 TCAS II system[1].

As it is difficult to separate functional definition for the two hybrid surveillance methods, this document does not describe only delta between DO-300 and DO-300A capabilities but aims to provide a consistent functional description of both hybrid and extended hybrid surveillance.

2.1 TCAS Functional Decomposition

[1] FAA TCAS Surveillance update presentation to EUROCAE WG75 4/5 September 2012.

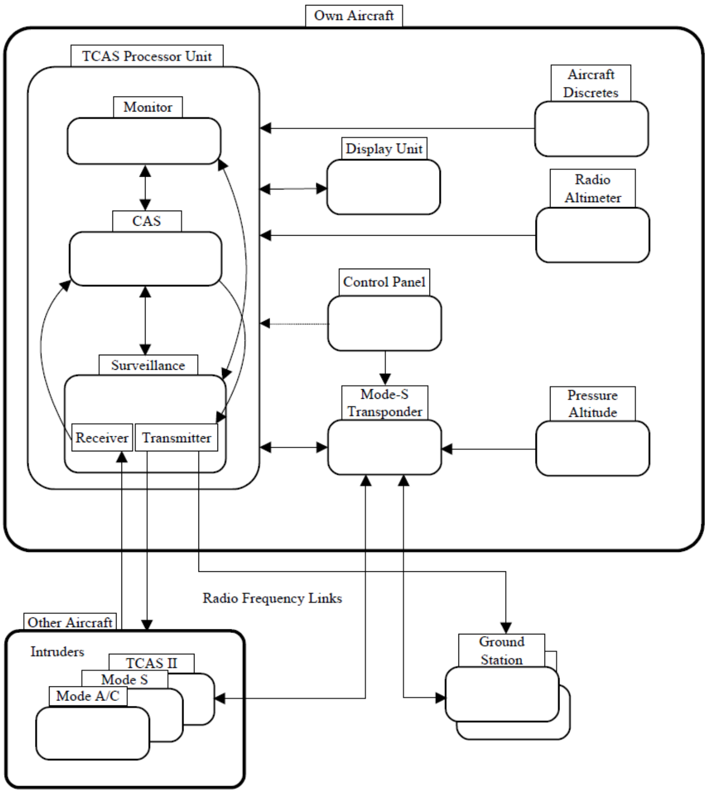

Figure 1: TCAS functional overview (adopted from DO-185B).

Figure 1 (from RTCA DO-185B) shows the TCAS functional components as well as the ancillary functional components of own and target aircraft. Surveillance function on this diagram provides the input to Collision Avoidance System (CAS). This input includes slant range, target's altitude and bearing for each tracked target and we refer to this set of information as to tracking data/parameters in the following. On the other hand, CAS generates, among others, the requests for active interrogation. Unfortunately, the granularity of this system block diagram is not sufficient for description of different types of surveillance considered in this document. As the purpose of this document is to focus only on the surveillance and interrogation management, a more detailed functional decomposition of these specific capabilities is proposed in the following.

2.2 Hybrid Surveillance Functional Decomposition

The functional decomposition proposed to facilitate the discussion of hybrid and extended hybrid surveillance requirements is shown in Figure 2. It includes the following set of basic functions:

Tracking Function

The primary aim of this function is to generate the input to CAS, in particular: slant range, target's altitude and bearing, whether using the active interrogation/reply method or using ADS-B and own position data.

Data Quality Monitoring Function

The primary aim of this function is to monitor and check whether data used for passive tracking meets applicability criteria for passive surveillance.

Surveillance Management Function

The primary aim of this function is to manage transitions between different types of surveillance.

Interrogation Management Function

The aim of this function is to request active interrogations according the needs of the actually used type of surveillance.

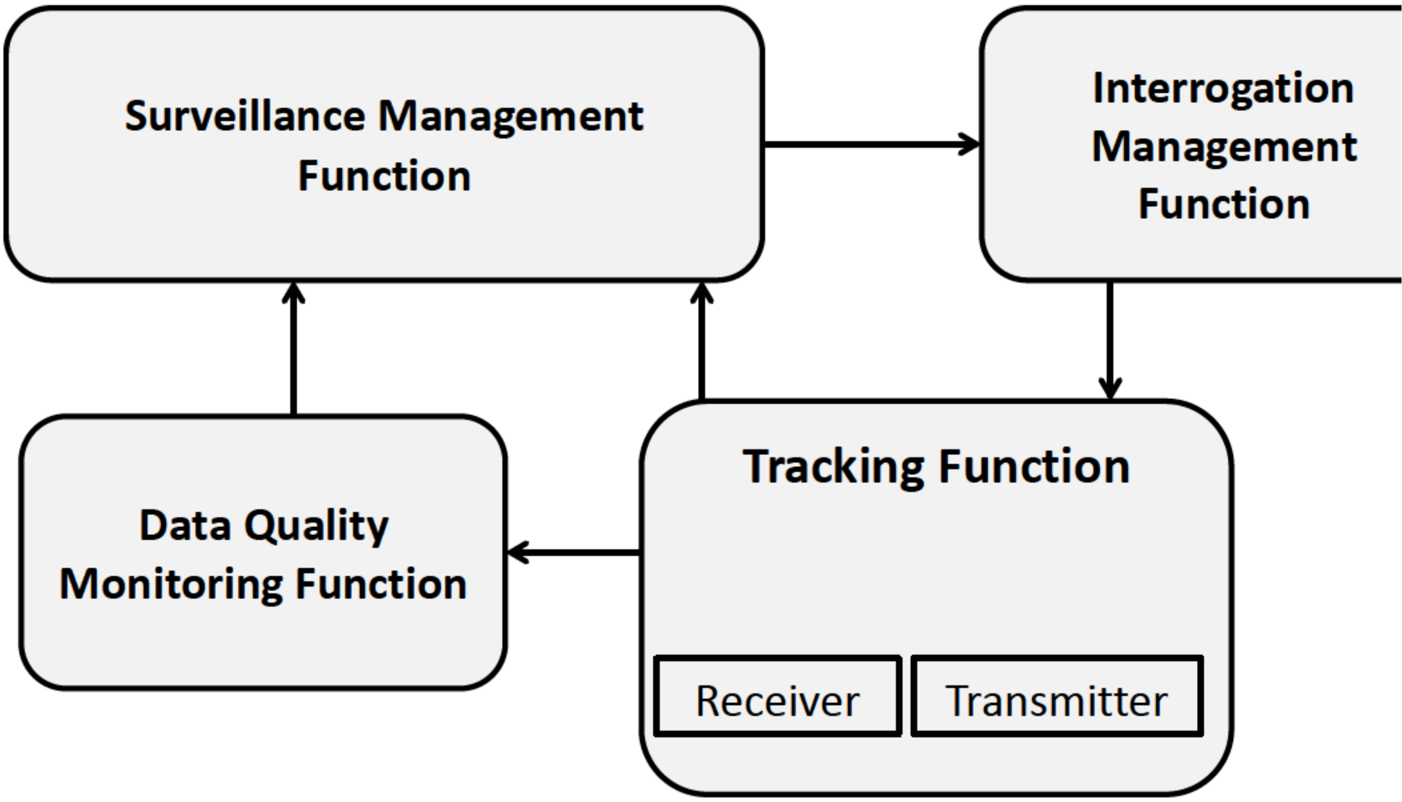

Figure 2: Functional decomposition used for hybrid surveillance description.

2.3 Functional Analysis

The primary purpose of the TCAS Surveillance function is to continuously provide the Collision Avoidance System with the position information about surrounding traffic (targets): slant range, bearing and target's altitude, the remaining parameters needed for collision avoidance logic (such as slant range rate, vertical rate) being determined from time evolution of these basic tracking parameters. This approach is the same for all surveillance methods discussed in this document and therefore the subsequent processing of the tracking parameters is not discussed here.

The basic TCAS method to obtain this data is through active interrogation of the target's transponder and determining the slant range and bearing from transmission characteristics of the replies (reply's delay, incoming direction), only altitude being reported directly by target's system (information being encoded in the transponder's reply). Target's transponder is interrogated every second in normal surveillance mode or every 5 seconds in reduced surveillance mode (when the target is not interpreted like a potential threat) which represents a considerable communication load for 1090 MHz frequency. This surveillance method is referred as active surveillance in the following.

Passive tracking introduced in DO-300 represents an alternative method how to obtain data for CAS using the position information reported by target's system in its ADS-B messages together with own position information obtained from onboard navigation. However as this information is **reported**, i.e., it is not directly determined/measured by own system, it is important to carefully assess quality and reliability of such reported information. The DO-300A MOPS defines two possible approaches to this assessment (referred as hybrid surveillance and extended hybrid surveillance, respectively) as well as the logic for transitions between different tracking modes and data assessment methods when applicability conditions change. As stated above, the aim of these alternative surveillance methods is to reduce or completely eliminate the need for active interrogations when it does not degrade the safety and effectiveness of the TCAS. In this context, passive tracking is used only outside the surveillance area where any kind of TCAS alerting (TA/RA) may be expected, boundary of this area being defined using so-called hybrid threat conditions in the DO-300A MOPS.

When the system is operating using the hybrid surveillance, passive tracking data are regularly validated through comparison with tracking data obtained through conventional active interrogation. Therefore this method still requires active interrogations, but the frequency of these interrogations is considerably reduced (once per 60s in the most of cases, this frequency being increased up to once per 10s in some "limiting" conditions). This method is allowed for any version of ADS-B Out transponders and it was introduced already in DO-300 MOPS (some changes being proposed in DO-300A).

Extended hybrid surveillance introduced in DO-300A eliminates completely active interrogations (again only when hybrid threat conditions are not satisfied), and uses data quality indicators provided together with own and ADS-B position information to assess whether own/ADS-B data are qualified for this type of surveillance (the specific sets of accuracy and integrity requirements are defined in the MOPS for this quality check). However, as these quality indicators are also reported (not measured by own system), an additional safety check is introduced for extended hybrid surveillance based on measuring of the target's signal (ADS-B or Mode S squitter) strength and comparing it with the specific hybrid surveillance threshold (Minimum Trigger Level (MTL)). If the signal is stronger than this threshold, the cross-check validation with active interrogation (using the hybrid surveillance criteria) is required independently whether all other conditions for extended hybrid surveillance are satisfied or not. Extended hybrid surveillance is allowed only for targets with ADS-B Out version 2 or higher (due to the use of reported quality indicators).

These additional internal mitigation means address a potential failure of target's avionics resulting in wrong position (and/or data quality indicators) information provided in its ADS-B reports. From operational perspective, the worst case operational impact of such situation (driving the performance requirements for these mitigation means) is that TCAS will switch to active surveillance (and issue the potential alerts) later than expected. This operational impact can be evaluated using standard TCAS (without hybrid surveillance) operations with reduced surveillance range. This type of analysis was performed within the RTCA SC147 for the US data and in the scope of this task the simulations were done also for European environment. The associated results are provided in Appendix A of this document.

Extended hybrid surveillance can be used also during operations on the airport surface, but in this case hybrid threat conditions and signal strength checks are disabled as they are not usable for surface operations.

To summarize, TCAS with extended hybrid surveillance capability is able to track targets through three different surveillance methods as shown in Table 1, two of these methods allowing a considerable reduction of 1090 MHz load.

Table 1: Active interrogations across different surveillance methods.

	Tracking Mode	Interrogation Interval	Interrogation Use
Active Surveillance	Active	1s or 5s (reduced surveillance)	Tracking
Hybrid Surveillance	Passive	10s – 60s	ADS-B cross-check ((re)validation)
Extended Hybrid Surveillance	Passive	No interrogations	N/A

2.4 Tracking and Surveillance Switching Logic

Tracking of a target in TCAS is always started through acquisition of the track. According DO-185B/ED-143 and DO-300 the track can be acquired using squitters but must be confirmed only using the active interrogations method and therefore its tracking starts using active surveillance.

DO-300A defines an alternative method to acquire a track using passive tracking providing that predefined applicability conditions are met. As only limited information is available before acquisition of the track, these applicability conditions uses just data that can be obtained directly from received ADS-B reports without any additional processing: qualification of own and ADS-B data for extended hybrid surveillance (i.e., assessment of the quality indicators provided directly in the reports) and signal strength lower than extended hybrid threshold (this criterion is not used during surface operations).

After acquisition of the track, it is maintained using one of the three surveillance methods depending on applicability conditions which are currently satisfied. The principle is to use extended hybrid surveillance whenever the applicable conditions are met, hybrid surveillance whenever it is possible but conditions for extended hybrid surveillance are not satisfied, and active surveillance in the remaining cases. The transition between surveillance modes takes place whenever it is required due to changes in the applicability conditions (see Table 2).

Table 2: Applicability conditions for different types of surveillance.

Mode\Checks	Hybrid threat check	Own data quality check	ADS-B data quality check	Passive cross-check (re)validation	Signal strength check	Surface / Airborne (taking off)
Ext. Hybrid Surv.	F	T	T	N/A	T	Airb
Ext. Hybrid Surv.	N/A	T	T	N/A	N/A	Surf
Hybrid Surv.	F	N/A	N/A	T	N/A	Airb
Hybrid Surv.	N/A	N/A	N/A	T	N/A	Surf

The transition between different surveillance methods should not lead to drop the track except in the situations where strong discontinuity is detected between data obtained via active and new surveillance methods. Note, that it is not allowed to mix data obtained using active and passive tracking within the input of collision avoidance logic, especially when computing the slant range rate and vertical rate (different origin of data and consequently different biases lead typically to discontinuities in the tracks). Therefore a correlation interval shall be used during the transition between active and passive tracking. Overall scheme of the possible transitions between different surveillance methods is shown in Figure 3.

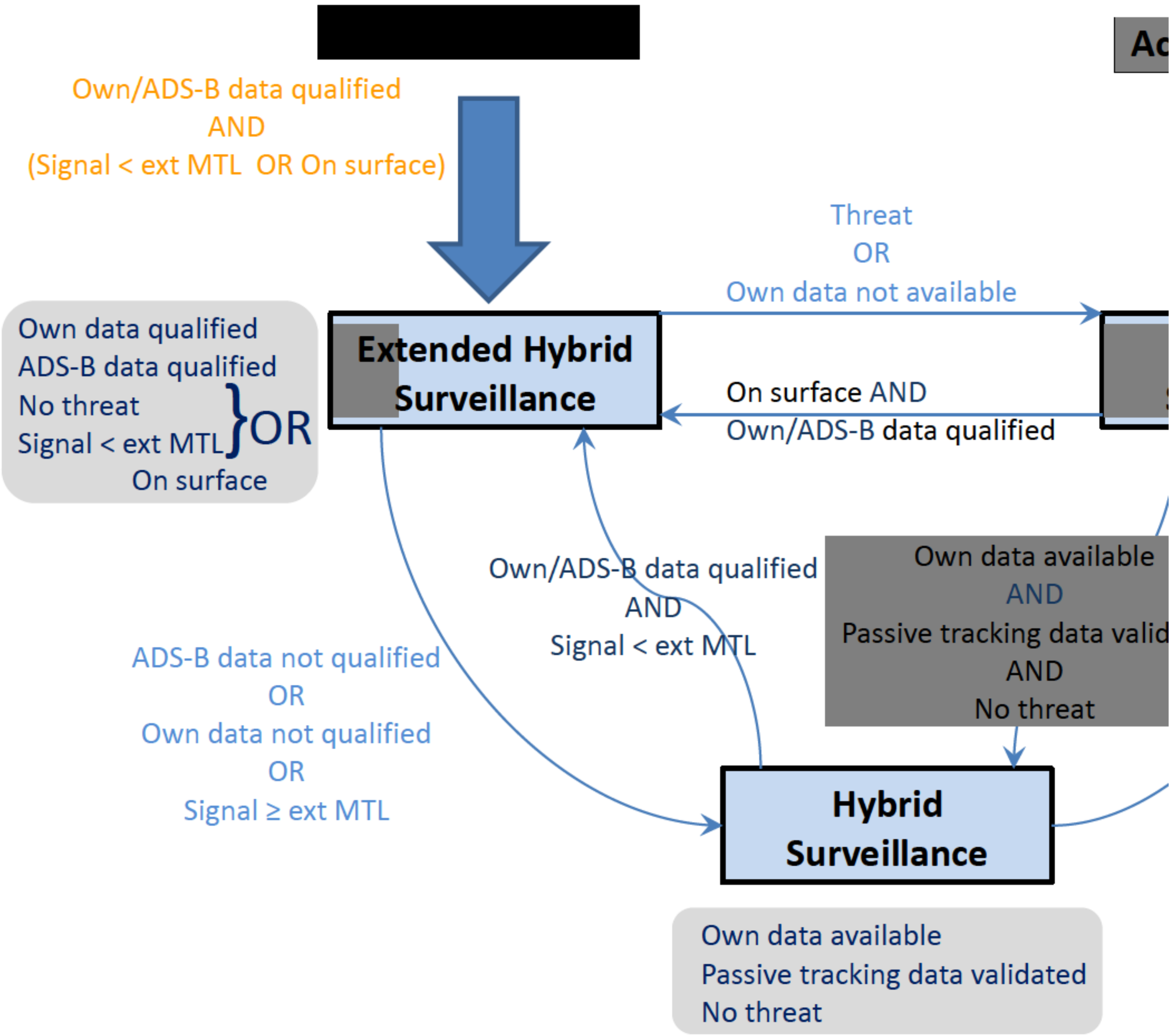

Figure 3: Overview of possible transitions between different surveillance methods. Note, that some abbreviations were introduced in the figure: Signal < ext MTL means that signal strength is lower than extended hybrid surveillance Minimum Trigger Level (MTL); Threat/No threat describes whether hybrid threat conditions are satisfied or not.

3 Functional block Functional and non-Functional Requirements

3.1 Functional Requirements

Identifier	REQ-09.47-TS-0001.001
Requirement	TCAS with extended hybrid surveillance capability shall meet all the minimum performance requirements of TCAS II 7.1 (DO-185B §2.2) except the requirements which are specifically modified in this chapter.
Title	Compatibility with TCAS II 7.1
Status	
Rationale	
Category	
Validation Method	
Verification Method	

3.1.1 Tracking Function

Identifier	REQ-09.47-TS-0001.002
Requirement	Surveillance function of the TCAS with extended hybrid surveillance capability shall be able to provide the input to CAS (namely slant range, target's altitude and bearing) through two different methods: • Active tracking (according the DO-185B/ED-143 requirements) where the range and bearing are determined using UF=0/DF=0 Mode-S interrogation/reply process (time delay and incoming direction of the reply being used to identify the slant range and bearing, respectively). • Passive tracking where the range and bearing are determined using own and target's (ADS-B) reported positions.
Title	Required tracking methods
Status	
Rationale	
Category	
Validation Method	
Verification Method	

Identifier	REQ-09.47-TS-0001.003
Requirement	TCAS with extended hybrid surveillance capability shall use the barometric altitude obtained in ADS-B report (Mode S DF=17) for the same purposes as altitude data from DF=0 or DF=4 Mode S replies.
Title	Barometric altitude use
Status	
Rationale	
Category	
Validation Method	
Verification Method	

Identifier	REQ-09.47-TS-0001.004
Requirement	Passive tracking shall be used only when both own and target's ADS-B data are qualified for extended hybrid surveillance or tracking parameters obtained from this data are validated against parameters obtained using active interrogation method (data for the same time of applicability shall be used).
Title	Passive tracking prerequisites
Status	
Rationale	Passive tracking shall be used only when input data quality is evaluated as sufficient for it.
Category	
Validation Method	
Verification Method	

Identifier	REQ-09.47-TS-0001.005
Requirement	Own and ADS-B data shall be considered as qualified for passive tracking when they meet performance requirements for extended hybrid surveillance.
Title	Data qualification
Status	
Rationale	This requirement links the functional and performance requirements.
Category	
Validation Method	
Verification Method	

Identifier	REQ-09.47-TS-0001.006
Requirement	The range input to the CAS shall be always determined using the same type of tracking (active or passive). The mixing of the two methods is not allowed in this context (this includes the determination of the time derivation of the slant range).
Title	No active and passive tracking mixing
Status	
Rationale	Due to different origins of data used for passive and active tracking, there are different biases and a potential mixing of two types of parameters may result in discontinuities in the tracking parameters.
Category	
Validation Method	
Verification Method	

3.1.2 Data Monitoring Function

Identifier	REQ-09.47-TS-0001.007
Requirement	TCAS with extended hybrid surveillance capability shall each surveillance update cycle monitor whether the own position information is qualified for extended hybrid surveillance.
Title	Own data quality monitoring
Status	
Rationale	Monitoring is key for selection of suitable surveillance method.
Category	
Validation Method	
Verification Method	

Identifier	REQ-09.47-TS-0001.008
Requirement	TCAS with extended hybrid surveillance capability shall each surveillance update cycle monitor whether the target's ADS-B data are qualified for extended hybrid surveillance.
Title	ADS-B data quality monitoring
Status	
Rationale	Monitoring is key for selection of suitable surveillance method.
Category	
Validation Method	
Verification Method	

Identifier	REQ-09.47-TS-0001.009
Requirement	TCAS with extended hybrid surveillance capability shall at least once every surveillance update cycle, if available, monitor whether the signal strength of the intruder's squitter (either DF=11 or DF=17) is below the extended hybrid surveillance MTL using the maximum signal strength of the squitters received since the last check.
Title	Monitoring the signal strength of the intruder's squitter
Status	
Rationale	Monitoring is key for selection of suitable surveillance method.
Category	
Validation Method	
Verification Method	

Identifier	REQ-09.47-TS-0001.010
Requirement	TCAS with extended hybrid surveillance capability shall continuously monitor whether own aircraft is airborne/taking off or operating on the surface.
Title	Monitoring own aircraft airborne/taking off status
Status	
Rationale	Monitoring is key for selection of suitable surveillance method as the applicability conditions varies depending on surface/airborne status of own aircraft.
Category	
Validation Method	
Verification Method	

Identifier	REQ-09.47-TS-0001.011
Requirement	Own aircraft 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 (≥35 knots) • TCAS Air/Ground (OOGROUN) indicates in air
Title	Own ship taking off/airborne criteria
Status	
Rationale	Detailed criteria for system identification of airborne/taking off status of own aircraft.
Category	

Validation Method	
Verification Method	

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

Identifier	REQ-09.47-TS-0001.012
Requirement	Own aircraft **shall** be considered to be operating on the surface when both these conditions are true: • Ground speed input is valid AND is < 25 knots • TCAS Air/Ground (OOGROUN) indicates on-ground
Title	Own ship operating on surface condition
Status	
Rationale	Detailed criteria for system identification of surface status of own aircraft.
Category	
Validation Method	
Verification Method	

3.1.3 Tracking Management

Identifier	REQ-09.47-TS-0001.013
Requirement	TCAS with extended hybrid surveillance capability shall allow the acquisition of valid (according DO-185B §2.2.4.6.2.2.1) Mode S targets using one of the two methods: • When both own and target's data are qualified for extended hybrid surveillance, and either the target's signal strength is below the extended hybrid surveillance MTL or the ownship is operating on the surface, the track shall be acquired using ADS-B reports (without active interrogations) and passive tracking. • In all remaining cases, standard TCAS targets acquisition using active interrogations (and active tracking) as specified in RTCA DO-185B §2.2.4.6.2.2.2 shall be used.
Title	Acquisition of Mode S target
Status	
Rationale	This requirement introduces the passive acquisition option.
Category	
Validation Method	
Verification Method	

Identifier	REQ-09.47-TS-0001.014
Requirement	TCAS with extended hybrid surveillance capability shall maintain the established tracks using one of the three surveillance methods: • Active surveillance (active interrogations used for tracking); • Hybrid surveillance (active interrogations used for (re)validation of passive tracking only); • Extended hybrid surveillance (passive tracking without active interrogations).
Title	Maintaining established tracks

Status	
Rationale	
Category	
Validation Method	
Verification Method	

Identifier	REQ-09.47-TS-0001.015
Requirement	When all conditions for extended hybrid surveillance are fulfilled the extended hybrid surveillance shall be used. When these conditions are not fulfilled but the conditions for hybrid surveillance are fulfilled the hybrid surveillance shall be used. When conditions for either extended hybrid surveillance or hybrid surveillance are not fulfilled the active surveillance shall be used.
Title	Priorities of surveillance methods
Status	
Rationale	This requirement ensures that always the method with most effective communication is used (when the applicable conditions are met).
Category	
Validation Method	
Verification Method	

Identifier	REQ-09.47-TS-0001.016
Requirement	TCAS with extended hybrid surveillance capability shall continuously (each surveillance update cycle) monitor whether the hybrid threat conditions are satisfied for the tracked targets.
Title	Monitoring the hybrid threat conditions
Status	
Rationale	This check is required to ensure timely transition to active surveillance.
Category	
Validation Method	
Verification Method	

Definition of hybrid threat conditions:

To avoid possible oscillations between active and passive tracking, the two sets of hybrid threat conditions are defined (depending whether the system is in active or passive tracking mode) in order to create a hysteresis between the two transition directions. For simplicity, we refer in the document only to hybrid threat conditions having in mind that based on the context, modified hybrid threat conditions may be applicable.

The hybrid threat conditions are defined as follows:

- When passive tracking is currently used (hybrid threat conditions):

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

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

- When active tracking is currently used (modified hybrid threat conditions):

$$-(s - 4900\text{ ft})/\min(-1\text{ft/sec}, \dot{s}) < 65\text{ sec}$$

$$-(r - 3.2\text{NM})/\min(-6\text{kt}/3600, \dot{r}) < 65\text{ sec}$$

In the above:

$$s = |\text{own altitude} - \text{track altitude}| = \text{altitude separation, in ft}$$
$$\dot{s} = (\text{own altitude rate} - \text{track altitude rate})\,\text{sign}(\text{own altitude} - \text{track altitude});$$
$$= \text{rate of change of } s\text{, in ft/s, with negative values indicating decreasing separation;}$$
$$r = \text{track slant range, in NM;}$$
$$\dot{r} = \text{rate of change of } r \text{ in NM/s, with negative values indicating decreasing range;}$$
$$\text{sign}(x) = 1 \text{ if } x \ge 0; -1 \text{ if } x < 0.$$

Identifier	REQ-09.47-TS-0001.017
Requirement	Active surveillance (and active tracking) shall be used when both hybrid threat conditions are true.
Title	Active surveillance for threats
Status	
Rationale	
Category	
Validation Method	
Verification Method	

Note: When the data for range rate computation are not available (it may happen just after the transition between active and passive tracking but it may not exceed 5 surveillance update cycles) the second condition shall be considered as false.

Identifier	REQ-09.47-TS-0001.018
Requirement	Hybrid surveillance (with passive tracking) shall be used for maintaining the track when: • At least one hybrid threat condition is not true (this criterion is not used for surface operations); • Own position information is available and valid; • Passive tracking parameters are validated against data obtained from active interrogation according the applicable performance requirements. • Conditions for extended hybrid surveillance are not satisfied.
Title	Hybrid surveillance applicability conditions
Status	
Rationale	
Category	
Validation Method	

Verification Method	

Identifier	REQ-09.47-TS-0001.019
Requirement	Extended hybrid surveillance (with passive tracking) shall be used for maintaining the track when: • At least one hybrid threat condition is not true (this criterion is not used for surface operations); • Own position information is qualified • Target's ADS-B position is qualified • Target's signal strength (squitter or extended squitter) is lower than extended hybrid surveillance Minimum Trigger Level (MTL). When own aircraft is operating on surface, the hybrid threat conditions and signal strength criteria are not applicable (they are ignored).
Title	Hybrid surveillance applicability conditions
Status	
Rationale	
Category	
Validation Method	
Verification Method	

Identifier	REQ-09.47-TS-0001.020
Requirement	Maintaining the track using active surveillance shall be performed according the current TCAS II 7.1 specifications (DO-185B §2.2.4.6.2.2.3).
Title	Maintaining a track using active surveillance
Status	
Rationale	No changes with respect to TCAS II 7.1.
Category	
Validation Method	
Verification Method	

Identifier	REQ-09.47-TS-0001.021
Requirement	Maintaining the track using hybrid or extended hybrid surveillance shall meet the TCAS II requirements for maintaining of established track (DO-185B §2.2.4.6.2.2.3).
Title	Maintaining a track using active surveillance
Status	
Rationale	No changes with respect to TCAS II 7.1 tracking requirements when using passive tracking.
Category	
Validation Method	
Verification Method	

Identifier	REQ-09.47-TS-0001.022

Requirement	Direct transition from active surveillance to extended hybrid surveillance is allowed only for surface operations. In all other cases, the validation (hybrid surveillance) of the passive tracking data shall be performed first.
Title	Active to extended hybrid surveillance transition
Status	
Rationale	Additional mitigation mean profiting from the fact that needed data are already available in this situation.
Category	
Validation Method	
Verification Method	

Identifier	REQ-09.47-TS-0001.023
Requirement	TCAS with extended hybrid surveillance capability shall not switch between the active and passive tracking mode until there is enough data to determine all inputs for collision avoidance logic using the new tracking mode means (in particular, slant range rate and vertical rate which are derived from slant range and altitude evolution in time, respectively).
Title	Active and passive tracking switching
Status	
Rationale	Due to different origins of data used for passive and active tracking, there are different biases and a potential mixing of two types of parameters may result in discontinuities in the tracking parameters.
Category	
Validation Method	
Verification Method	

3.1.4 Interrogation Management

Identifier	REQ-09.47-TS-0001.024
Requirement	When TCAS with extended hybrid surveillance capability is tracking a target using extended hybrid surveillance, it shall not interrogate this target.
Title	Not interrogations in extended hybrid surveillance
Status	
Rationale	
Category	
Validation Method	
Verification Method	

Identifier	REQ-09.47-TS-0001.025
Requirement	When TCAS with extended hybrid surveillance capability is tracking a target using hybrid surveillance it shall interrogate the target using UF=0, RL=0 in order to validate its passive tracking data.
Title	Interrogations form for hybrid surveillance
Status	
Rationale	This is the change with respect to DO-300 where the long form of reply (112 bits) was used. RL=0 ensures that only short form of messages (56 bits) will be used. This brings additional 1090Mhz load reduction.
Category	

Validation Method	
Verification Method	

Identifier	REQ-09.47-TS-0001.026
Requirement	When TCAS with extended hybrid surveillance capability is tracking a target using hybrid surveillance, the frequency of the validations shall meet the performance requirements for hybrid surveillance.
Title	Interrogations form for hybrid surveillance
Status	
Rationale	Link between functional and performance requirement.
Category	
Validation Method	
Verification Method	

Identifier	REQ-09.47-TS-0001.027
Requirement	When TCAS with extended hybrid surveillance capability is tracking a target using hybrid surveillance, active interrogations shall be transmitted and the replies shall be used to revalidate the tracking parameters obtained via passive tracking.
Title	Validation requests
Status	
Rationale	Revalidation for hybrid surveillance
Category	
Validation Method	
Verification Method	

Identifier	REQ-09.47-TS-0001.028
Requirement	When TCAS with extended hybrid surveillance capability is tracking a target using hybrid surveillance, and a valid reply to active interrogation is not received during the current TCAS Processing Cycle then attempts to elicit a valid reply shall be performed during subsequent TCAS Processing Cycles.
Title	Validation requests
Status	
Rationale	Missing reply to revalidation request (hybrid surveillance)
Category	
Validation Method	
Verification Method	

Identifier	REQ-09.47-TS-0001.029
Requirement	When TCAS with extended hybrid surveillance capability is tracking a target using hybrid surveillance, and a valid reply to active interrogation is not received during the current TCAS Processing Cycle then the revalidation interrogations shall count as tracking interrogations with respect to the interrogation limits in DO-185B §2.2.4.6.2.2.3 and those interrogation limits shall be observed.
Title	Validation requests
Status	
Rationale	Applicability of the TCAS II interrogation limiting algorithms.
Category	

Validation Method	
Verification Method	

Identifier	REQ-09.47-TS-0001.030
Requirement	When TCAS with extended hybrid surveillance capability is tracking a target using active surveillance, the interrogations shall meet all standard TCAS II requirements as specified in DO-185B §2.2.4.6.2.2.3.
Title	Interrogations at active surveillance
Status	
Rationale	Compatibility with TCAS II 7.1.
Category	
Validation Method	
Verification Method	

3.2 Interface Requirements

Identifier	REQ-09.47-TS-0001.031
Requirement	Own position (latitude and longitude) information shall be available to TCAS with extended hybrid surveillance capability.
Title	Own position information availability
Status	
Rationale	This information is necessary for passive tracking.
Category	
Validation Method	
Verification Method	

Identifier	REQ-09.47-TS-0001.032
Requirement	Own position accuracy and integrity indicators shall be available to TCAS with extended hybrid surveillance capability.
Title	Own position accuracy and integrity indicators availability
Status	
Rationale	This information is necessary for assessment whether extended hybrid surveillance can be used.
Category	
Validation Method	
Verification Method	

Identifier	REQ-09.47-TS-0001.033
Requirement	Own ground speed information shall be available to TCAS with extended hybrid surveillance capability.
Title	Own ground speed information availability
Status	
Rationale	This information is needed for detecting airborne/taking off vs. Surface

	operations status.
Category	
Validation Method	
Verification Method	

Identifier	REQ-09.47-TS-0001.034
Requirement	Own ground speed information used by TCAS with extended hybrid surveillance capability shall remain valid even when own aircraft is stationary.
Title	Own ground speed validity when own aircraft stationary
Status	
Rationale	This requirement aims to avoid potential issues with the use of GNSS velocities which becomes invalid when stationary or slowly moving (surface operations).
Category	
Validation Method	
Verification Method	

3.3 Performance Requirements

Identifier	REQ-09.47-TS-0001.035
Requirement	In order to be qualified for extended hybrid surveillance, the targets ADS-B reports shall meet the following performance requirements: The barometric altitude is valid. The reported ADS-B Version Number ≥ 2 The reported NIC ≥ 6 (<0.6 NM) The reported NACp ≥ 7 (<0.1 NM) The reported SIL = 3 The reported SDA = 2 or 3
Title	ADS-B data quality requirements
Status	
Rationale	
Category	
Validation Method	
Verification Method	

In order to allow validation of the system in current European environment where most of the targets are still equipped with version 0 or 1 of ADS-B Out, this requirement should be relaxed for experimental design (only for SESAR validation purposes!). In this context the targets with the reported ADS-B Version Number lower than 2 could be considered as qualified when they meet the following requirements:

- *For intruders with the ADS-B Version Number = 1 shall be:*

  The reported NIC ≥ 6 (<0.6 NM)

  The reported NACp ≥ 7 (<0.1 NM)

  The reported SIL = 3

- *For intruders with the ADS-B Version Number = 0, shall be:*

  The reported NUCp ≥ 6

Based on the Table 2-200 in RTCA DO-260B this value corresponds to NIC ≥ 6 (<0.6 NM),NACp ≥ 7 (<0.1 NM), and SIL = 2.

Identifier	REQ-09.47-TS-0001.036
Requirement	In order to be qualified for passive tracking own aircraft position shall meet the following data quality requirements: • Own horizontal position uncertainty (95%) is < 0.1 NM • Own horizontal position integrity bounds is <0.6 NM with an integrity level of 1e-7.
Title	Own position data quality requirements
Status	
Rationale	
Category	
Validation Method	
Verification Method	

Identifier	REQ-09.47-TS-0001.037
Requirement	The track shall be acquired using ADS-B reports only if all the following requirements are met: • Two ADS-B reports have been received within 5 surveillance update intervals. • The altitudes in the two ADS-B reports 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. • Altitude encoding (25/100ft increments) is the same in both ADS-B reports (Q-bit value). • The ICAO aircraft address is the same in both ADS-B reports and is valid (not all zeros or ones). In other cases the track shall be acquired using active tracking.
Title	Acquiring track using ADS-B reports
Status	
Rationale	
Category	
Validation Method	
Verification Method	

Identifier	REQ-09.47-TS-0001.038
Requirement	In order to be validated for hybrid surveillance, the passive tracking data shall meet all the following requirements when cross-checked with active interrogation/reply parameters. • The observed difference in slant range shall be less than 290 meters (340 meters for revalidation); • The bearing (when available) difference shall be less than 45 degrees; • The altitude difference shall be less than 100 feet.
Title	Performance requirements for hybrid surveillance validation

Status	
Rationale	
Category	
Validation Method	
Verification Method	

Note: 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.

Identifier	REQ-09.47-TS-0001.039
Requirement	The frequency of revalidation for target under hybrid surveillance shall be between 10 and 60 seconds according following rules: 1) If the track does not satisfy the hybrid threat altitude condition, it shall be revalidated every 60 seconds.; 2) If the track fulfil the hybrid threat altitude condition but not the hybrid threat range condition, the revalidation interval *t* shall be calculated: o if range rate is higher than +300 kt, the revalidation interval shall be set to 60 seconds o else the revalidation interval is determined from the equation bellow: $t = \max\left(10, \min\left(60, \mathrm{trunc}\left(\frac{-(v_0 + at_{thr}) - \sqrt{(v_0 + at_{thr})^2 - 2a(r_0 + v_0 t_{thr} - s_{mod})}}{a}\right)\right)\right),$ where 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. *a* is the assumed range acceleration of -11 ft/s2; 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.
Title	Revalidation interval for hybrid surveillance
Status	
Rationale	
Category	
Validation Method	
Verification Method	

Note: There are no active interrogations to the target which is tracked using Extended Hybrid Surveillance.

Identifier	REQ-09.47-TS-0001.040
Requirement	The maximum delay from the time when the conditions requiring the transition from passive to active tracking and the time when surveillance function starts to

	provide inputs to CAS based on active tracking shall not be more than 3 surveillance update intervals.
Title	Maximum delay for transition from passive to active tracking
Status	
Rationale	
Category	
Validation Method	
Verification Method	

Identifier	REQ-09.47-TS-0001.041
Requirement	The extended hybrid surveillance MTL shall be set to -68±2dBm.
Title	Extended hybrid surveillance MTL
Status	
Rationale	This value is based on the analysis of real flight data. This threshold shall be at least as high as standard TCAS interference limiting MTL in order to avoid unwanted drop of a target. At the same time it shall ensure timely switching to active surveillance in case of incorrect ADS-B data to do not infringe TCAS performance (see Appendix A for study of the potential operational impact of such situation).
Category	
Validation Method	
Verification Method	

3.4 Safety Requirements

Identifier	REQ-09.47-TS-0001.042
Requirement	When the target is tracked using extended hybrid surveillance and the signal strength of its squitter (DF=11) or ADS-B (DF=17) reports becomes higher than extended hybrid surveillance MTL, the validation of the passive tracking data through cross-check with active interrogation reply is required.
Title	Signal strength test
Status	
Rationale	This is an important new mitigation mean independent of the position and data quality information provided by target. If the reported data are erroneous, the aim of this check is to ensure timely switch to active surveillance when the target approaches.
Category	
Validation Method	
Verification Method	

Identifier	REQ-09.47-TS-0001.043
Requirement	TCAS with extended hybrid surveillance shall not allow tracks under passive surveillance (hybrid or extended hybrid) to enter into the Potential Threat or Threat substates of Intruder status.
Title	Alerting only with active surveillance
Status	
Rationale	TCAS alerting shall be always based on active tracking data. Therefore, it is

	necessary to ensure switching to active surveillance prior providing alerting.
Category	
Validation Method	
Verification Method	

4 European Operational Context for Hybrid Surveillance

4.1 Introduction

This section provides justification on why Hybrid Surveillance provides a coherent approach with other European programme such as the Mode S and ADS-B programme and also provides a good technical solution to ensure coherent and long term management of the 1030/1090MHz frequency band.

The RF frequency band 1030/1090 MHz is used to support cooperative civil and military surveillance systems and Airborne Collision Avoidance System (ACAS) in Europe.

Different techniques used to support civil and military surveillance include SSR Mode A/C, SSR Mode S, Multilateration, and ADS-B.

All these activities contribute to the traffic on these frequencies Bands and sometimes reach values upper the expected standard capabilities. Although the global activity stays at an acceptable level considerations have to be put in place to optimise the different techniques to maintain a high level of performance and to cope with more traffic and new applications to be deployed to support new separation modes.

4.2 Mode S and ADS-B Programme

Since twenty years several techniques have been developed, validated and are now in place as the Mode S which is deployed in whole Europe to support Elementary Surveillance (ELS) and Enhanced Surveillance (EHS). With the selective addressing, Mode S reduced the RF traffic in comparison with the classical SSR and optimises the Mode S signal activity. In the future this optimisation could be further improved for all call protocol or the aircraft register extractions.

ADS-B will be deployed and an initial version is now already available on more than 75% of flights. The use of an ADS-B surveillance layer will allow to reduce the ground active interrogations. The ADS-B Extended Squitter transmission rate is today of 6.2 messages per second but could be increased in the future. For ADS-B only the 1090MHz frequency is concerned however this frequency is more loaded than the 1030 MHz.

TCAS is operating in this environment and is used by a large fleet of aircraft representing 97% of air transport flights. This global use of TCAS in Europe impacts directly the performance of other systems using the same RF bands.

The three complementary surveillance techniques, AC/Mode S /ADS-B, use the same frequency band and are developed in the same airborne black box (the transponder). This solution optimises the airborne and ground cost and reinforces the role of this frequency band as the first aviation surveillance frequency band. In this scope the different techniques using the Mode S formats present a certain homogeneity and coherence. This situation has to be guaranteed by a strict management of the use of the RF bands.

For cost and interoperability reason it is necessary to keep the 1090 link as the main surveillance link. The optimization of these RF frequency bands is therefore necessary to ensure the continuity of existing surveillance systems therefore avoiding the deployment of another link.

In this environment an optimisation of certain TCAS protocols is whished. The use of Hybrid surveillance is perceived as a good technical solution for the expected benefit related to the RF frequency pollution and in line with the coherence of existing surveillance European programmes.

4.3 Today TCAS activity on 1030/1090MHz in Europe

The 4 main sources of Mode S transmissions are TCAS, Mode S All Call, Roll call, Extended Squitters. The classical SSR activity is always presents but is not considered in the following description.

Based on recordings performed on aircraft and on the ground the TCAS transmissions are described in the following tables and show their importance in the FRUIT generated on 1090 MHz and in the transponder occupancy time.

1090 MHz
The statistics of TCAS activity (DF0) is mainly depending on the time of day and the high values will be found in close proximity of airport. The Table 3 resumes this situation in Paris area (LFOB station) taken in April 2012 and in March 2011 at an altitude of 30000 feet.

Table 3: Measured 1090MHz TCAS and ground surveillance transmissions.

Year	Time of day	Transmission from All aircraft		Transmission from One aircraft	
		DF0 /s	DF4/5/11 /s	DF0 /s	DF4,5,11 /s
2012	6H40	**386**	**270**	**7.58**	**16,2**
	11H00	186	230	3.56	16
	11H00	250	228	9.97	15,3
	13H26	165	217	5.32	15,6
	16H00	297	262	5.45	16
	16H00	267	252	7.58	16,6
2011	9H00	345	149	3.53	8,63
	11H00	**346**	**202**	**6.46**	**10,94**
	15H00	269	194	7.52	11,33

The number of replies per second corresponding to the radar surveillance activity is stable. The Beluga activity (Transmission from One aircraft) is about 10 in 2011 and 16 in 2012. The difference is due to new Mode S radar installed in the Paris area. The total replies issued from all aircraft reflect this stability with an average value around 230 replies/second and represents the FRUIT generated by radars. The own aircraft DF0 activity is depending of the position of this aircraft against others and is not significant.

The “All Aircraft” DF0 activity, i.e. activity generated by TCAS, is directly dependant on the number of aircraft present in this area at a given time. Depending on the time of the day the number of DF0 varies between 160/s and 386/s. With an average value of 250 DF0/s the TCAS activity is a little bit higher than the global surveillance activity (230/s). However during peak time the TCAS activity could be up to more than 40% higher than 1090 activity generated by ground surveillance system.

The TCAS activity (DF0) is the main source of Mode S FRUIT on 1090 MHz RF band in airport proximity and impacts directly the Probability of reception by radars and ADS-B receivers.

Using another recording made at another place in Europe it is possible to show on Figure 4 the TCAS proportion of Mode S transmissions (in red).

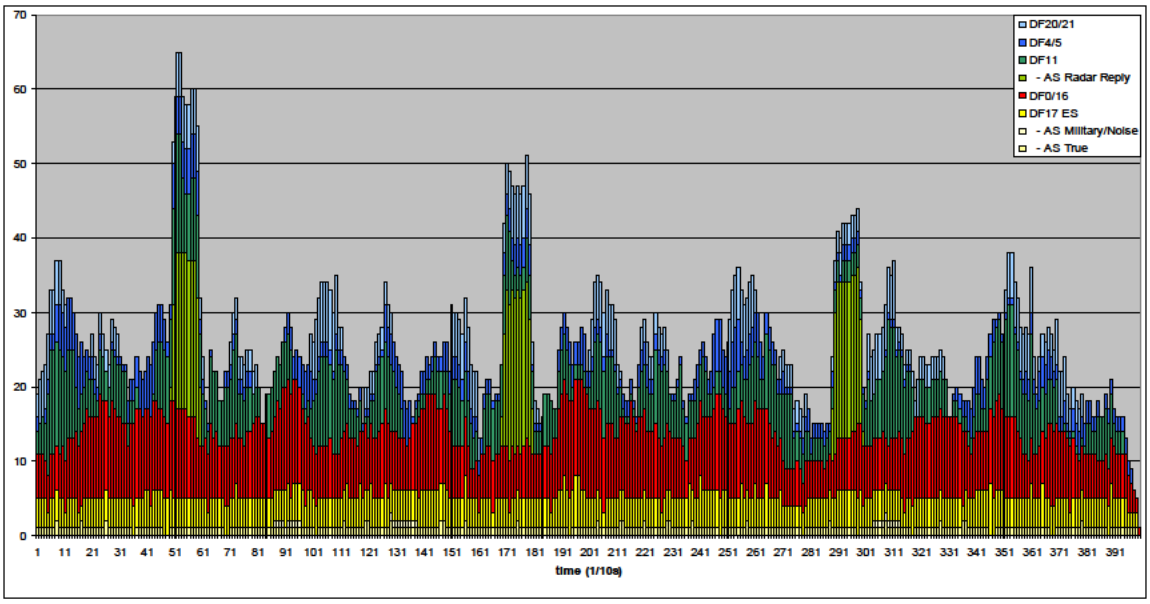

Figure 4: Real measurement of Mode S transmissions in Europe.

1030 MHz

Related to the 1030 MHz activity only measurement on the ground has been done and is summarised in Table 4:

Table 4: Measured 1030 MHz TCAS and ground surveillance activity

Year	Time of day	UF0/s	UF4,5,11/s	Ratio
2012	15H-16H	254	6.45	**39**
		276	7.68	36
		233	8.2	28

The radar visibility is reduced on the ground and the consequence is the low values measured related to the Surveillance UF.

The number of UF0 detected at EEC is similar to the number of DF0 measured on board the Beluga aircraft. If we take the average value of 250 UF0 received per second with 16 DF0 transmitted by one aircraft it means that all aircraft received 250-16 interrogations which are not directed to them. **This activity increase significantly the occupancy time of the transponder by adding 234*49.75 µs=11641.5µs of additional occupancy.**

The picture below shows, as a reference, the traffic due to the Mode S ground interrogation (UF4/5/11) and the activity of these ground systems with the suppression. The signal with suppression pulse (P5) triggers the transponders without reply. This action generates short transponder occupancy. More you will be close of the radar more this suppression activity will be important. If we make now the comparison between this source of occupancy time and the TCAS UF0 activity, which is more or less in the same condition (close proximity of airport), this last stays the first cause of pollution. The impact is more important due to the higher contribution of DF0 to the occupancy time 49.75 µs in comparison with the 35 µs for the suppression P5 pulse.

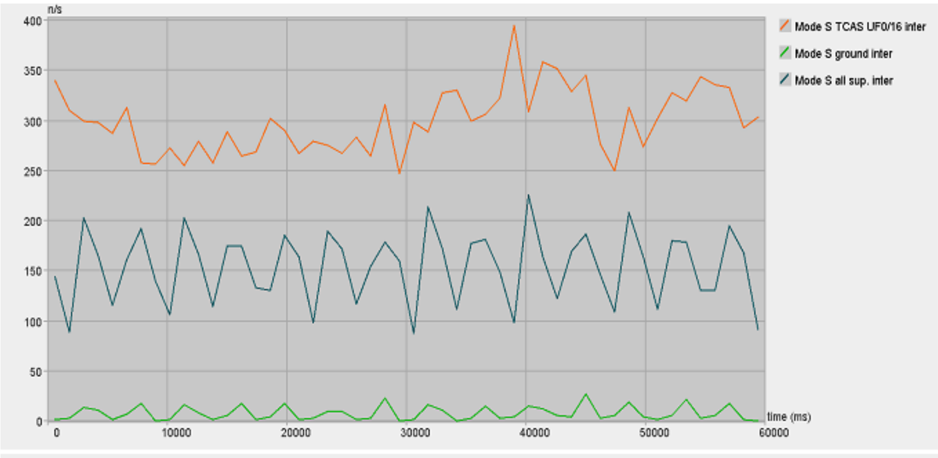

Figure 5: The UF0 contribution to the transponder occupancy is double with a number of interrogations higher and with a dead time higher for each interrogation.

4.4 Tomorrow transmission on 1090 in Europe

If the transmissions on 1090 RF band are not correctly managed it is possible that the surveillance performance collapse. SESAR WP 15.1.6 Study interim report shows that future increase of traffic could result in a large decrease of performance depending of traffic density if nothing is done to improve the 1090 MHz RF band usage, see Figure 6[2].

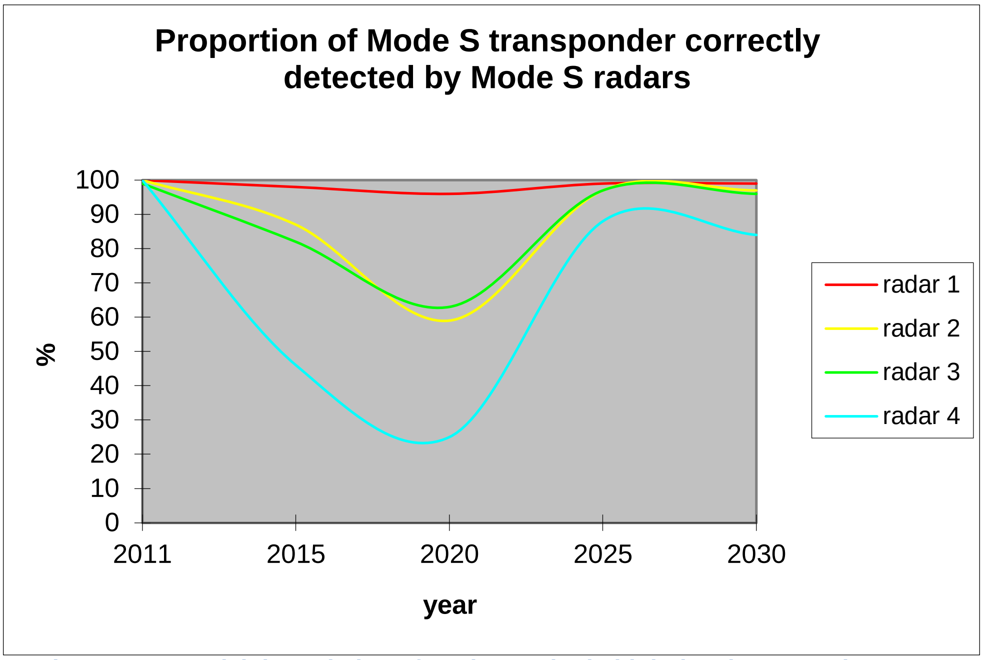

Figure 6: Potential degradation of Mode S radar in high density RF environment

[2] Data extracted from interim 15.1.6 report.

On this graph it is possible to see that radar could have their performance to suddenly drop if they are located in high RF density area (radar 4). However optimization of 1030/1090 RF bands could allow to recover a better performance even with further traffic increase.

The performance of the different applications depends on the usage of the RF bands. If there are too many transmissions on 1090 MHz band the probability of reception decreases resulting in either reduction of range or the need to have higher performance systems or to deploy more ground receivers. It is therefore very important to maintain a lower transmission rate on 1030/1090 RF bands

4.5 TCAS RF contribution improvement

The TCAS RF activity is a significant contributor to RF pollution and is inefficient when compare to other type of surveillance.

Different improvements are being designed by RTCA 147 SWG (see Table 5) to reduce the number of active interrogations used by TCAS to confirm the positions of other aircraft (note, that most of the proposed DO-185B changes are not considered in the final proposal). TCAS hybrid surveillance will rely more on ADS-B data and react differently when being on the ground or interrogating aircraft on the surface.

Table 5: List of proposed TCAS changes to reduce TCAS RF contribution (some of them, in particular for DO-185B, are not included in the final proposal).

Ref.	Name	Summary / *Info*
DO-300 CP 004	Exclusive Use Short Replies for Validation	Interrogations which elicit long DF=16 cross link replies containing latitude and longitude information for validation are no longer required.
DO-300 CP 005	Variable validation intervals	More time (10 to 60s) between valid int. depending on range and range rate
DO-300 CP 006	Revalidation	Two before switching to active
DO-300 CP007/8	Extended Hybrid surveillance	ADS_B report conditions o Version >= 2 o NACp > = 7 o NIC >= 6 o SIL is 3 o SDA is 2 or 3 ADS-B only if signal strength >-68dBm +/-2 dB or own ship on the ground *ADS-B report conditions will need to be changed for test/validation in current European environment (version 0, NUCp>) with certified aircraft*
DO-300 CP 009	Drop passive track	Reduce unnecessary interrogations when a hybrid surveillance track fails to receive updates due to link margin Invalid position then active No message then track drop
DO-300 CP 010	Validation ranges tolerances	Validation range tolerance < 290 Revalidation range tolerance < 340 *Value based on NACp= 8 (<0.05NM)*

Ref.	Name	Summary / *Info*
DO-300 CP 011	Passive Determination of NTA	
DO-185B CP NNA	On Ground Surveillance Improvements	10dB Attenuation at power on the ground +/- 10,000ft. --> +/-3000ft
DO-185B CP NNB	Limit Interrogations During Track Drop	
DO-185B CP NNC	Mode S Surveillance Flight Test Change	
DO-185B CP NND	Monitoring TCAS on ground	Interrogation of TCAS aircraft on the ground when own TCAS on the ground no longer permitted for maintaining NTA3 and NTA6.
DO-185B CP XXX	Track Drop & re-interrogation	Diverging track , TAU <60s, bad reply rate then < 1 interrogation per surveillance period

Table 6: RF benefit of hybrid surveillance based on US scenario model (Lincoln laboratory MIT).

CP - File Name	Description	% 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								
DO-185B CP NNA	Interference Limiting Initialization while on ground. Reduce altitude volume while on ground.	10%	NA								
DO-185B CP NND	While on the ground, don't interrogate other TCAS equipped aircraft also on the ground	14%	NA								
Current DO-300	Current DO-300 w/o Modifications	17%	NA								
DO-300 CP 011	Monitoring of range for NTA3 and NTA6 performed with ADS-B position messages instead of interrogations	36%	23%								
DO-300 CP 006	Prevent early transition to active surveillance because a validating reply was not received.	19%	2%								
DO-300 CP 005	Increase the revalidation interval from 10 seconds to up to 60 seconds for certain conditions	30%	16%								
DO-300 CP 004	Use of standard DF=0 replies for Hybrid Surveillance validation instead of long DF=16 cross link replies.	34%	20%								
DO-300 CP 007	For well qualify ADS-B equipped intruders eliminate active interrogations to a/c whose receive signal strength is <-68 dBm	26%	11%								
DO-300 CP 008	While TCAS is on the ground for qualified ADS-B equipped intruders – do not interrogate them until own ship is taking off.	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%

US simulations[3] have shown that TCAS Extended hybrid surveillance could reduce by more than 80% the TCAS contribution, see Table 6. However the benefits of this new improvement depend on local environment and model assumptions and therefore they need to be validated/verified in European environment. This is the objective of SESAR 9.47 validation activities and will be further elaborated in the Verification& Validation plan.

[3] FAA TCAS Surveillance update presentation to EUROCAE WG75 4/5 September 2012

Another point, that can be seen in Table 6 is, that the DO-185B changes brings only limited benefits with respect to DO-300A compliant system. This is caused by the fact that they address primarily the situations (ground operations, track drop) when passive surveillance should be used by DO-300A system (assuming ADS-B Out equipped and qualified traffic). In this context, an operational validation of these changes should be ideally performed with the system without hybrid surveillance to evaluate correctly their benefits. In this context, the subsequent SESAR 9.47 activities will not address these changes and Group E in Table 6 will be targeted in the SESAR 9.47 prototyping task.

5 References

[1] EUROCAE ED-143/RTCA DO-185B: TCAS II MOPS (TCAS II version 7.1), published in 2008

[2] RTCA DO-300: MOPS for TCAS II Hybrid Surveillance, published in 2006

[3] RTCA DO-300A – draft 0.6 (November 2012), update of DO-300, FRAC expected in December 2012.

[4] FAA TCAS Surveillance update presentation to EUROCAE WG75 4/5 September 2012

[5] SESAR WP15.1.6 Interim report (used in Section 4.4).

5.1 Use of copyright / patent material /classified material

Copyright or patent material shall not be included in a specification without prior consent of the copyright or patent owner. When such consent is obtainable, a line citing the reference source shall be added in the specification.

5.1.1 Classified Material

Specifications containing classified material shall be appropriately made and handled. If only a limited amount of classified or sensitive information is found it shall be added as an appendix.

Appendix A Safety Effects of Limited Surveillance Range on TCAS

A.1 Introduction

As described in Chapter 2, the use of ADS-B position information for TCAS surveillance purposes brings a potential hazard associated with relying on the data provided by an external system (target's avionics). In this context, it is required that the passive surveillance (whether hybrid or extended hybrid) always transition to active surveillance before a target becomes a TCAS threat and the associated alerting is required. Several mitigation means are defined within the requirements provided in this document adn DO-300A MOPS to achieve this objective. On the other hand, it is important to understand the potential operational impact of this hazard in order to identify whether the safety objectives associated with these internal mitigation means are adequate.

From operational perspective, the worst case impact of the situation described above (driving the performance requirements for these mitigation means) is that TCAS will switch to active surveillance (and issue the potential alerts) later than expected. Such worst-case scenario can be analyzed using operations with standard TCAS (without hybrid surveillance) but considering reduced surveillance range. This type of analysis was previously performed within the RTCA SC147 for the US data but it was not verified for other environments.

This Appendix provides the results of the relevant analysis for European environment performed within SESAR 9.47 using encounter-based model methodology.

A.2 Background

A.2.1 Methodology

The validation will build on the model-based methodology that is used in TCAS II studies conducted in Europe for more than a decade. It relies on a set of tools including several models to allow replicating the environment in which TCAS is being operated. These models consist essentially of:

- an 'encounter model' that allows generating a very large number of encounters on which TCAS is simulated and then indicators are computed;
- a 'pilot response model" that allows simulating actual and not only theoretical pilots' responses to RAs; and
- an 'altimetry error model' that allows simulating the altimetry errors applicable in the considered airspace.

The 'encounter model' methodology is a powerful technique by which a very large set of risk bearing encounters (which are rare events) can be stochastically generated to assess the safety benefits of TCAS or any other ATM safety nets. Studies made with safety encounter models are usually performed on a set of at least 100,000 encounters.

There are two main types of 'encounter models':

- safety encounter models' used to compute safety related indicators; and
- ATM encounter models' used to compute more operational indicators.

A 'safety encounter model' is the most appropriate one for this type of project as the main focus is to evaluate the safety implication of introducing an automatic reaction to RAs. This model also allows computing some operational indicators (e.g. vertical deviations in response to RAs).

As shown in Figure A1, these models are then used in particular to determine the risk, or 'logic system risk', that remains when TCAS is being operated (which results from the risk ratio achieved by TCAS and the underlying risk in the absence of TCAS). The 'logic system risk' is usually determined through the performance of TCAS simulations that include the modelling of pilot response to RAs in a very large set of modelled encounters.

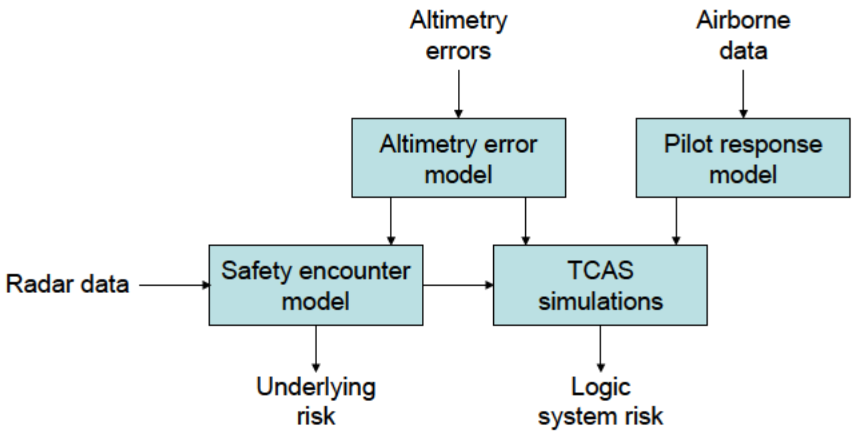

Figure A7: Methodology and tools for TCAS studies

A.2.2 Tools

Safety encounter models

This study makes use of a safety encounter model developed within the AVAL project [A1].

A 'safety encounter model' is a mathematical model of traffic situations involving two aircraft that captures the properties of 'close' encounters captured from radar data. The encounters that matter are those in which two aircraft are on a close encounter course. This is measured by the separation at the 'Closest Point of Approach' (CPA), i.e. the local minimum in the physical distance between two aircraft. It is defined by a horizontal component ('Horizontal Miss Distance - HMD') and a vertical component ('Vertical Miss Distance - VMD'). The safety encounter model addresses encounters with a HMD less than 500 ft at CPA. The VMD can be larger (but with a maximum value) because the model includes a significant proportion of encounters with vertical manoeuvres that increase the aircraft vertical separation at the CPA.

The model defines the statistical distributions and interdependencies of the encounter parameters. These define the characteristics of individual trajectories and their relationship to one another when combined into an encounter that is likely to occur in ATM operations.

The most recent version of the European safety encounter model was developed by the EUROCONTROL AVAL project in 2009 [A1]. It has been developed based on preceding safety encounter models developed by the EUROCONTROL ASARP [A2] and ACASA [A3] projects to reflect current operations (e.g. introduction of Very Light Jets in the European airspace).

Figure A2 illustrates the parameters used to define the AVAL safety encounter model with an example of encounter represented with its vertical and horizontal profiles.

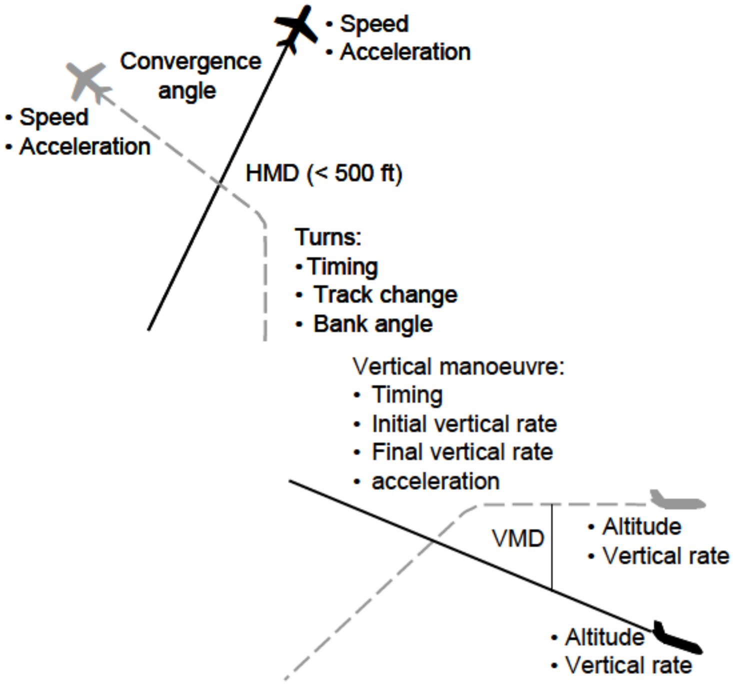

Figure A8: Parameters used to define the AVAL safety encounter model

The probabilities of each of the encounter parameter have been determined by analysing very a large set of encounters extracted from European radar data and counting the number of instances of an encounter with given properties.

The altitude at which each encounter occurs is a dominant feature of the encounter model. The airspace is divided into a number of altitude layers whose boundaries have been chosen to reflect the differing characteristics of the encounters at different altitudes.

Table A1: AVAL encounter model airspace layers

Layer	Altitude range
1	100 ft – FL50
2	FL50 – FL135
3	FL135 – FL215
4	FL215 – FL285
5	FL285 – FL415

About two third of the encounters taken into account by the 'safety encounter model', occur in TMA airspace (i.e. below FL135).

The behaviour of an aircraft in an encounter is subject to the limitations of its aerodynamic performance. AVAL has defined the aircraft performance classes based on three parameters:

- the engine type, i.e. piston (P), turboprop (T) or jet (J);
- the Maximum Take-Off Mass (MTOM), including a limit at 5,700 kg to separate light aircraft (L) not subject to the European ACAS mandate from heavier aircraft (H) equipped with TCAS; and
- the maximum cruising speed, i.e. very slow (VS), slow (S), medium (M) and fast (F)

All combinations of these three parameters are not possible. Table A2 describes the fourteen performance classes defined in the AVAL safety encounter model (grey cells represent not operationally meaningful cases).

Table A2: AVAL aircraft performance class

Engine type	MTOM	Maximum cruising speed			
		< 250 kts	250 – 350 kts	350– 450 kts	> 450 kts
Piston	All	P_{VS}	P_S		
Turboprop	< 5,700 kg		TL_S	TL_M	
	> 5,700 kg	TH_{VS}	TH_S	TH_M	
Jet	< 5,700 kg	JL_{VS}	JL_S	JL_M	JL_F
	> 5,700 kg			JH_M	JH_F
Military jet	All				M_F

For each of the fourteen performance classes, five performance limits are defined:

- one overall limit:
  - maximum operating altitude;
- four that take different values in different altitude layers:
  - maximum climb rate;
  - maximum descent rate;
  - maximum speed; and
  - minimum speed.

Pilot models

Two pilot models will allow assessing the theoretical safety and also operational impact:

- Standard pilot model, which provides the theoretical response to RAs;
- Typical pilot model (developed by the ASARP project), which provides the wide range of pilots' behaviour identified in airborne data (from no response to aggressive response

Standard pilot model

The standard pilot response to corrective RAs is described in the ACAS SARPs [A4]. It notably requires the pilot to react to the initial RA within 5 seconds using an acceleration of 0.25 g to achieve the required vertical rate (e.g. 1500 fpm for "Climb" and "Descend" RAs) RAs. The ACAS logic has been tuned based on these standards responses to RAs. Table A3 summarises the parameters of the standard pilot model.

Table A3: Standard pilot model

Pilot model parameters	Standard values
Initial corrective RA delay	5 s
Other RA delay (1)	2.5 s

Standard RA acceleration (2)	0.25 g
Increase/Reversal RA acceleration	0.35 g
Climb/Descend RA rate	1500 fpm
Increase RA rate	2500 fpm
Level-Off RA rate (3)	0 fpm

(1): Other RAs include weakening, strengthening, increase and reverse RAs

(2): Standard RAs include initial, strengthening and weakening RAs

(3): In TCAS II version 7.1, the “Level-Off” RA replaces the former “Adjust Vertical Speed” RAs.

Typical pilot model

In ACASA and ASARP projects, the typical pilots’ responses to RAs have been analysed using airborne data recordings. While there was were basically two types of actual responses (i.e. smooth and aggressive) identified in the 90’s, the analysis of more recent data has shown that there is a wide range of typical pilot responses to RAs, a multidimensional continuum ranging from smooth to aggressive responses. Furthermore, this more recent data analysis has also shown that a non-negligible proportion of pilots still do not follow their RAs despite the ICAO regulation.

Therefore, the ASARP project has defined a typical pilot model to be representative of these different responses to RAs [A6]. It identifies 32 types of responses, based on the variations of the three parameters characterising a response.

- The time between the issuance of the RA and the beginning of the response;
- The vertical acceleration taken to perform the manoeuvre; and
- The vertical rate to perform the manoeuvre.

The model also includes a proportion of pilots who do not respond to the RAs derived from data analysis:

- 30% of non-responses to RAs below FL50; and
- 10% of non-responses to RAs above FL50.

When combined, 20% of RAs are not followed in the typical pilot model.

Figure A3 illustrates the characteristics of the typical pilot model.

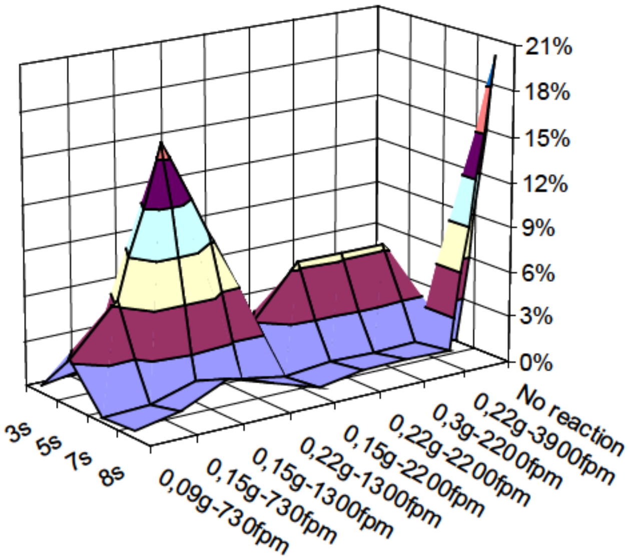

Figure A9: Typical pilot model from ASARP

A.3 Validation scenarios

A.3.1 TCAS equipage

The criteria of the European ACAS mandate (i.e. civil turbine-engined aircraft with more than 19 passengers or weighing more than 5,700 kg) will be applied to determine which aircraft are equipped in the scenarios. This implies that aircraft from 5 performance classes of the AVAL safety encounter model will be equipped (i.e. all turboprops and jets with a MTOM greater than 5,700 kg: THVS, THS, THM, JHM and JHF).

A.3.2 Reported altitude quantization

The EUROCONTROL PASS project has very recently defined assumptions about the transponder equipage of the various aircraft categories reflecting current situation [A9], determining for each of them the percentage of aircraft equipped with a Mode S transponders and the percentage of aircraft reporting altitude in 25ft/100ft aircraft quantization.

The following table summarises these percentages (the grey cells correspond to aircraft not equipped with TCAS II).

Table A4: Mode S equipage and reported altitude quantization

Engine type	MTOM	Mode S equipage	Altitude reporting	
			100 ft	25 ft
Piston	All	50%	80%	20%
Turboprop	< 5,700 kg	50%	80%	20%
	> 5,700 kg	100%	5%	95%
Jet	< 5,700 kg	100%	5%	95%
	> 5,700 kg	100%	5%	95%

Military jet	All	20%	80%	20%

A.3.3 TCAS simulations

The study used TCAS II version 7.1.

A.3.4 Encounters

For this study, a set of 500k encounters was generated rather than the 100k encounter usually used.

A.3.5 Radar range limitation

The radar range limitation was simulated from 1NM to 14NM in steps of 1NM.

The radar range limitation was simulated removing for each trajectory the plots distant by more than the simulated limitation before simulating TCAS.

A.4 Results

A.4.1 Number of RAs generated

The following figure shows the number of RAs generated on the 500,000 encounters of the European safety encounter model, versus the radar ranger limitation.

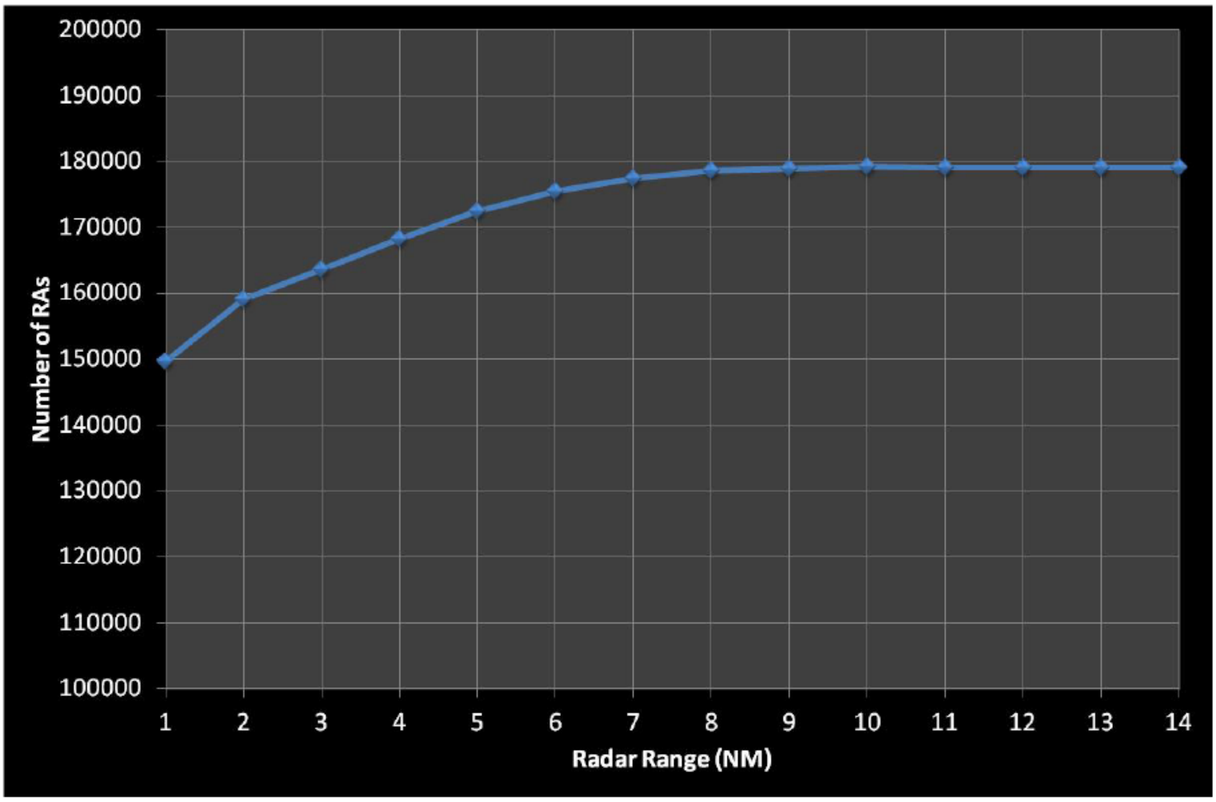

Figure A10: Number of RAs - Standard pilot scenario

The number of RAs decreases at 9NM and below. This means that the proportion of encounter for which RAs are triggered above 9NM is insignificant.

At 6NM, the RA number reduction is around 2%, which is very limited.

A.4.2 Number of crossing, reversal and increase RAs generated

Crossing, reversal and increase RAs are stressful for crews, therefore any change in the CAS logic or in TCAS operations should not result in an increased number of such RAs.

In addition, increase and reversal RAs are a good measure of the efficiency of initial RAs as they are triggered when the CAS logic considers the situation sufficiently debased so that a new RA is necessary.

The following figure shows the proportion of such RAs for the radar range limitations simulated.

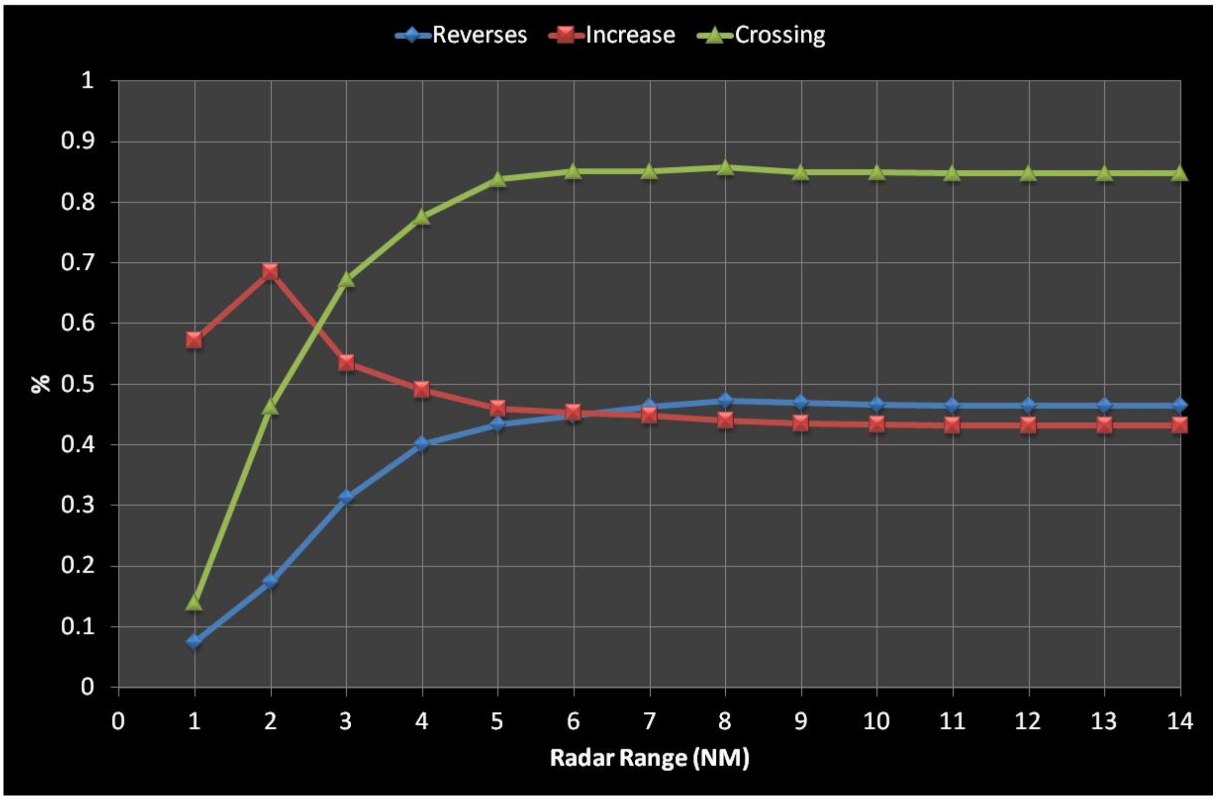

Figure A11: Standard pilot scenario

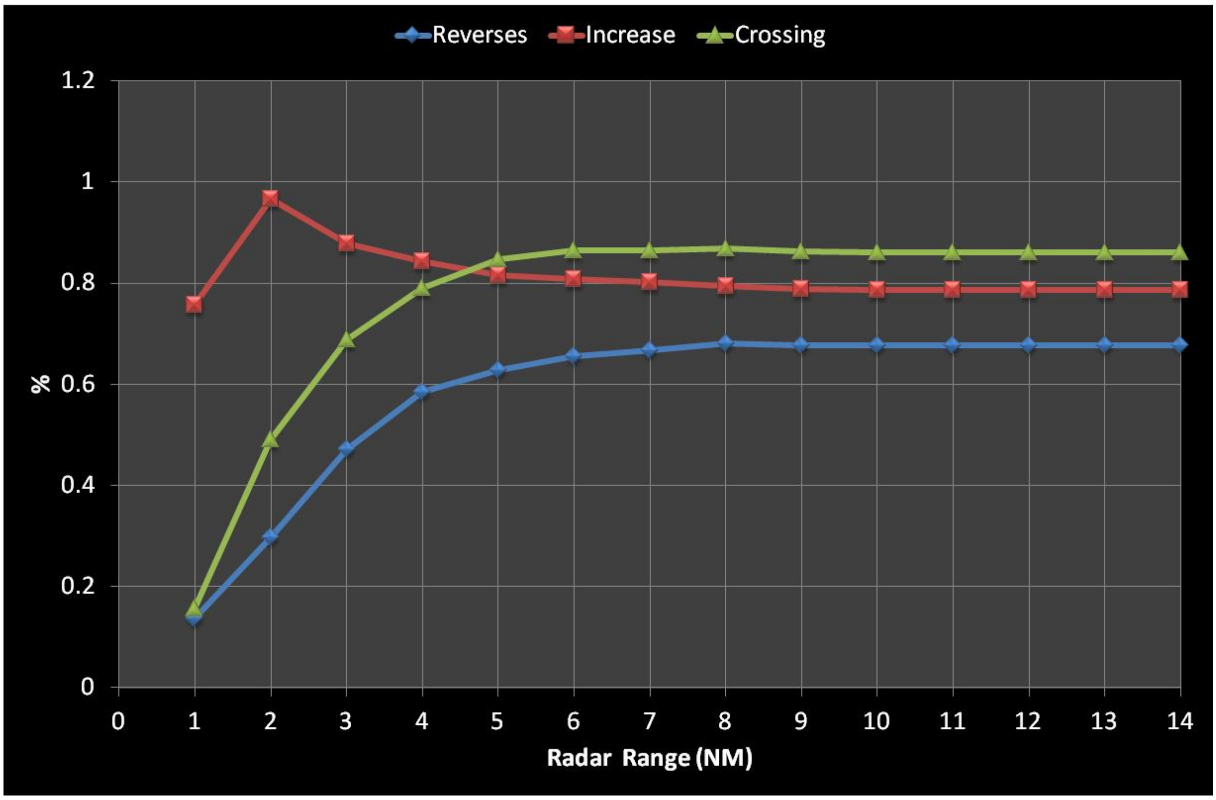

Figure A12: Typical pilot scenario

The most noticeable thing about this figure is the fact that the rate of increase RAs increases below 8NM, slightly, then noticeably below 6NM. This highlights the fact the when RAs are triggered when aircraft are too close, the initial RA is not sufficient anymore to ensure a sufficient vertical distance at CPA, therefore the vertical rate has to be increased. This shows that the shorter the ranger, the less efficient the initial RAs are.

The proportion of crossing and reversal RAs decrease significantly below 5NM. Reversal RAs need a certain amount of time before CPA so as to be triggered, and triggering the initial RA later results in less time available before CPA for a possible Reversal RA. Therefore with shorted ranges, it happens that reversal RAs are not triggered anymore.

Concerning crossing RAs, having the RA triggered later lets more time to the ongoing situation to evolve, with a possible reduction in the vertical rate which results in a crossing RA not being the best choice anymore. This can happen in case of an aircraft climbing with a fast vertical rate, which can result in a crossing RA being triggered, and then decreasing its vertical rate after the time of the crossing RA. If the RA is delayed, it can happen that the initial RA time is delayed within the phase with a reduced vertical rate, which results in the crossing RA not being the best choice anymore.

A.4.3 Risk ratios

The following figure shows the risk ratios for the radar range limitations simulated. The risk ratios are shown for all the altitude layers, for encounters below FL135 and for encounters above FL135.

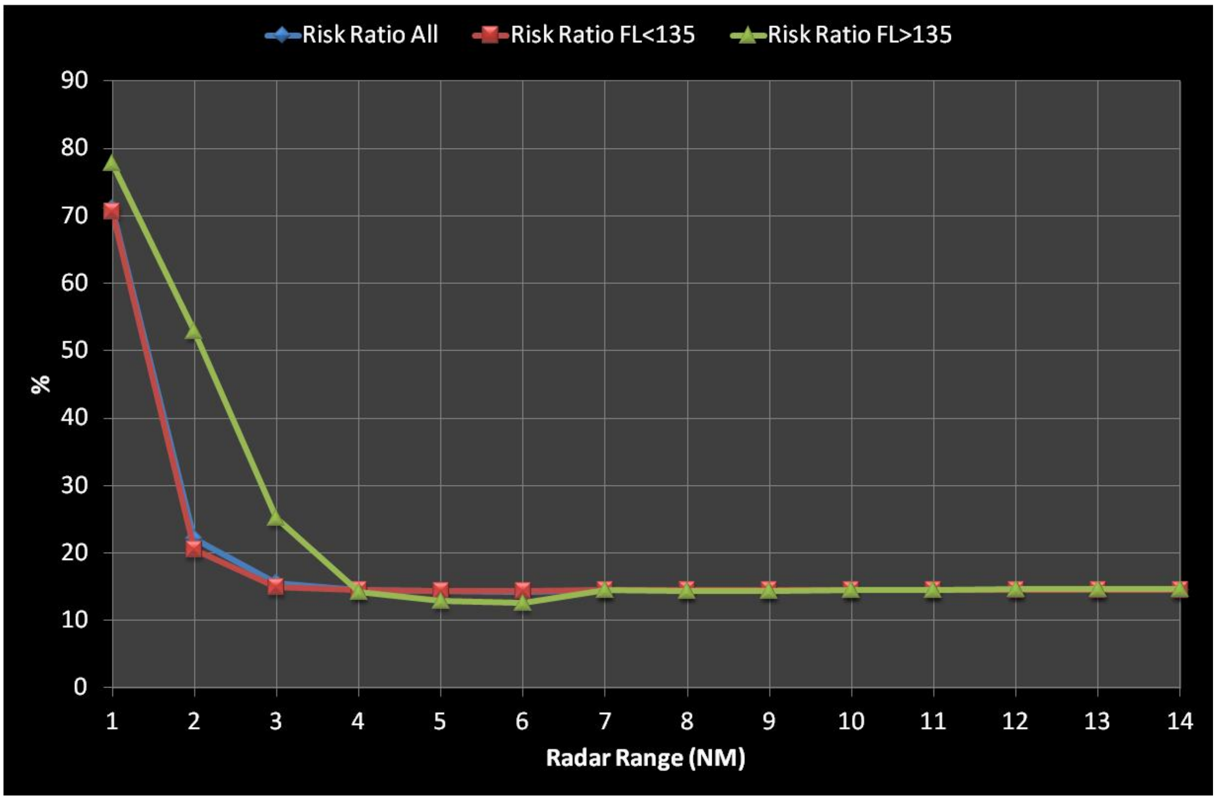

Figure A13: Risk ratios - Standard pilot scenario

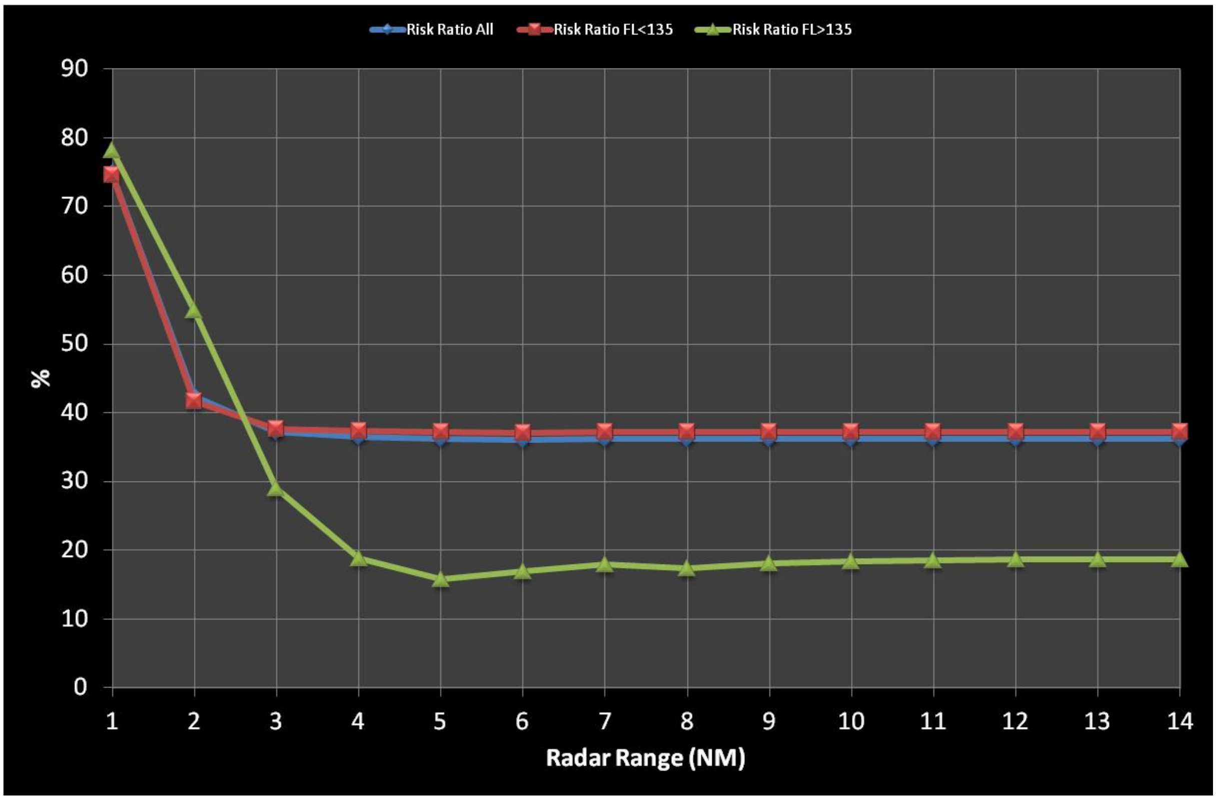

Figure A14: Risk ratios - Typical pilot scenario

The risk ratio mainly results from encounters below FL135, which can be seen by the high correlation between the risk ratio and the low altitude risk ratio. These two risk ratios start to increase below 3NM.

The high altitude risk ratio starts to decrease very slightly at 6NM and increases at 4NM. Indeed, for some encounters in which an intruder does not follow RAs or is not equipped with TCAS, it is better to wait before triggering an RA, as the wait offers a better perception of the situation, which permits to mitigate non responses to RAs. This explains the surprising decrease of the risk ratio at 6 NM.

When the range decreases at 4NM, the contribution to the risk ratio of the resolved situations is compensated by some unresolved situations.

Overall, the risk ratio increase is caused by the unresolved part of the risk ratio: indeed, situations solved by TCAS in normal use are no more solved when the range starts to be very low.

A.4.4 Encounters without ALIM

ALIM is the vertical separation TCAS tries to achieve. It range between 300 and 700 ft depending on the altitude. Counting the proportion of encounters which do not result in ALIM is therefore a useful thing to do as it permits to see if a CAS logic change has a negative effect or not.

The following figure shows the proportion of encounter without ALIM for the radar range limitations simulated.

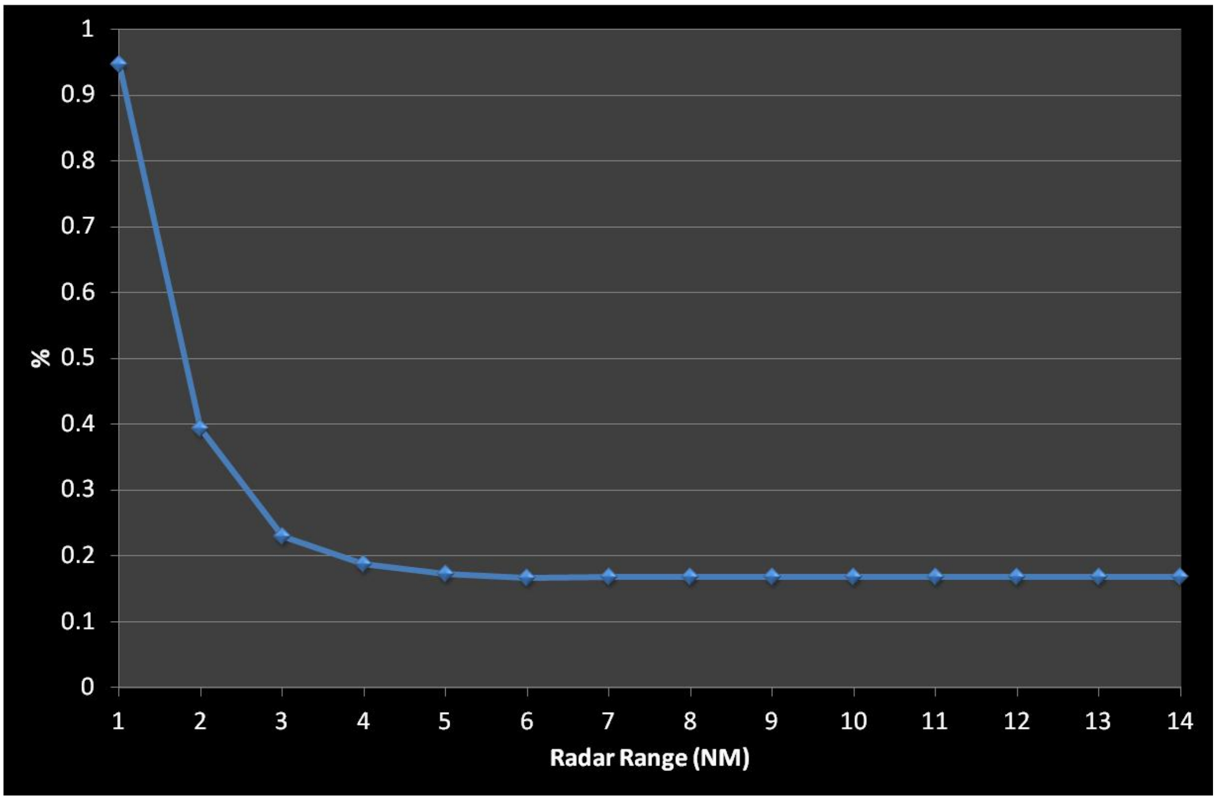

Figure A15: Encounters without ALIM - Standard pilot scenario

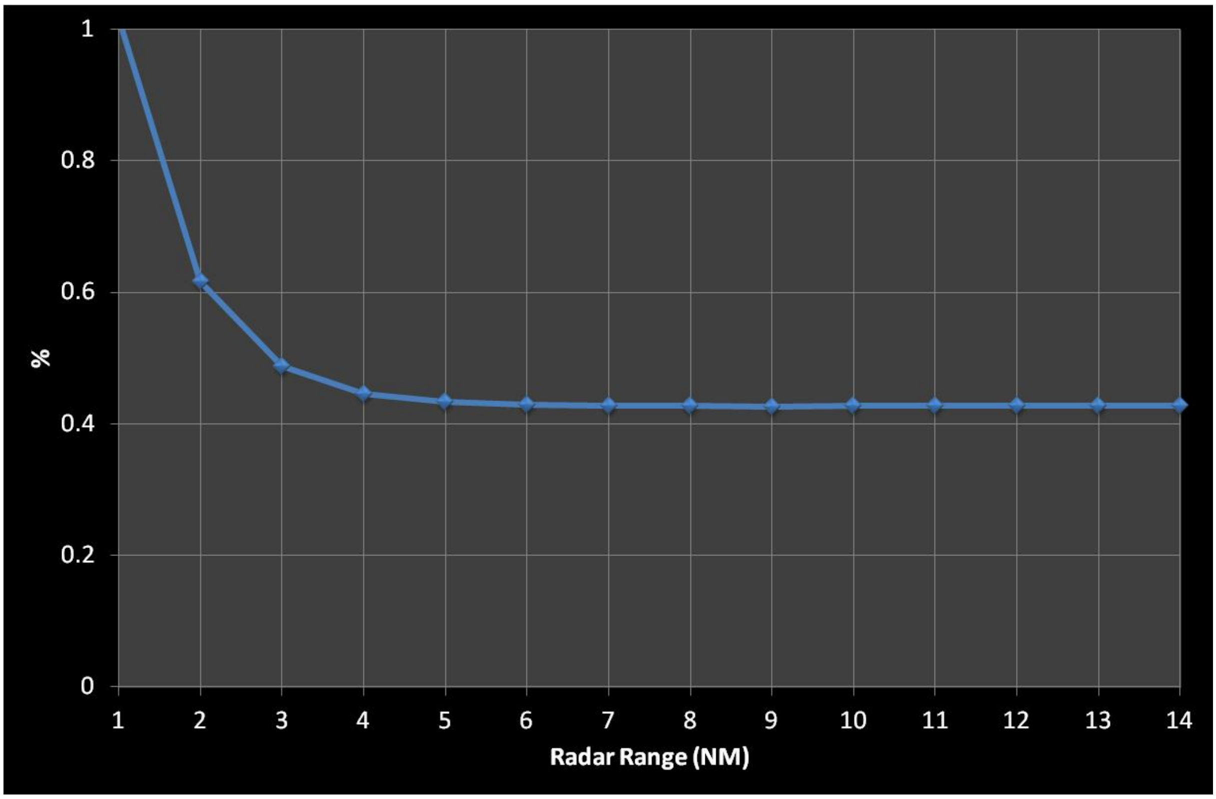

Figure A16: Encounters without ALIM - Typical pilot scenario

The rate of encounters for which ALIM is not satisfied increases at 5NM with the standard pilot scenario and 6NM and below with the typical pilot scenario. The increase starts to be significant below 4NM.

This confirms the trends observed with other metric, which tend to show that at and above 6NM, the limited range does not result in any debasement on the safety brought by ACAS.

A.5 Conclusion

The radar range limitations simulated had no or very limited effect above 6NM.

Significant effects were observed at and below 4NM.

Therefore, these are the limits where active surveillance shall be always used and which cannot be infringed by passive to active surveillance transition in order to do not degrade TCAS performance.

A.6 References

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[A2] **ASARP**, WP2 – ‘Final report on post-RVSM European safety encounter model’ – EUROCONTROL Mode S & ACAS Programme – ASARP/WP2/34/D, version 1.0, July 2005

[A3] **ACASA**, WP-1.2.5 – ‘European Encounter Model: Part 1/2’ – EUROCONTROL ACAS Programme – Specifications, ACASA/WP1.1/186, version 2.1, December 2001

[A4] **ICAO**, Annex 10 to the Convention on Civil Aviation, Volume IV, Surveillance Radar and Collision Avoidance Systems, 3rd edition, July 2002

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[A6] **ASARP**, WP4 – 'Final report on the analysis of airborne recorded data and pilot model specification' – EUROCONTROL Mode S & ACAS Programme – ASARP/WP4/19/D, version 1.0, April 2005

[A7] **EUROCAE/RTCA** , Minimum Operational Performance Standards for Traffic Alert and Collision Avoidance System II (TCAS II), ED-143/DO-185B, September 2008

[A8] **AVAL**, Safety benefits of ACAS in the future European ATM environment with Very Light Jets – AVAL final report, AVAL/WA7/41/D, October 2009

[A9] **PASS**, Overview of model-based simulation results - EUROCONTROL HQ ATC Domain, PASS/WA2/WP10/161/W, version 1.0, July 2010

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