EUROPEAN ORGANISATION
FOR THE SAFETY OF AIR NAVIGATION

EUROCONTROL

TCAS II performance in European TMAs

Part 2: Methodology

Safety Issue Rectification Extension 2006-2008 Project

SIRE+ Project

CND/CoE/CNS/09-048

Edition Number	**:**	**1.1**
Edition Date	**:**	**03rd February 2009**
Status	**:**	**Released**
Intended for	**:**	**EATM Stakeholders**

TCAS II performance in European TMAs
Part 2: Methodology

Safety Issue Rectification Extension 2006-2008 Project

SIRE+ Project

Drafted by: Hervé Drévillon

Authorised by: Thierry Arino on 03-02-2009

RECORD OF CHANGES

Issue	Date	Detail of changes
0.1	08-12-2008	Initial draft
0.2	08-12-2008	Revised version following internal review
0.3	11-12-2008	Complete draft following progress meeting
1.0	19-01-2009	Initial version delivered to EUROCONTROL
1.1	03-02-2009	Revised version following EUROCONTROL review

IMPORTANT NOTE: ANY NEW VERSION SUPERSEDES THE PRECEDING VERSION, WHICH MUST BE DESTROYED OR CLEARLY MARKED ON THE FRONT PAGE WITH THE MENTION *OBSOLETE VERSION*

TABLE OF CONTENTS

LIST OF FIGURES

GLOSSARY

ACAS	Airborne Collision Avoidance System – a system standardised in the ICAO SARPs that uses transponder replies from other aircraft to warn the pilot of a risk of impending collision. Hereafter, ACAS always refers to ACAS II – a system that generates traffic advisories (TAs) and also generates resolution advisories (RAs) in the vertical plane.
RA downlink	A communication channel enabling a TCAS-equipped aircraft to transmit detailed information about on-going RAs. These data can notably be collected by Mode S ground stations.
Resolution Advisory	A resolution advisory (RA) is an ACAS alert instructing the pilot on how to modify or regulate his vertical speed in order to reduce the risk of collision diagnosed by the system.
Safety issue	An issue that has the potential to debase the safety benefits brought by ACAS, possibly leading to reduced vertical separations or even NMACs.
SIR SIRE SIRE+	Safety Issue Rectification and Safety Issue Rectification Extension – a series of studies commissioned by EUROCONTROL in order to improve TCAS safety performance. SIRE+ addresses two safety issues: - SA01: inappropriate reversal logic operation, - SA-AVSA: misinterpretation of AVSA RAs leading to unintentional responses in the opposite sense.
TCAS	Traffic alert and Collision Avoidance System – an aircraft equipment that is an implementation of an ACAS.
Threat	A transponder-equipped aircraft within the surveillance range of ACAS and that is tracked by ACAS.
TMA	A volume of controlled airspace set up at the confluence of airways in the vicinity of one or more major airports to protect inbound and outbound traffic. A TMA is generally defined as a series of areas around approaching and departing routes, constrained both horizontally and vertically. A TMA typically spans over a few tens of NM around the airport(s) and rises from a few thousands of feet above the ground to a defined FL.

1. Introduction

1.1. Context

1.1.1. The **Airborne Collision Avoidance System (ACAS)**[1] has been introduced in order to reduce the risk of mid-air collisions. It serves as a last resort safety net irrespective of any separation standards.

1.1.2. From 1st January 2005 in the European Civil Aviation Conference (ECAC) area, all civil fixed-wing turbine-engined aircraft having a Maximum Take-Off Mass (MTOM) exceeding 5,700 kg or a maximum approved passenger seating configuration of more than 19 shall be equipped with an ACAS II compliant equipment (i.e. the Traffic alert and Collision Avoidance System (TCAS) II version 7.0).

1.1.3. Following the identification of two severe safety issues in TCAS II version 7.0, EUROCONTROL has commissioned the Safety Issue Rectification (SIR) initiative, culminating with the present SIRE+ project, to address these two issues. This initiative has proposed to resolve these safety issues through two changes to the TCAS II Minimum Operational Performance Standards (MOPS) ([DO185A]), identified as Change Proposals (CP) 112E and 115. Both EUROCAE Working Group 75 (WG75) and RTCA Special Committee 147 (SC147) have evaluated and endorsed these proposals.

1.1.4. As part of the validation of CP112E and CP115 conducted within RTCA SC147 and EUROCAE WG75, the SIRE+ project has assessed the performance of TCAS II version 7.0 in two US Terminal Control Areas (TMAs); i.e. New York ([SIRE+1]) and Boston ([SIRE+2]). The objective of these studies was notably to gain some insight in the current operation of TCAS in busy US TMAs, enabling to assess the operational and safety effect of CP112E and CP115 introduction. As radar data from several European Air Navigation Service Providers (ANSPs) became available to EUROCONTROL, the opportunity arose to conduct a similar assessment of TCAS II version 7.0 operational and safety performance in major European TMAs.

1.2. Scope and objectives

1.2.1. The objectives of the study are to perform an analysis of TCAS II version 7.0 performance in European airspace, both from an operational standpoint and from a safety standpoint. The study has been conducted using radar and Resolution Advisory (RA) downlink data collected in three major European TMAs over three months during the 2007-2008 winter period.

1.2.2. As both radar and RA downlink data were available to the SIRE+ project for this study, it provided the opportunity to compare the two different methodologies that had previously been used for the New York and Boston analyses. Indeed, the New York study relied on radar data only and RAs were generated through TCAS simulation, while the Boston analyses used the RA downlink information.

[1] In this document, ACAS refers to ACAS II, as it is the only version which use has been mandated in Europe.

1.2.3. This comparison of methodologies has been conducted on a set of radar and RA downlink data provided by one European ANSP. It consisted in determining two sets of encounters with RA, one through each methodology, and computing various indictors on each of these encounter sets.

1.3. Document overview

1.3.1. Section 1 is the present introduction.

1.3.2. Section 2 presents on overview of the data used to conduct the present methodology comparison and of the two methodologies that have been compared.

1.3.3. Section 3 compares the outcomes of the simulation- and RA downlink-driven methodologies on the same set of radar data.

1.3.4. Section 4 concludes on this comparison and on the validity of the simulation-based methodology used in absence of RA downlink information.

2. Data sample and methodologies

2.1. Context and objective

2.1.1. Given the availability of both radar and RA downlink data from several European ANSPs to the SIRE+ project, it was possible to conduct a comparison of the two methodologies that have previously been used for previous studies assessing TCAS performance. This comparison has been performed on the data collected from one European ANSP and the objective was to:

- Capture two different sets of radar encounters, using both the simulation- and RA downlink-driven methodologies,
- Compute indicators for each of these encounter sets, so as to characterize them and assess the differences.

2.1.2. It has to be noted that the sample of radar data used for this comparison was not limited to a TMA, contrary to the main study presented in Part 2 of this document.

2.2. Data sample

2.2.1. The data used to perform the comparison between the RA downlink- and simulation-driven methodologies have been recorded during 99 days by a single Mode S station between 28th October 2007 and 3rd February 2008. The amount of data recorded over this period is roughly 210,000 Mode S flight hours.

2.2.2. The format used to store the radar data was EUROCONTROL ASTERIX category 48 ([EURO1]), which stores RA downlink information in addition to the usual range and altitude information. This was a prerequisite for the feasibility of this study as it allows performing TCAS simulations on the radar data and comparing this simulation outcome to RA downlink reports.

2.3. Overview of simulation-driven methodology

2.3.1. When assessing the performance of TCAS in a given airspace through radar data, two methodologies can be used, depending on the availability of RA downlink information for this airspace. As Mode S surveillance expands in Europe and in the US, RA downlink data more and more become an additional source of information when evaluating the behaviour of TCAS.

2.3.2. The simulation-driven methodology only uses radar tracks and has been used in the past on Secondary Surveillance Radar (SSR) data. It consists in identifying close encounters using TCAS-like criteria and in simulating the behaviour of TCAS on these encounters off line. This methodology was noticeably used for the assessment of the operational performance of CP115 in New York airspace ([SIRE+1]) and several EUROCONTROL TCAS safety studies ([ACA1], [ASAR1], [SIRE+1], [SIRE+2]), as RA downlink data were not available for these studies.

2.3.3. With this methodology, radar tracks, which are generally updated every 4 to 12 seconds, are interpolated into 1-second update rate trajectories to reflect the performance of TCAS surveillance. Because of the sensitivity of the collision

avoidance logic to altitude and vertical speed, this interpolation step sometimes leads the TCAS simulation to miss RAs that actually occurred or issue RAs when none actually were. To cope with this issue, jittering the encounters before applying the TCAS simulation can improve confidence in the simulation result.

2.3.4. The encounters with a potential for a TCAS alert are identified through geometrical capture criteria applied to pairs of radar tracks. These criteria include a 'closing time test' (similar to the 'range test' and the 'altitude test' used by TCAS to determine threats on a collision course) and a 'miss distance test' to prevent the capture of encounters where aircraft pass relatively far from each other in the horizontal dimension.

2.3.5. Table 1 indicates the thresholds used for the parameters of these different tests, as well as the equivalent TCAS parameters used to trigger RAs in TCAS II version 7. Theses thresholds depend on the altitude the encounter occurs at.

Altitude layers	1,000 ft - 2,350 ft	2,350 ft - FL50	FL50 - FL100	FL100 - FL200	FL200 - FL420	Above FL420
Range test criteria (s)	21	26	31	36	41	41
TCAS RA range test threshold	15	20	25	30	35	35
Altitude test criteria (ft)	700	700	700	700	800	900
TCAS RA altitude test threshold	600	600	600	600	700	800
Miss distance test criteria (NM)	0.6	0.75	0.95	1.2	1.5	1.5
TCAS RA miss distance test threshold (NM)	0.2	0.35	0.55	0.8	1.1	1.1

Table 1: Capture criteria

2.3.6. The process put in place for the capture of encounters with the potential for a TCAS alert, using the above TCAS-like criteria, is described in Figure 1.

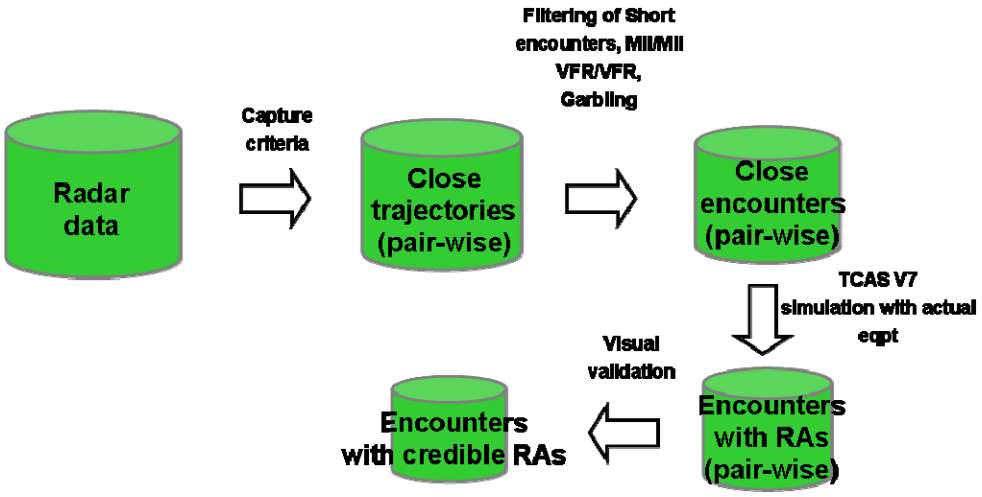


Figure 1: Capture of encounters based on TCAS-like criteria

2.3.7. First, radar data are passed through the capture criteria, resulting in a set of close encounters. This encounter set however includes every possible pair of close tracks, including those between two aircraft not fitted with TCAS (military, light aircraft). It also includes encounters where garbling issues or surveillance artefacts led to the capture criteria to be passed. Consequently, these encounters need to be run through several filters in order to remove undesired ones.

2.3.8. In a second step, TCAS simulations are performed on the remaining encounters that passed the filters, with the actual TCAS equipage of each aircraft being determined using RA downlink BDS10 information. This simulation step is usually followed by a visual validation of the remaining encounters in order to remove:

- Unwanted encounters missed by the automated filters (e.g., involving a military aircraft with a Mode A code that can also be used by civilian flights).
- Encounters with deliberate RAs (interceptions by military aircraft with their transponder switched on, test flights, …);
- Encounters in which RAs were triggered because of some imprecision in the measure of aircraft position, typically at the limit of the radar range.

2.4. Overview of RA downlink-driven methodology

2.4.1. The RA downlink-driven methodology bases the identification of encounters of interest on RA downlink data, through the RA reports contained in RA downlink BDS30. This methodology has been applied when assessing the performance of CP115 in Boston TMA ([SIRE+2]).

2.4.2. Information available through RA downlink notably contain callsigns, Mode A, aircraft radar identifiers, ICAO 24-bit addresses of aircraft involved in RAs, thus allowing the identification of aircraft with RAs and the corresponding threats. Using this knowledge, tracks are directly selected in radar data to build the encounters with reported RAs.

2.4.3. The capture process based on RA downlink is thus more straightforward than using TCAS simulation. In addition, it enables to identify encounters that simulation-driven methodology would miss because of specific geometries not matching the capture criteria.

2.4.4. However, encounters identified using RA downlink information also have to be checked visually, as actual RAs can be generated against non-existent threats (spurious RAs) or threats not on a collision course (e.g. garbled response to TCAS interrogations by military aircraft in close formation).

3. Comparison of simulation - and RA downlink -driven methodologies

3.1. Capture success

3.1.1. Not all encounters were an RA has been actually issued can be successfully captured through either methodology. The main causes for this are spurious RAs (caused by an error from the TCAS surveillance against threats that are not on a collision course) and RAs occurring on the edge of the Mode S station surveillance area. In these cases, it will not be possible to associate two close aircraft trajectories to an RA found in RA downlink messages.

3.1.2. The process based on simulation uses a step which requires an interpolation of the data, because radar data is not provided in 1s steps and because TCAS simulations require data in 1s steps. This interpolation can result in some differences with what actually occurred.

3.1.3. However, the capture step itself, which precedes the simulation step, can introduce a bias, as all the encounters which should be captured are not always captured. Indeed, when approaching the limits of the radar, it is possible that aircraft trajectories are not complete, or that an aircraft is just outside the radar coverage. In addition, it happens that the TCAS-like capture criteria are too stringent to capture an encounter for which RA was reported in RA downlink, because the aircraft had quite a large horizontal separation. Eventually, it sometimes happens that for an encounter for which an RA was reported in RA downlink, there is no threat in the radar data, which could have triggered an RA. In this case, it is impossible for the simulation based process to capture a matching encounter.

3.1.4. Capturing encounters based on RA downlink information can also fail in some specific cases, typically when the threat can not be found (in this case, the RA results from a garbling issue or from a TCAS surveillance artefact), or when the encounter occurs at the limit of the radar coverage.

3.1.5. Figure 2 shows the success of the capture process for both methodologies. It is a measure of the proportion of RAs missed only because of the capture process compared to those that have actually occurred.

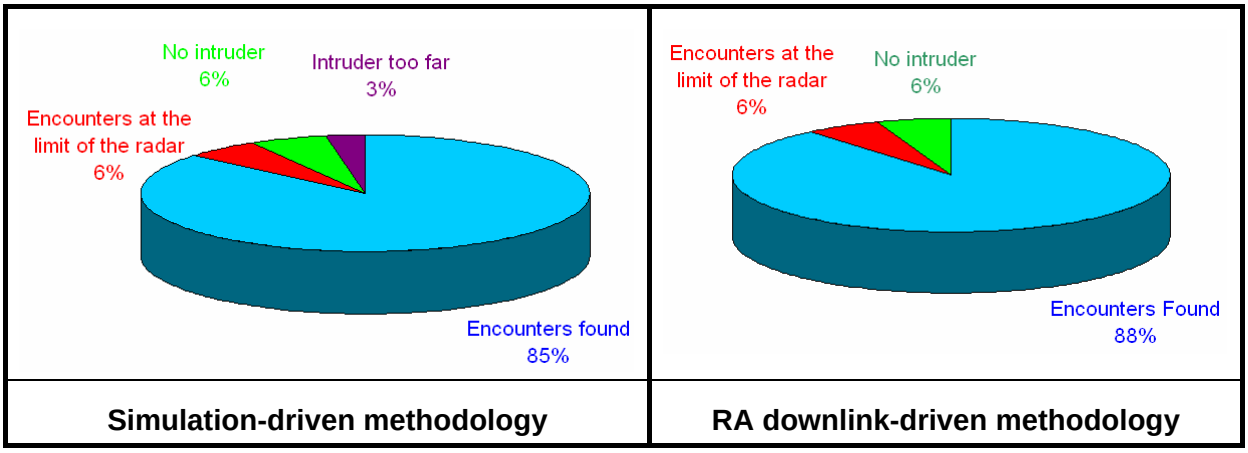


Figure 2: Capture success for simulation-driven methodology

3.1.6. With the simulation-driven methodology, 6% of encounters where an RA occurred were missed because they occurred at the radar coverage limit. 6% were missed because no threat was found and 3% because the threat was found, but the encounter did not meet the capture criteria (typically, because they end up with a large Horizontal Miss Distance (HMD) at closest approach). Consequently, 85% of the encounters which could have been captured were actually captured.

3.1.7. As for the RA downlink-driven methodology, 6% of encounters where an RA occurred were missed because they occurred at the radar coverage limit. 6% were missed because no threat could be identified. Consequently, 88% of the encounters which could have been captured were actually captured.

3.1.8. One can assess that at the maximum, 85% of the RAs can be reproduced though the simulation based process, and 88% through the RA downlink process, for this airspace using this radar data.

3.1.9. The difference between the simulation based process and the RA downlink based process results from the fact that the capture based on TCAS-like criteria can not capture encounters when the involved aircraft have an important horizontal separation. On the contrary, the RA downlink process captures encounters solely on the basis of their identifiers; therefore the geometry of the encounters has no importance on the capture success.

3.2. Number of RAs

3.2.1. The simulation-driven methodology generated 139 RA events, while the RA downlink contained reports for 144 events. 75 events were found in both results, therefore leading to a reproducibility rate of 52%. In Figure 3, they are shown in the intersection of the blue area on the left (RA downlink RAs) and of the pink area (simulated RAs) on the right.

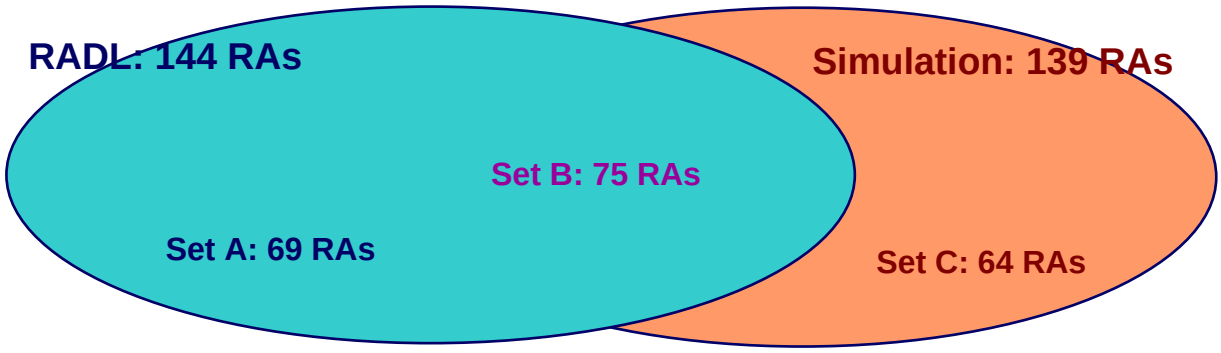


Figure 3: Number of RAs

3.2.2. There are 64 events for which an RA was simulated and which did not actually receive an RA according to RA downlink data. On the contrary, 69 events for which RA downlink indicated an RA were not reproduced by the simulation.

3.2.3. Disabling the Miss Distance Filter (MDF) of the TCAS logic results in an increased reproducibility rate of 61% (i.e., 89 common RA events found through the two methodologies). **Consequently, 9% of RAs are not reproduced through simulation because of the MDF sensitivity to the quality of data fed to TCAS.**

3.3. Comparison of encounter sets

3.3.1. This section provides the comparison of the two sets of encounters obtained through both methodologies by computing a number of indicators that characterize these encounter sets. These indicators have been used in previous TCAS performance assessments.

3.3.2. Figure 4 shows the proportions of Climb/Descend, Adjust Vertical Speed Adjust (AVSA) and preventive RAs, obtained through each methodology.

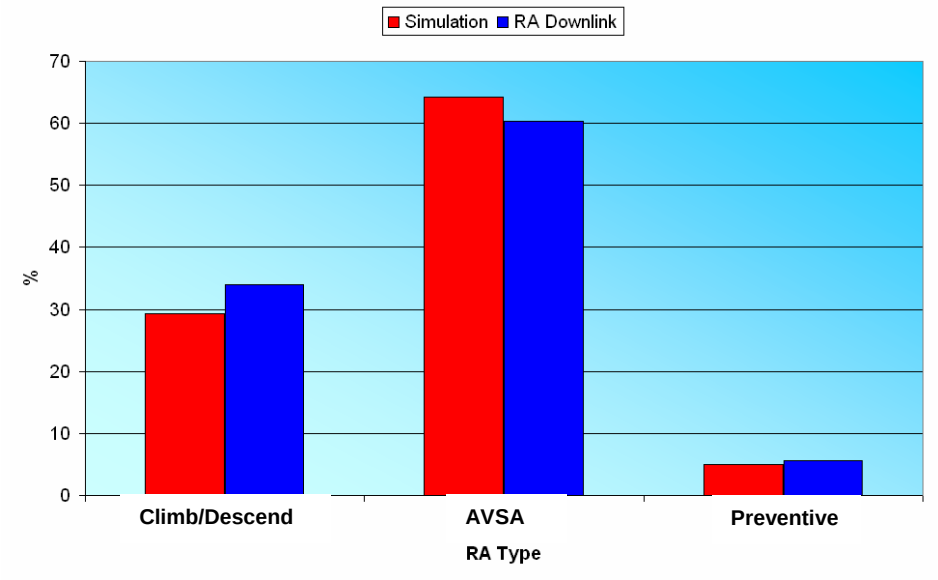


Figure 4: RA types for both methodologies

3.3.3. Both the simulation- and RA downlink-driven methodologies result in a distribution in which nearly two thirds of the RAs are AVSA, while another third Climb/Descend RAs. In both cases, preventive RAs are a very minor part of all RAs.

3.3.4. Figure 5 presents the altitude distribution of RA events obtained through each methodology.

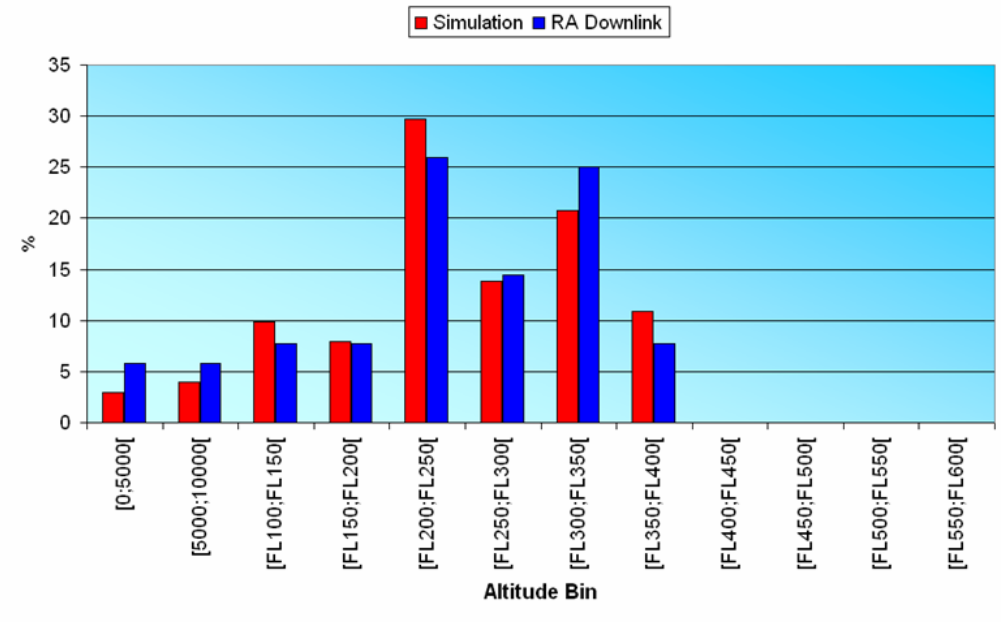


Figure 5: Altitude distribution for both methodologies

3.3.5. The two distributions are very similar: most encounters occur in upper airspace (i.e., over Flight Level (FL) 200).

3.3.6. Figure 6 shows the HMD distribution in RA events obtained through each methodology.

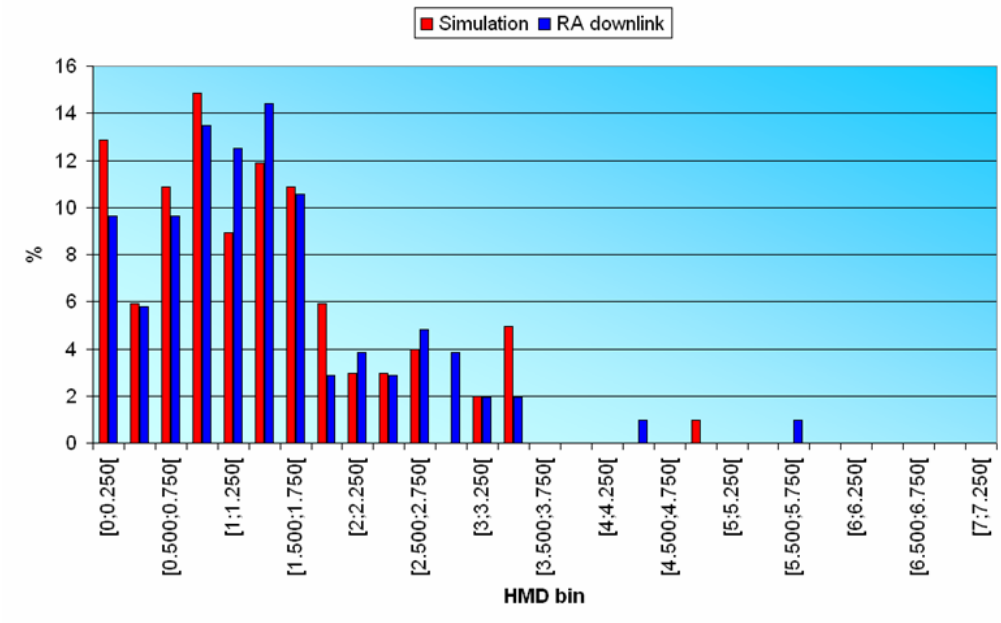


Figure 6: HMD distribution for both methodologies

3.3.7. The two distributions are very similar, with 80% of the encounters below 2 Nautical Miles (NM).

3.3.8. Figure 7 shows the distribution of Vertical Miss Distances (VMD) in RA events obtained through each methodology.

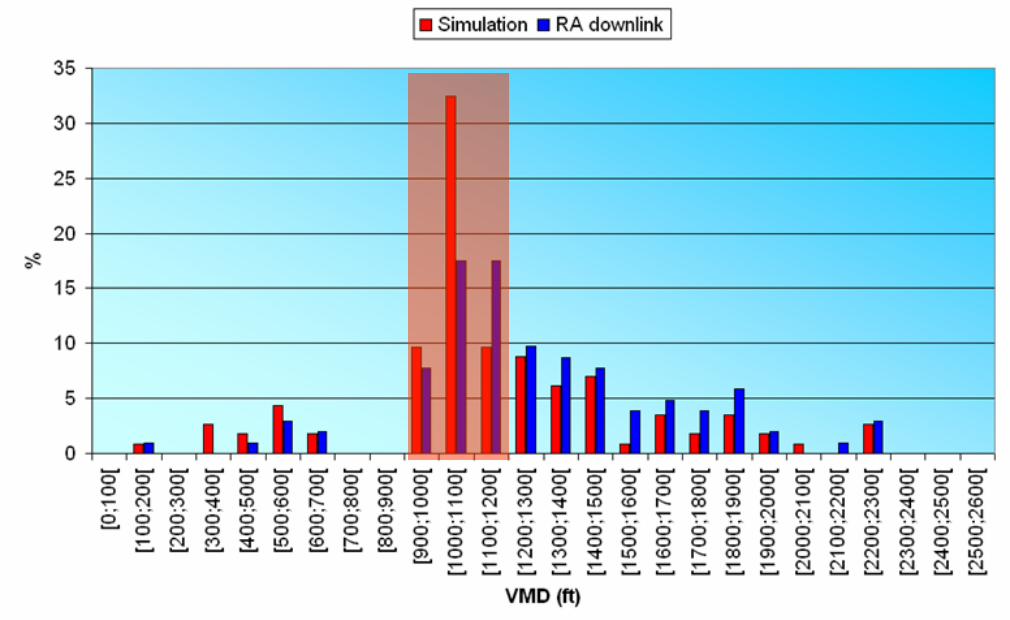


Figure 7: VMD distribution for both methodologies

3.3.9. Both distributions have a peak around 1000 ft, even though the distribution obtained with the simulation based process has a peak between 1000ft and 1100ft, and the distribution based on RA downlink has a lesser peak between these two values, but balanced between 1100 ft and 1200 ft. This peak around 1000 ft results from 1000 ft level-off geometries which are typical in the core area.

3.3.10. The time at which RAs were issued has been compared in the subset of encounters found through both methodologies (i.e. set B). Figure 8 shows the distribution of time differences. A negative difference means that the RA occurred earlier in the simulation than indicated in RA downlink data (this is the expected behaviour, because of the rotation period of the radar).

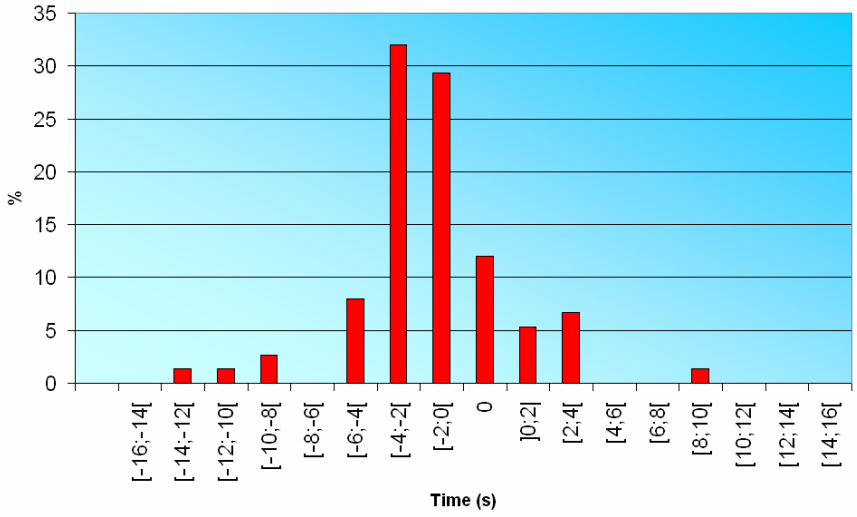


Figure 8: Time difference between simulation and RA downlink

3.3.11. Because the rotation period of the radar used to collect the radar and RA downlink data is 4 second, Figure 8 indicates that 75% of simulated RAs occur within the same radar rotation as when the RA was downlinked. In most other cases, the difference is however close to this rotation time.

3.4. Analysis of differences

3.4.1. Paragraph 3.2 showed that a number of RAs which are simulated are not present in the RA downlink, and vice versa. This section aims at analysing these discrepancies.

3.4.2. Figure 9 shows the distribution of VMD versus HMD for the encounter obtained with the RA downlink based process. The blue dots represent encounters also present in set C (simulation), whereas the red dots represent the encounters which are not present in set C.

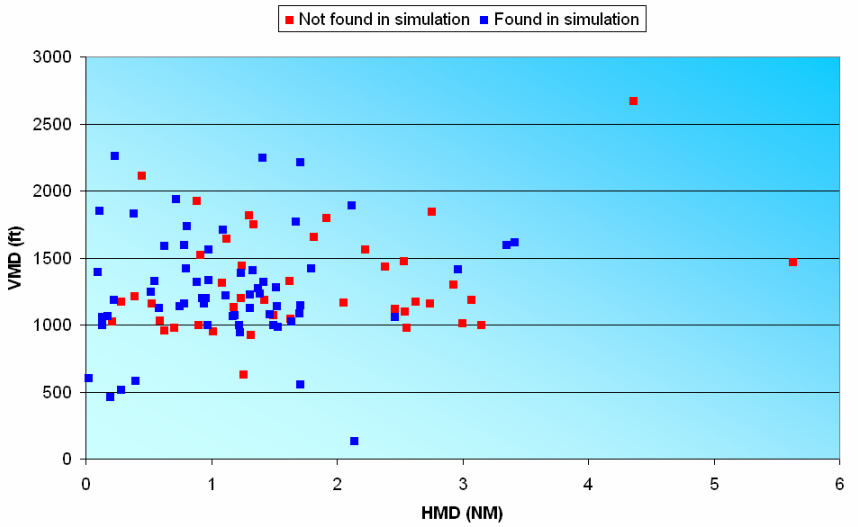


Figure 9: RA downlink encounters – VMD vs HMD

3.4.3. Figure 10 shows the distribution of VMD versus HMD for the encounters obtained through the simulation-driven methodology. The blue dots represent encounters also present in set A (RA downlink), whereas the red dots represent the encounters which are not present in set A.

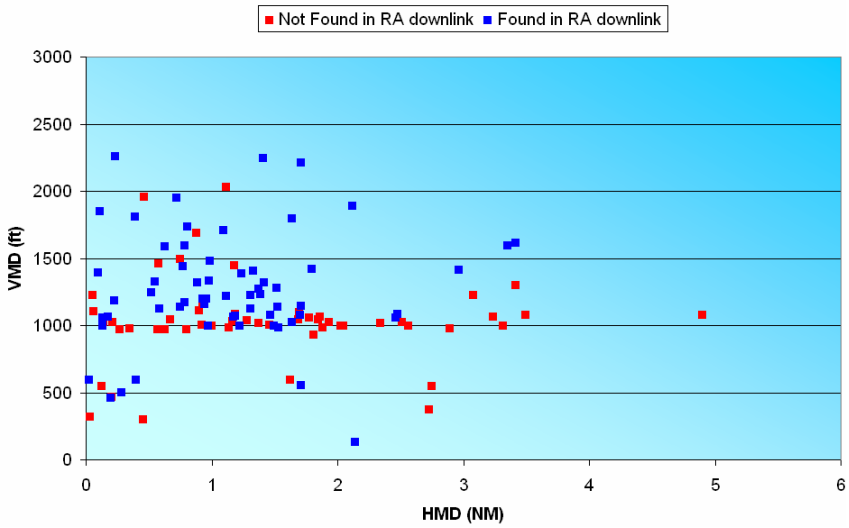


Figure 10: Simulation encounters – VMD vs HMD

3.4.4. These two figures show that on average, the encounters present in set A (RA downlink) and not in the set C (simulation), and vice versa, have an average HMD between 27% and 52% higher than encounters from set B (common to both sets A and C). **This observation shows that the higher the HMD, the more difficult to reproduce RAs.**

3.4.5. 50% of the encounters from set C (simulation) which are not present in RA downlink reports have a VMD between 950 ft and 1,000 ft. This observations shows that **the reproducibility of RAs in 1,000ft level-off encounters is not as good as in other geometries because VSL RAs are sensitive to quality of altitude and vertical rate information.**

3.4.6. This analysis shows that the set of encounters for which an RA is simulated but not reported in the RA downlink, and the set of encounters for which an RA is reported in the RA downlink but not simulated, are close.

4. Conclusion

4.1. Capturing encounters either through TCAS simulation or using RA downlink data leads to distinct, but very comparable, sets of encounters. Indeed, the geometric characteristics (i.e. altitude, HMD, VMD) of the two sets of encounters are almost identical. Consequently, the RAs obtained in simulation are also almost identical to those that have been reported though the RA downlink, in terms of RA type.

4.2. The RAs reported though the RA downlink may not be reproduced in simulation for two main reasons.

- The altitude quantization performed by aircraft transponders and then the interpolation of radar plots to 1-second update rate trajectories creates some differences in the vertical trajectories used by the simulation-driven methodology, compared to actual trajectories. Because the TCAS logic is very sensitive to altitude and vertical rate data, this can result in a different behaviour in simulation.
- The MDF feature may also behave differently in simulated and actual encounters, resulting in some RAs being filtered or not.

4.3. However, although some differences exist in individual encounters, similar trends are observed in both encounter sets. Consequently, using the simulation-driven methodology to conduct TCAS performance analyses is equivalent to using the RA downlink-driven one.

5.

6.

References

[ACA1] ACASA – 'CENA radar data processing for the European Encounter Model' – EUROCONTROL ACAS Programme – WP1.1/090, Version 1.0, February 2000

[ASAR1] ASARP – 'Final report on the post-RVSM radar data processing' – EUROCONTROL Mode S & ACAS Programme' – WP1/18/D, Version 1.0, March 2005

[DO185A] 'Minimum operational performance standards for Traffic alert and Collision Avoidance System II airborne equipment' – RTCA - 1997

[EURO1] EUROCONTROL – 'EUROCONTROL Standard Document for Surveillance Data Exchange - Part 4: Category 048' – EUROCONTROL RDE Task Force – Edition 1.15, April 2007

[SIRE+1] SIRE+ – 'Operational performance of CP115 in New York airspace' – EUROCONTROL Mode S & ACAS Programme – SIRE+/WP6/59/D, Version 1.1, December 2005

[SIRE+2] SIRE+ - 'Operational performance of CP115 in Boston airspace' – EUROCONTROL Mode S & ACAS Programme – SIRE+/WP5/37/D, Version 1.0, March 2007

7. Acronyms

ACAS	Airborne Collision Avoidance System
ANSP	Air Navigation Service Provider
ASTERIX	All purpose STructured Eurocontrol SuRveillance Information eXchange format
AVSA	Adjust Vertical Speed, Adjust
BDS	Comm-B Data Selector
CP	Change Proposal
DSNA	Direction des Services de la Navigation Aérienne
ECAC	European Civil Aviation Conference
EUROCAE	European Organisation for Civil Aviation Equipment
EUROCONTROL	European Organisation for the Safety of Air Navigation
FL	Flight Level
HMD	Horizontal Miss Distance
ICAO	International Civil Aviation Organization
MDF	Miss Distance Filter
MOPS	Minimum Operational Performance Standards
MTOM	Maximum Take-Off Mass
NM	Nautical Mile
NMAC	Near Mid-Air Collision
RA	Resolution Advisory
SA01	SAfety issue 01
SA-AVSA	SAfety issue AVSA
SARPs	Standards And Recommended Practices
SC147	Special Committee 147
SIR	Safety Issue Rectification
SIRE	Safety Issue Rectification Extension
SSR	Secondary Surveillance Radar

TCAS	Traffic alert and Collision Avoidance System
TMA	Terminal Control Area
VFR	Visual Flight Rules
VMD	Vertical Miss Distance
WP	Work Package
WG75	Working Group 75

*** END OF DOCUMENT ***

DOCUMENT CHARACTERISTICS

TITLE		
TCAS II performance in European TMAs Part 2: Methodology Safety Issue Rectification Extension 2006-2008 Project SIRE+ Project		
	ALDA Reference:	09/04/14-10
Document Identifier	**Edition Number:**	1.1
	Edition Date:	03rd February 2009

Abstract

The objective of this study was to analyse TCAS II version 7.0 performance in European Terminal Control Areas (TMAs), both from an operational standpoint and from a safety standpoint. The study has been conducted using radar and Resolution Advisory (RA) downlink data collected in three major TMAs over three months during 2007-2008 winter period.

Part 2 of the report describes methodology used for analysis of events covered in part 1, as well as data collection techniques.

Keywords			
TCAS ACAS	TMAs	SIRE	Methodology

Contact Person(s)	**Tel**	**Unit**
Stanislaw Drozdowski	+32.2.729.3760	Mode S & ACAS Programme
John Law	+32.2.729.3766	Mode S & ACAS Programme

STATUS, AUDIENCE AND ACCESSIBILITY					
Status		**Intended for**		**Accessible via**	
Working Draft	☐	General Public	☐	Intranet	☐
Draft	☐	EATMP Stakeholders	☑	Extranet	☐
Proposed Issue	☐	Restricted Audience	☐	Internet (www.eurocontrol.int)	☐
Released Issue	☑				

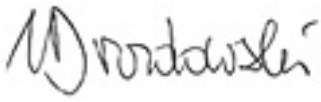
ELECTRONIC SOURCE		
Path:		
Host System	Software	Size
Windows_XP	Microsoft Word / Adobe Acrobat	3.76 MB

EUROCONTROL Headquarters
Mode S & ACAS Programme
96 Rue de la Fusée
B-1130 BRUSSELS

Tel: +32 (0)2 729 3766
E-mail: acas@eurocontrol.int

DOCUMENT APPROVAL

The following table identifies all management authorities who have successively approved the present issue of this document.

AUTHORITY	NAME AND SIGNATURE	DATE
ACAS Operational Expert	 Stanislaw Drozdowski	20 April 2009
Mode S & ACAS Programme Manager	 John Law	20 April 2009