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Collision risk due to TCAS safety issues

Investigation and analysis of TCAS II safety issues in the European airspace

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Abstract

EUROCAE and RTCA have jointly developed revised Minimum Operational Performance Standards (MOPS) for Traffic alert and Collision Avoidance System (TCAS) II, to be known as TCAS II version 7.1. The reasons for the change were the failure of TCAS to reverse some Resolution Advisories (RA) when a reversal is required to resolve the collision threat (safety issue SA01a) and frequent instances of flight crews' unintentional incorrect manoeuvres in the wrong direction to "Adjust Vertical Speed" RAs (safety issue SA-AVSA).

As previously presented in the 2008 SIRE+ Study, due to the combination of these two safety issues, aircraft equipped with TCAS II version 7.0 face a mid-air collision risk of 2.7×10^{-8} per flight hour, corresponding to one collision every 3 years in the European airspace. This exceeds the tolerable rate for catastrophic events related to equipment hazards (10^{-9} per flight hour) by a factor of more than 25.

The current study has reviewed the previous computation with recent (2009) UK and French data. Two SA01a events and two SA-AVSA events were found, in recordings with 3,400,000 flight hours of traffic. Using these additional events, an update of the initial risk of collision (i.e., one collision every 3 years) was made. The new figure computed indicates that the risk of collision with issues SA01 and SA-AVSA is assessed to be one collision every 7.5 years. The corresponding probability (i.e., 9.8×10^{-9} per flight hour) exceeds the tolerable rate for catastrophic events caused by equipment-related hazards by a factor of about 10. The severity of these two issues continues to call for a rapid implementation of the solution, TCAS II logic version 7.1.

Keywords

TCAS	RA	ACAS	CP115
AVSA	Adjust vertical speed	Level-off	LOLO
CP112	SA01	SA-AVSA	RTCA
EUROCAE	DO-185B	ED-143	Version 7.1

Contact Person(s)	Tel	Unit
Stanislaw Drozdowski	+32.2.729.3760	CND/CoE/AT/AO
John Law	+32.2.729.3766	CND/ND/TD/SU

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EUROCONTROL Headquarters
ATC Operations & Systems
96 Rue de la Fusée
B-1130 BRUSSELS

Tel: +32 (0)2 729 3760
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	10 May 2010
ATC Systems & Operations Head of Unit	Martin Griffin	10 May 2010
Surveillance Programmes Manager	John Law	10 May 2010
Principal Manager Network Development	p.o. A. WANDELS Pascal Dias	10 May 2010

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Collision risk due to TCAS safety issues

Investigation and analysis of TCAS II safety issues in the European airspace

Drafted by: Stéphan Chabert

Authorised by: Thierry Arino on 12/04/10

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Executive Summary

TCAS II logic version 7.0 safety issues have been identified in 2000 [EMO1] and 2003. These issues are referenced to as issue SA01 and issue SA-AVSA [SIRE+8].

Issue SA01 deals with the failure of TCAS to reverse some Resolution Advisories (RA) when a reversal is required to resolve the collision threat (i.e. safety issue SA01 described in [DO-298]).

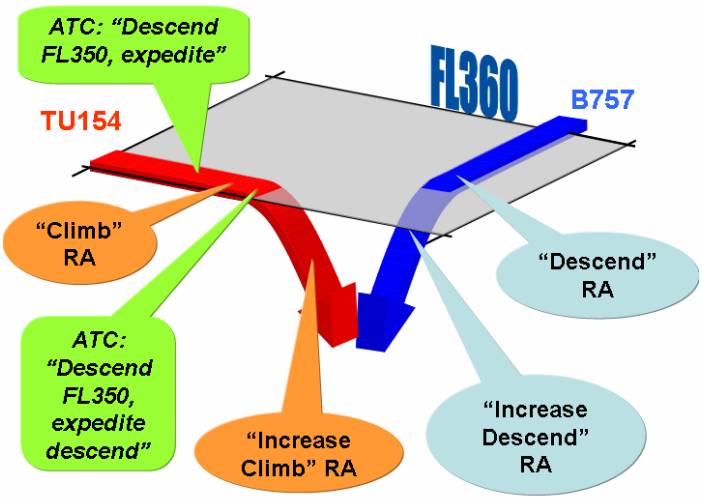

Figure 1: Issue SA01: Überlingen collision

Issue SA-AVSA deals with frequent instances of flight crews' unintentional incorrect manoeuvres in the wrong direction to "Adjust Vertical Speed" RAs (i.e., safety issue SA-AVSA described in [DO-299]).

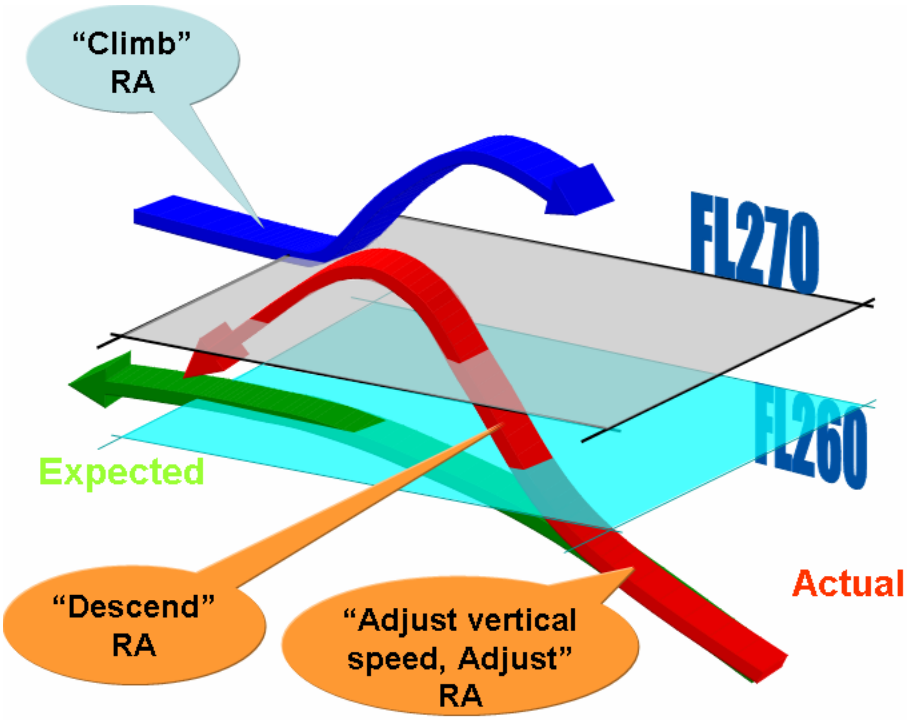

Figure 2: SA-AVSA event in French airspace in 2003

Solutions to these issues are now available [DO-185B] with TCAS II logic version 7.1.

Due to the combination of these two safety issues, and according to an initial computation performed on data dating from 2005 [SIRE+8], aircraft equipped with TCAS II version 7.0 face a mid-air collision risk of 2.7×10^{-8} per flight hour, corresponding to one collision every 3 years in the European airspace. This exceeds the tolerable rate for catastrophic events related to equipment hazards (10^{-9} per flight hour) by a factor of more than 25.

The probability of occurrence used in this risk of collision computation is now dating from 2002 for SA01 and 2005 for SA-AVSA and needs to be updated using up to date data. The current study is therefore revisiting this computation with recent UK and French data.

UK and French events with RAs, extracted from RA downlink and ASMT data dating from 2009, were analysed so as to track these two issues. Two SA01a events and two SA-AVSA events were found, in recordings with 3,400,000 flight hours of traffic.

Using these additional events, an update of the initial risk of collision (i.e., one collision every 3 years) was made. The new figure computed indicates that the risk of collision with issues SA01 and SA-AVSA is assessed to be one collision every 7.5 years. The corresponding probability (i.e., 9.8×10^{-9} per flight hour) exceeds the tolerable rate for catastrophic events caused by equipment-related hazards by a factor of about 10.

If only recently recorded SA01 and SA-AVSA events are considered, the risk of collision with issues SA01 and SA-AVSA is assessed to be one collision every 9.5 years. The corresponding probability (i.e., 7.6×10^{-9} per flight hour) also exceeds the tolerable rate for catastrophic events caused by equipment-related hazards by a factor of more than 7.

These figures, even though lower than the initial value of 3 years between two collisions, are still comparable, and still unacceptable.

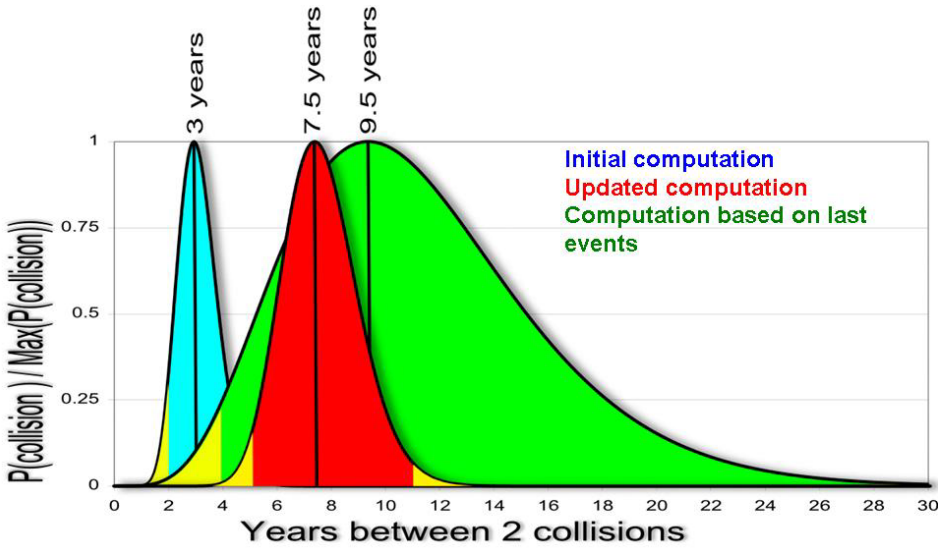

Figure 3: Risk of collision, initial, and updates

In summary, this study shows once again that looking for issues SA01 and SA-AVSA in a monitoring leads to finding them, even over a short period of time.

The severity of these two issues continues to call for a rapid implementation of the solution, TCAS II logic version 7.1.

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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.
ACASA project	ACAS Analysis – a study commissioned by EUROCONTROL in support of the mandate for the carriage of ACAS II in Europe, before implementation of RVSM.
AVSA RA	An “Adjust Vertical Speed, Adjust” RA is an RA requiring the pilot to reduce his aircraft vertical rate to 2000, 1000, 500 or 0 fpm. It is a restriction of manoeuvre intended to maintain a minimum vertical separation from the intruder. The proper response to an AVSA RA is always a reduction in vertical speed.
CP112E	A change to the TCAS II MOPS addressing a safety issue labelled SA01 and related to an inappropriate reversal logic operation. This change is included in TCAS II version 7.1.
CP115	A change to the TCAS II MOPS addressing the safety issue of unintentional opposite responses to initial AVSA RAs. It consists in replacing AVSA RAs with a single “Level-off” RA. This change is included in TCAS II version 7.1.
Intruder	A transponder-equipped aircraft within the surveillance range of ACAS and that is tracked by ACAS.
Near Mid-Air Collision	An encounter in which the horizontal separation between two aircraft is less than 500 ft and the vertical separation is less than 100 ft. The rate of NMACs to actual collisions is 10 to 1.
Positive RA	An RA requiring the flight crew to perform a manoeuvre in order to achieve a minimum vertical separation from the intruder.
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.
RA sense	The sense of an ACAS II RA is “upward” if it requires a climb or a limitation of the rate of descent and “downward” if it requires a descent or a limitation of the rate of climb.
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.

SIRE+	Safety Issue Rectification – a series of studies (SIR, SIRE, SIRE+) 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.

Acronyms

ACAS	Airborne Collision Avoidance System
ACASA	ACAS Analysis
ATC	Air Traffic Control
AVSA	Adjust Vertical Speed, Adjust
CAS	Collision Avoidance System
CP	Change Proposal
CPA	Closest Point of Approach
EMOTION-7	European Maintenance Of TCAS II version 7.0
FAA	Federal Aviation Administration
FL	Flight Level
HMD	Horizontal Miss Distance
ICAO	International Civil Aviation Organization
IFR	Instrument flight rules
MOPS	Minimum Operational Performance Standards
NM	Nautical Mile
NMAC	Near Mid-Air Collision
RA	Resolution Advisory
SIR	Safety Issue Rectification
TA	Traffic Advisory
TCAS	Traffic Alert and Collision Avoidance System
TMA	Terminal control Area
UK	United Kingdom
VFR	Visual flight rules
VMD	Vertical Miss Distance
VTT	Variable Threshold Test

1. Introduction

1.1. Background and purpose

1.1.1. TCAS II logic version 7.0 safety Issues have been identified in 2000 [EMO1] and 2003. These issues are referenced to as issue SA01 and issue SA-AVSA [SIRE+8]. The associated risks of collision because of these issues were computed in the past [EMO2, EASA], and solutions to these issues are now available [DO-185B].

1.1.2. However, the probability of occurrence used in this risk of collision computation is now dating from 2002 for SA01 and 2005 for SA-AVSA and needs to be updated using up to date data. The current study is therefore revisiting this computation with recent UK and French data.

1.1.3. This report also presents an analysis of the operational performances of TCAS in the European airspace. This analysis was conducted using the DSNA OSCAR test bench and RA downlink data. It provides general statistics about the RAs in the European airspace, on topics such as the geometries of encounters or the localisation of RAs.

1.1.4. The methodology and tools used for this analysis are similar to those already put in place for the analysis of Boston, Paris, London, and New York TMAs [SIRE+1, SIRE+2, SIRE+3, SIRE+4].

1.2. Document overview

1.2.1. Part 2 presents some background on issue SA01 and SA-AVSA.

1.2.2. Part 3 presents briefly the data used and the methodology used for this study.

1.2.3. Part 4 presents general operational statistics about the RAs, such as the type of RAs triggered and response rates.

1.2.4. Part 5 presents the result of the monitoring of issues SA01 and SA-AVSA, and the update of the risk of collision with these issues.

2. Background

2.1. ACAS and TCAS

2.1.1. ACAS standard

2.1.1.1. ICAO has developed, since the beginning of the eighties, standards for Airborne Collision Avoidance Systems (ACAS).

2.1.1.2. ACAS II provides two levels of alert to the pilot: Traffic Advisories (TAs) and vertical RAs. The TAs aim to help the pilot to prepare for a possible RA and in the visual search for the 'intruder' aircraft, whereas the RAs are indications to the pilot of manoeuvres intended to provide safe vertical separation from one or several 'threats', or manoeuvre restrictions intended to maintain existing separation[1]. When the threat aircraft is also fitted with an ACAS system, both ACAS' co-ordinate their RAs through the Mode S data link, in order to select complementary resolution senses.

2.1.1.3. The ACAS II mandate applies worldwide to all civil fixed-wing turbine-engined aircraft having a maximum take-off mass exceeding 5,700 kg, or a maximum approved passenger seating configuration of more that 19.

2.1.1.4. The European policy regarding ACAS II is to require the mandatory carriage and operation of an airborne collision avoidance system by defined civil aircraft in the airspace of the Member States of the European Civil Aviation Conference (ECAC). This implementation process has been managed by the Mode S Programme in EUROCONTROL on behalf of the ECAC States.

2.1.2. TCAS equipments

2.1.2.1. TCAS II version 7.0, as specified in [DO-185A], is the only equipment which complies fully with ACAS II standards and recommended practices (SARPS), published by ICAO. Therefore version 7.0 is required to meet the ACAS II mandate in the ECAC Member States. Version 7.0 was developed to address a number of issues identified through the operational monitoring of the former version 6.04a performance.

2.1.2.2. In the former TCAS II version 6.04a, negative RAs[2] were announced as "Reduce Climb, Reduce Climb" or "Reduce Descent, Reduce Descent". The proper response to a negative RA is always a reduction in vertical speed, i.e. a manoeuvre towards level flight. However, pilots sometimes misunderstood the aural message as "Climb" or "Descend" and responded to the RA by increasing their vertical rate. Version 7.0 replaced the aural annunciation associated to negative RAs with "Adjust Vertical Speed, Adjust".

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[1] A guide to the use of ACAS and its functionality can be found in the EUROCONTROL ACAS brochure ([ACA1]).

[2] A negative RA is typically issued when a TCAS-equipped aircraft is climbing or descending towards another aircraft, and the TCAS logic determines that the TCAS-desired vertical miss distance between the two aircraft can best be achieved by the TCAS aircraft reducing its vertical speed, while maintaining its current vertical direction. These RAs, mainly occurring in 1000 ft level-off geometries, represent two thirds of all RAs observed in the European airspace [EMO1].

2.1.2.3. TCAS II version 7.0 also introduced the capability to reverse the sense of RAs (e.g., from climb to descend) to resolve deteriorating conditions during an encounter with another TCAS-equipped aircraft. A reversal may be needed after the initial RA when one pilot does not respond to TCAS RA guidance, or worse, manoeuvres in the opposite direction.

2.2. Probability of occurrence, severity and risk of collision

2.2.1. In this study, a probability of occurrence of an issue is a frequency, expressed per flight hour. It is computed as the ratio of the number of occurrences of the issue, divided by the number of flight hours necessary for these occurrences of the issue to occur.

2.2.2. The severity is the probability that, knowing that an SA01 or SA-AVSA event occurs, it will lead to a collision.

2.2.3. The risk of collision with the issue is computed as the product of the probability of occurrence of the issue by the severity of the issue.

2.3. Safety Issue SA01

2.3.1. Description

2.3.1.1. The design principles of TCAS II version 7.0 allow only one sense reversal and care has been taken to ascertain the relative position of aircraft and their trajectories before taking the decision to reverse the ongoing RA. Notably, reversing the on-going RA is not permitted while aircraft are manoeuvring in the vertical dimension and are at co-altitude. This can lead to delaying the decision to reverse if both aircraft are climbing or descending at similar vertical speeds. In the extreme, no sense reversal can be issued although it would be required. This safety issue, labelled SA01, can occur either in encounters with an unequipped aircraft[3] or in TCAS-TCAS encounters.

2.3.1.2. The SA01 issue was initially predicted early in 2000 by analyses and simulations conducted within a EUROCONTROL project named European Maintenance Of Tcas version 7 (EMOTION-7) ([EMO1]). This issue was subsequently observed during European monitoring efforts from 2001 to 2005. Analysis indicates that the SA01 issue has been a factor contributing to two major events: the Yaizu (Japan) accident in 2001 and the Überlingen mid-air collision in 2002. In 5 years, 8 other occurrences have been observed in the European airspace. Each of these events resulted in severe losses of separation where collision was only avoided by chance. These severe incidents were only identified when actual occurrences of safety issue SA01 were actively tracked.

2.3.1.3. Safety issue SA01 can occur when two aircraft are flying at the same Flight Level (FL) and are converging in range. A very late Air Traffic Control (ATC) instruction then induces the intruder to manoeuvre, thwarting the initial RAs. Figure 4 illustrates this issue for two aircraft at FL110, and the behaviour expected from TCAS.

[3] In this situation, a TCAS unit operating in stand-by or TA-only mode is also considered unequipped

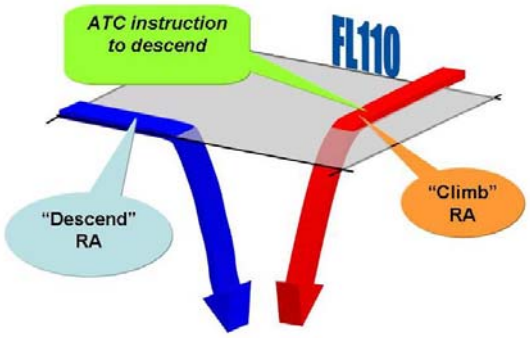
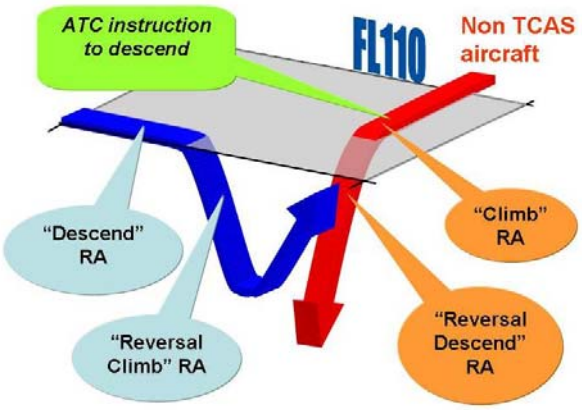
Current behaviour due to issue SA01	Expected behaviour
	

Figure 4: Issue SA01

2.3.2. SA01 issue illustration: Überlingen mid-air collision

2.3.2.1. This scenario occurred over Überlingen on 1st July 2002. As indicated in Figure 5, it involved a Boeing 757 on a northern course (in blue in Figure 5) and a Tupolev 154 on a western course (in red in Figure 5). Both aircraft were level at FL360 and on converging tracks.

2.3.2.2. ATC gave the Tupolev 54 a late instruction to expedite its descent to FL350. As the flight crew started to descend, a "Climb" RA was triggered by its TCAS II unit, requesting a 1500 fpm climb rate. Despite this "Climb" RA, the Tupolev 154 flight crew continued to descend according to the ATC instruction. A coordinated "Descend" RA was generated onboard the Boeing 757, requesting a 1500 fpm descend rate. The flight crew responded correctly and followed this RA.

2.3.2.3. As the Boeing 757 started its descent, its TCAS unit strengthened its advisory to an "Increase Descent" RA, requesting a 2500 fpm rate of descend. This RA was also correctly followed by the flight crew. Because the Tupolev 154 flight crew had not acknowledged his instruction, the controller repeated the instruction to expedite descent to FL350. This time, the flight crew acknowledged and increased the rate of descent. Despite an "Increase Climb" RA requesting a 2500 fpm rate of climb, the Tupolev 154 flight crew continued to descend and the aircraft collided at 34890 ft.

2.3.2.4. As indicated in 2.3.1, the sense of the initial RAs was not reversed because the aircraft remained at co-altitude until they collided. In this accident, a reversal in the sense of RAs might have prompted action to avoid the collision.

2.3.2.5. It is important to note that, although the Überlingen accident involved two TCAS-equipped aircraft, a similar event can occur with an aircraft not equipped with TCAS, or having its TCAS unit set on TA-only mode, manoeuvring in the same direction as the TCAS-equipped aircraft.

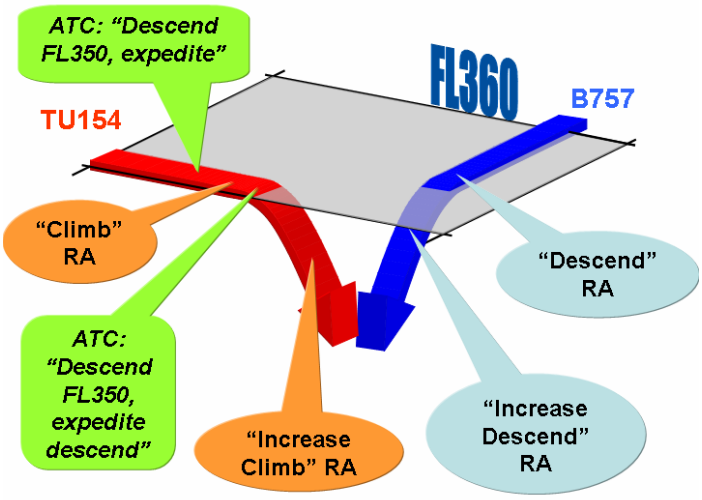


Figure 5: Überlingen collision description

2.3.3. Probability of collision

2.3.3.1. Using data provided by a major European airline, an assessment of the probability of occurrence of issue SA01 has been performed by the EUROCONTROL EMOTION-7 project ([EMO2]) in 2002.

2.3.3.2. Analysis of the airborne data provided by this airline allowed to find 2 actual occurrences of issue SA01. Given the number of hours flown annually by this airline, it was derived that an SA01 event could be observed at an estimated rate of once every 211,330 flight hours in the European airspace, or 4.7×10^{-6} per flight hour.

2.3.3.3. Using this rate of occurrence, and data on additional SA01 events identified between 2002 and 2005 though a dedicated monitoring effort conducted within SIR [SIR] and SIRE [SIRE] projects, a probability of collision due to issue SA01 was derived, and was found to be 2.2×10^{-8} per flight hour, which corresponds to one collision every 4 years in the European airspace, due to issue SA01.

2.3.3.4. One issue with this probability of collision is the fact that it is based on a probability of occurrence which was computed in 2002, with only two events. This study is a good opportunity to update this figure using recent SA01 events.

2.3.4. CP112E solution to issue SA01

2.3.5. Solving the issue with the reversal logic was done through a significant code change of TCAS II version 7.0, which has been submitted to RTCA as Change Proposal 112E (CP112E) to amend the TCAS II MOPS.

2.3.6. CP112E brings two significant improvements to the reversal logic of TCAS II. First, it introduces a monitoring of the aircraft vertical rate in order to detect any non-compliance with the RA sense. Then it includes a better projection of the current aircraft trajectories to identify encounters where two co-altitude aircraft maintain similar vertical rates.

2.3.7. The former is designed to solve occurrences of SA01 between two TCAS-equipped aircraft while the former is intended to address occurrences of SA01 with an aircraft not equipped with TCAS. If CP112E detects either situation, it relaxes the conditions

for reversing the ongoing RA so that it can occur at an earlier time than with current TCAS II version 7.0.

2.4. Safety Issue SA-AVSA

2.4.1. Description

2.4.1.1. Monitoring of TCAS performance performed separately by airlines and by EUROCONTROL has highlighted several instances where flight crews responded unintentionally in the opposite direction to that specified by TCAS when an initial "Adjust Vertical Speed, Adjust" (AVSA) RA was issued. The proper response to an AVSA RA is always a reduction in vertical speed (i.e., a manoeuvre towards level flight). When a flight crew manoeuvres in the opposite direction to an AVSA RA, it is almost always manoeuvring towards the intruder and thus increases the risk of collision.

2.4.1.2. Several causes have been identified that can explain an unintentional opposite reaction to an AVSA RA, including a lack of training for this type of RAs. However, the main factor remains the design of the AVSA RAs. First, the aural annunciation associated with AVSA RAs (i.e., "Adjust Vertical Speed, Adjust") does not give explicit instructions on the required manoeuvre.

2.4.1.3. Then, some TCAS displays prove to be difficult to interpret when AVSA RAs are posted. Indeed, the position of the green arc on vertical speed displays can be misleading for some pilots who react to TCAS RAs according to the position of the green area relatively to the 0 fpm indicator. This is illustrated by Figure 6 which shows a number of RAs as they are displayed on a vertical speed tape and what the requested reaction to these RAs is. A correct behaviour when faced with positive RAs (e.g., "Climb" or "Descend" RAs) leads to opposite reactions to AVSA RAs requesting vertical rates of 500, 1000 or 2000 fpm

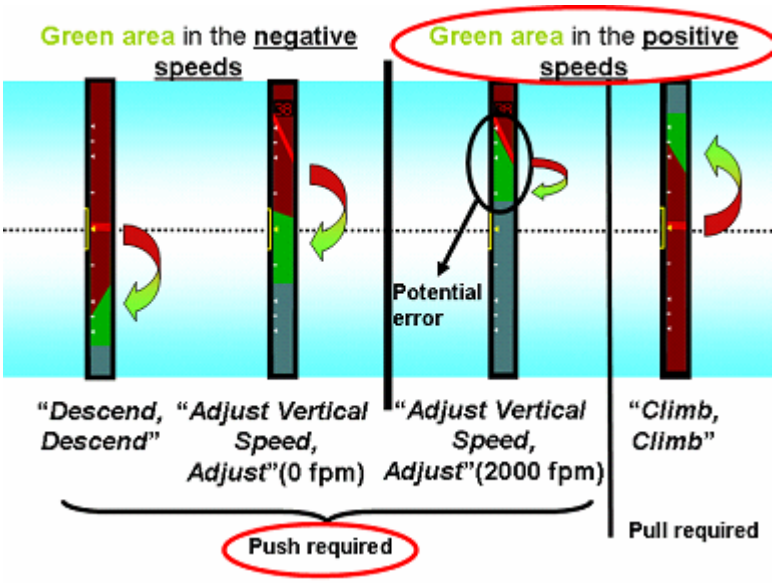


Figure 6: Requested reactions to RAs

2.4.1.4. Several European airlines have assessed the frequency of this issue through their Flight Data Management programme and have discovered that unintentional opposite responses occurred in close to 5% of initial AVSA RAs. Numerous occurrences have

also been identified through accident investigation, pilot and controller reports. This highlights that issue SA-AVSA can be observed as soon as it is actively tracked.

2.4.2. SA-AVSA illustration

2.4.2.1. An occurrence of the SA-AVSA safety issue occurred in French airspace in 2003 and is shown in Figure 7. It involves an Airbus 320 level at FL270, heading South (in blue in Figure 7), and a second Airbus 320 cleared to climb to FL260, heading North (in red in Figure 7). The second aircraft's rate of climb was about 3300 fpm.

2.4.2.2. When passing through FL253, its TCAS triggered an initial AVSA RA requiring a reduction in the rate of climb to 1000 fpm. However, the flight crew misinterpreted the RA and reacted opposite to it: the rate of climb was increased to more than 6000 fpm instead.

2.4.2.3. The closure rate increased between the two aircraft and the initial AVSA RA was strengthened to a "Descend" RA. The flight crew followed this second RA but the manoeuvre took some time to be effective due to the significant change in vertical speed to be achieved.

2.4.2.4. As a result of this opposite reaction to the initial AVSA RA, the climbing Airbus 320 busted its flight level by 1200 ft and the level Airbus 320 received a "Climb" RA requesting a 1500 fpm rate of climb. Even though the flight crew correctly followed this last RA, the aircraft were only separated by 300 ft vertically and 0.8 Nautical Miles (NM) horizontally at their point of closest approach.

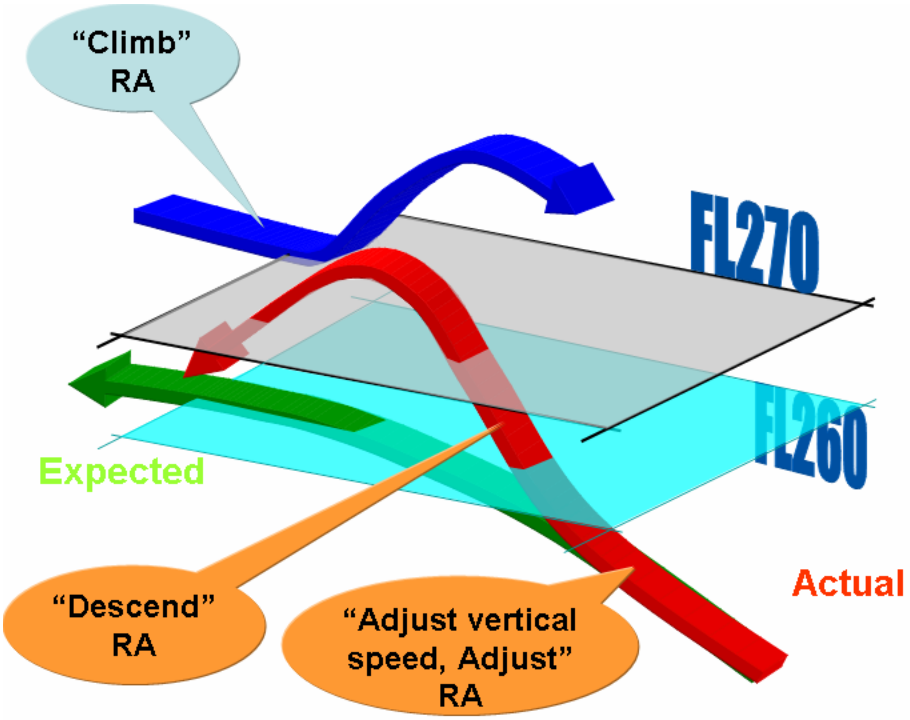


Figure 7: SA-AVSA event in French airspace in 2003

2.4.2.5. If the flight crew had correctly reduced their rate of climb as required by TCAS, simulations show that not only would the climbing Airbus 320 have levelled off correctly, but that the level Airbus 320 would not have received any RA.

2.4.3. Probability of collision

2.4.3.1. In 2004 and 2005, 15 opposite responses to initial AVSA RAs leading to an altitude bust have been identified in French airspace, involving operators from various States. Given the total number of 3.93×10^{6} flight hours flown during these two years, the probability of occurrence of such opposite responses can be estimated to 3.82×10^{-6} per flight hour.

2.4.3.2. A probability of collision resulting from an opposite response to an initial AVSA RA was derived from the miss distances in the observed events and was estimated to 1.41×10^{-3}.

2.4.3.3. By combining the above two figures, the resulting estimated risk of collision because of SA-AVSA amounts to 5.4 collisions per 10^{9} flight hour. This rate is equivalent to 1 collision every 15 years when extrapolated for European airspace as a whole.

2.4.3.4. This study will provide the opportunity to update this probability using recent SA-AVSA events.

2.4.4. CP115 solution to issue SA-AVSA

2.4.4.1. It has been observed that enhancements in training alone can only improve the behaviour of a flight crew when an AVSA RA is issued, but are not sufficient to avoid all the opposite reactions. Therefore, to fully address issue SA-AVSA a complete solution had to be envisaged, including a change in the TCAS logic.

2.4.4.2. The solution adopted by RTCA SC147/EUROCAE WG75, and endorsed by major airlines participating to these groups, is to simplify the TCAS RA design and replace the different AVSA RAs with a single Level-off RA. The associated aural message, “Level-off, Level-off”, is straightforward and the associated manoeuvre corresponds to the standard manoeuvre already performed in critical situations. Additionally, this replacement also simplifies the TCAS operational procedure and training.

2.4.4.3. This solution, referenced in the RTCA arena as CP115, is illustrated in Figure 8, in the case of climbing aircraft. The result is equivalent for descending aircraft.

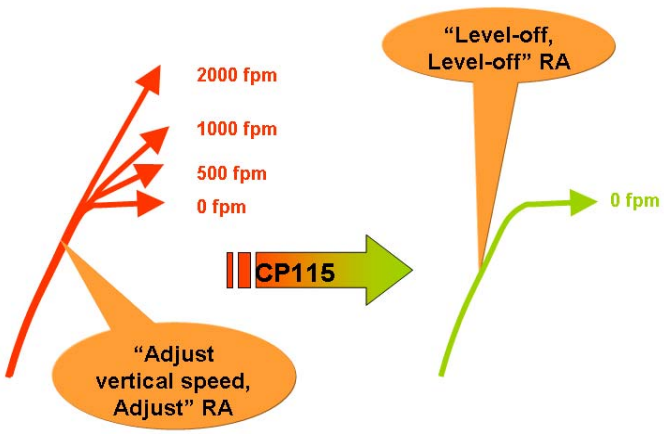


Figure 8: Solution to the SA-AVSA issue

2.5. Risk of collision due to issues SA01 and SA-AVSA

2.5.1. The combined risk of collision due to both issues SA01 and SA-AVSA, to be updated in this study, was computed in [SIRE+8]. It was found to be one collision every 3 years, with a range of 2 to 5 years at the 95% confidence level. This is illustrated by the figure below, which shows the combined probability of collision due to issues SA01 and SA-AVSA.

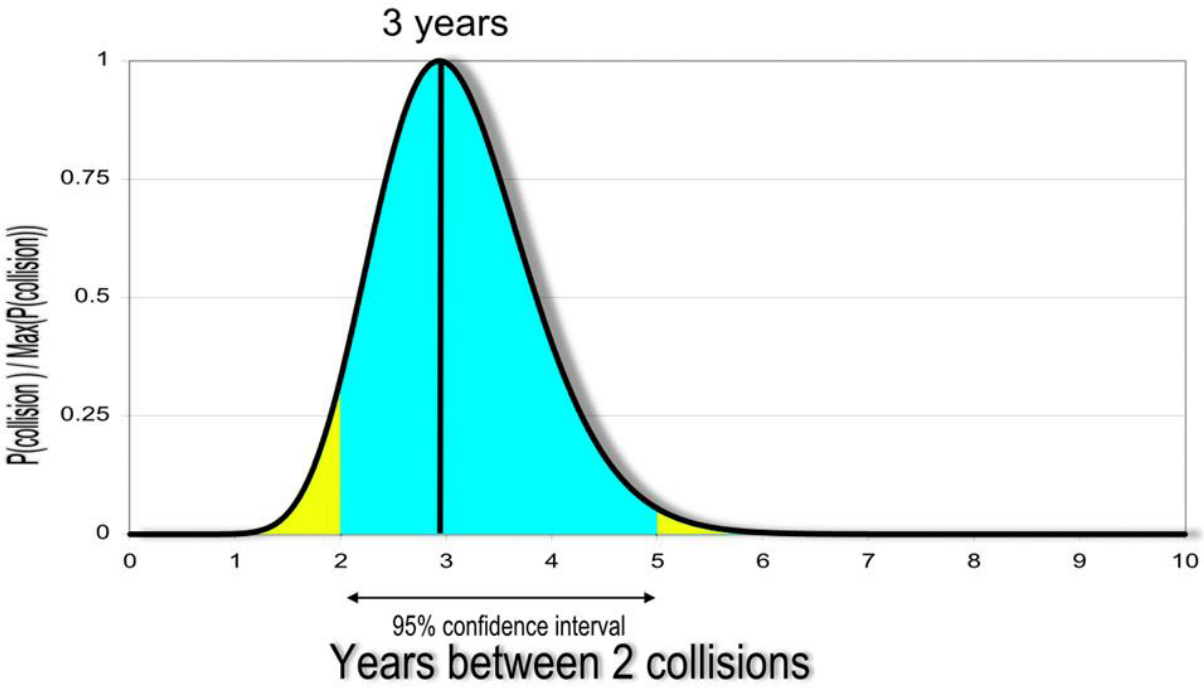


Figure 9: Risk of collision with issues SA01 and SA-AVSA

3. Data and methodology

3.1. Data used for the study

3.1.1. The available data provided by DSNA encompasses 6 months of RA downlink data for 2009. The recording period ranges from April 2009 to September 2009, for 4 radars, and corresponds to approximately 1,000,000 flight hours:

- Roissy
- Chaumont
- La Dole
- Vitrolles

3.1.2. The available data provided by NATS encompasses data from March 2009 to November 2009, for 12 radars, and corresponds approximately to 2,400,000 flight hours. It must be mentioned however, that there is an uncertainty on the computation of this number of flight hours, which was made counting the flight hours for a few days, and then extrapolating to the full period of time considered. However, despite the uncertainty on this figure, this estimate is considered good enough to be used in this study.

- Allans Hill
- Belfast
- Burrington Combined
- Burrington SSR
- Claxby
- Clee Hill
- Cromer
- Debden
- Fitfull Head
- Glasgow
- Heathrow 10
- Pease Pottage

3.1.3. The following figure shows an estimate of the zone covered by the radars, as the exact radius of all the radars used is not known.

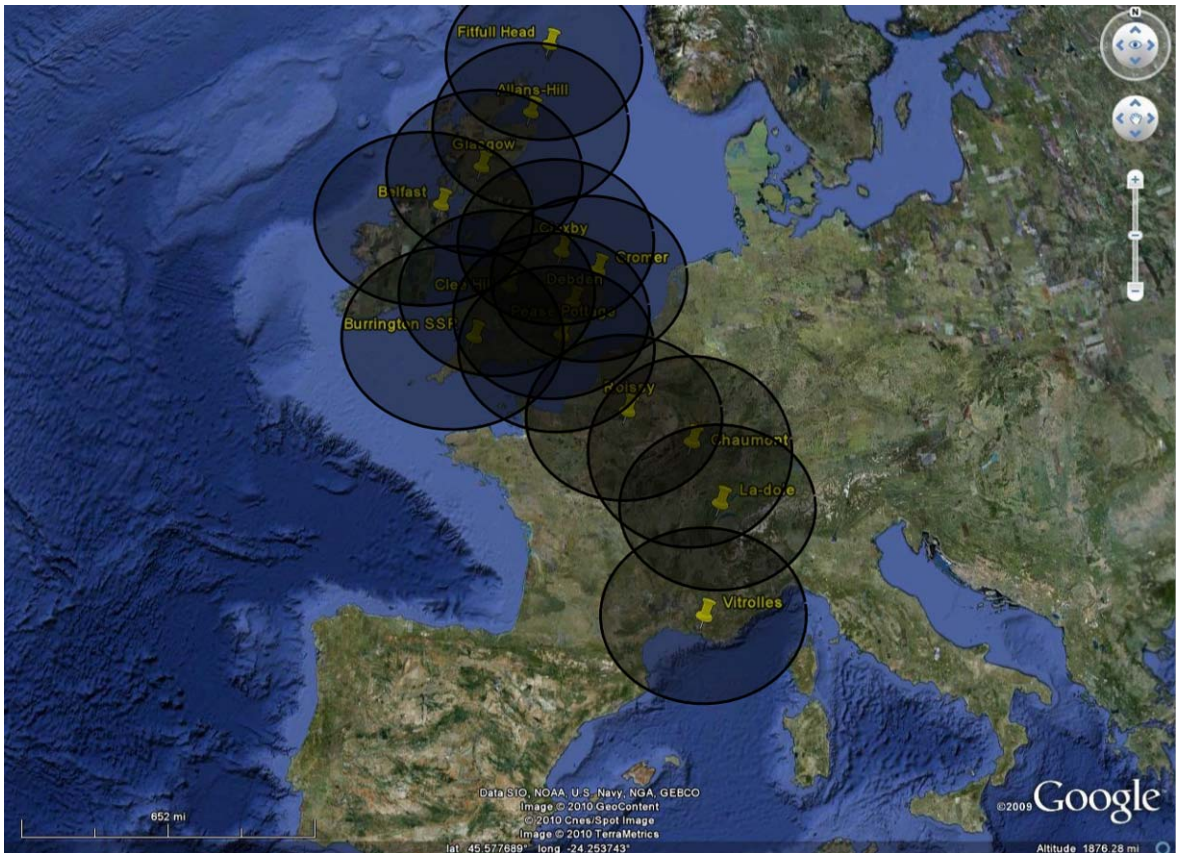


Figure 10: Radar coverage

3.1.4. These radars permit to cover all the UK, and most of the European core area. Western part of France is not covered.

3.1.5. The data provided by NATS contains only the RA events (i.e., RAs and trajectories of involved aircraft), whereas the data provided by DSNA contains the full radar data. As a result, the processing of DSNA data required an initial step of identification of the RA events.

3.2. Capture of encounters based on RA downlink from DSNA

3.2.1. A methodology has been established to capture and reproduce the events that are of interest in the scope of the present study.

3.2.2. It consists in first decoding the radar data in ASTERIX category 48 format, to get RA downlink data, which contains information on the RAs received by aircraft.

3.2.3. Then trajectories of aircraft involved in RAs are extracted from radar data, using the callsigns and Mode A of one or of the two aircraft known from RA downlink. These pairs of trajectories are called encounters.

3.2.4. Then a set of filters are passed on the extracted encounters to remove:

- Duplicate encounters. Indeed, the radars have some overlap, therefore it is frequent to extract the same encounter from several radars. An algorithm is passed to detect identical encounters from different radars.
- Encounters involving only military aircraft;

- Encounters with RAs caused by military interceptions;
- Encounters considered incomplete to be used for the present study (e.g., plots missing, encounters not complete because they are close to the limit of the radar range, etc.).

3.2.5. Following this step, a first manual check of all the encounters was made to refine the automatic filtering.

3.2.6. Then a second manual check of discarded encounters was performed by an ATC expert so as to get back those involving military aircraft under civilian control, which were discarded in the previous step.

3.2.7. From this filtering based on RA downlink, 519 RAs were found.

3.3. Capture of encounters based on NATS ASMT data

3.3.1. The methodology applied to NATS data was similar, except that these data only contains small ASMT[4] files with aircraft of interest. The pre-processing was therefore different in that ASMT files were decoded rather than ASTERIX files, however the following steps, including manual check, were identical. In addition to this decoding, NATS made available a table summarizing the information for all the RAs on the period of time covered by the data provided.

3.3.2. As a result of this treatment, 749 RAs were found.

3.3.3. The manual check performed for DSNA and NATS data does not ensure with 100% confidence that all military encounters under military control were discarded for the computation of general statistics on RAs. For the identification of new occurrences of SA01 issues and SA-AVSA issues however, which is the main goal of this study, a more accurate check was made so as to ensure that the encounters to be used for the update of the risk of collision do not involve such aircraft.

[4] **A**utomatic **S**afety **M**onitoring **T**ool. ASMT was developed by the EUROCONTROL Experimental Centre (EEC), in co-operation with the Maastricht Upper Airspace Centre, for pilot operational use in 2000. **ASMT** provides an automatic monitoring facility for safety related occurrences based on operational data. It detects and categorises each occurrence for assessment by trained operational experts.

4. Operational statistics on identified RAs

4.1. Introduction

4.1.1. This part presents some operational statistics about the extracted RAs, about the place where they took place, and about the geometries of the encounters in which they were triggered.

4.2. Statistics on the RAs

4.2.1. Coordinated RAs

4.2.1.1. The proportion of coordinated RAs[5] was found to be low, equal to 14.8%. This rate is consistent with the rate found in other monitoring [PASS], which equals 17%.

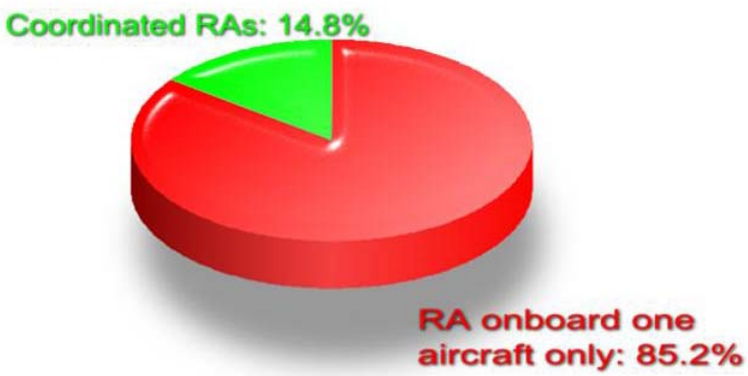


Figure 11: Rate of coordinated RAs

4.2.1.2. This rate is pretty low, and is due to the significant proportion of low altitude encounters against VFR traffic (i.e., not equipped with TCAS), and to the significant proportion of encounters in which the VTT logic of the CAS logic applies (i.e., 1000 ft level-off encounters, in which a level aircraft has its RA delayed, or even not triggered with TCAS II logic version 7.0). This feature of the CAS logic aims at reducing the issuance of RAs in situations where there is no risk of collision, as illustrated below.

4.2.1.3. The left view shows the horizontal plane, whereas the right view shows the vertical profiles.

[5] A coordinated RA means an RA onboard both aircraft

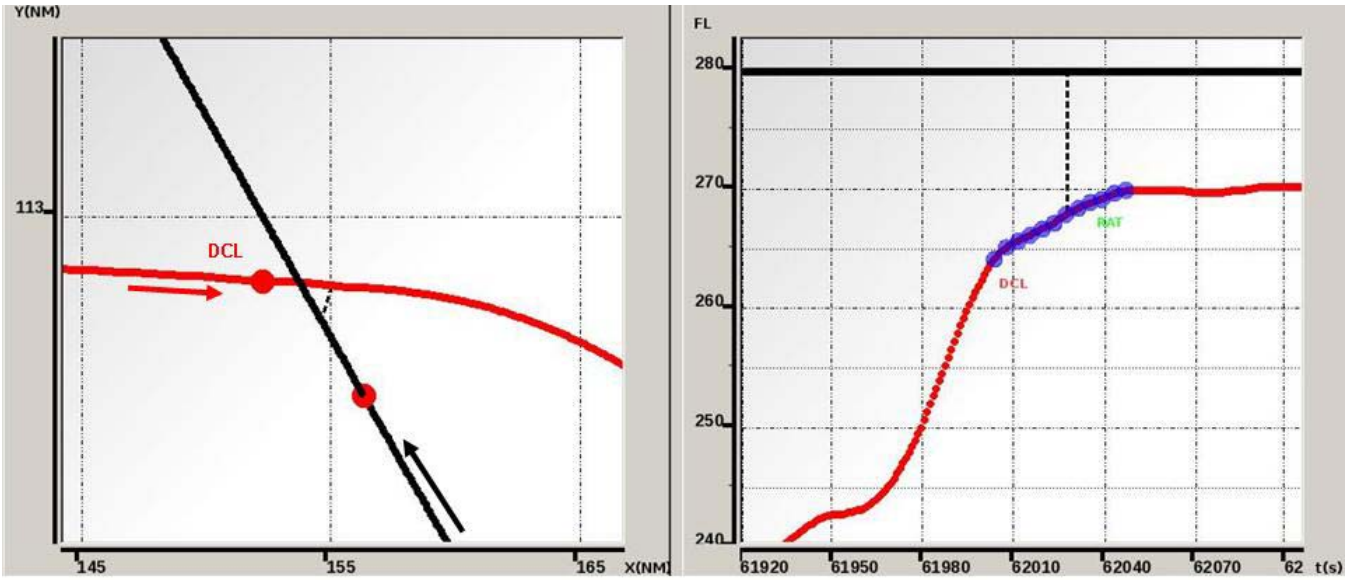


Figure 12: 1000 ft level-off encounter with only one aircraft having an RA
DCL: "Adjust vertical speed, Adjust" RA, **RAT**: RA terminated
The red circles on the horizontal trajectories show where the aircraft were at the time of the initial RA

4.2.1.4. The climbing aircraft receives an adjust vertical speed RA, requesting to limit the rate of climb. The upper aircraft, level at FL200, does not receive any RA, despite the fact that it is also equipped with TCAS. In this geometry, TCAS II logic version 7.0 delays or even does not trigger RAs for the level aircraft.

4.2.1.5. As a result, the VMD is 1200 ft and the HMD is 1.07 NM.

4.2.2. Type of alerts

4.2.2.1. The following figure shows the type of RAs per altitude band. The airspace was divided into 3 altitude bands, one below 5000 ft, which is close to the bottom of TMAs in the airspace considered for this study, one above FL135, which is a common boundary between TMA and en-route operations in the airspace used for this study, and another between these two. Indeed, just dividing the airspace into two parts, above and below FL135 would have partially hidden the proportion of monitor vertical speed RAs below 5000 ft.

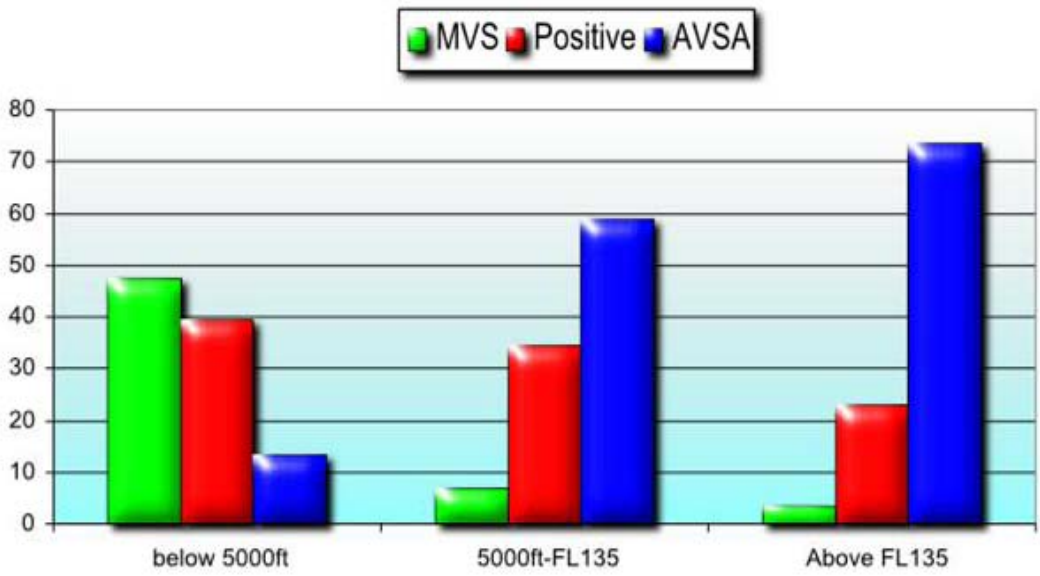


Table 1: RA types per altitude layer

4.2.2.2. Below 5000 ft, nearly 50% of RAs are monitor vertical speed RAs. The other half of RAs is mainly composed of positive RAs (Climb and Descend RAs), and of adjust vertical speed RAs for the remaining 13%.

4.2.2.3. Over 5000 ft, the proportion of adjust vertical speed RAs increases, to nearly 60% between 5000 ft and FL135, and up to 75% above FL135. Monitor vertical speed RAs are very rare over 5000 ft.

4.2.3. Response to RAs

4.2.3.1. An attempt was made to quantify the rate with which RAs are followed. For this purpose, some rules had to be defined to qualify properly the type of reaction to an RA.

4.2.3.2. In this study, an RA can be followed in 3 different ways:

- Complied, meaning the RA is correctly followed; or
- With a weak reaction; or
- With an over reaction.

4.2.3.3. Two type of non reactions can be determined:

- Opposite reaction; or
- Lack of reaction.

4.2.3.4. This work was done for positive RAs and for adjust vertical speed RAs. The results are not shown for monitor vertical speed RAs as it is more difficult to classify the reaction of pilots in several categories. In addition, these RAs are almost all complied with, therefore there is little interest in showing the result as a diagram.

4.2.3.5. The following tables explain how, for each type of RA, the five categories of reaction were defined. The first table presents the rules for adjust vertical speed RAs and the second table for positive RAs.

Reaction Type	Identification
Complied	Change in Vertical rate, in the correct sense. It includes level off at adjacent FL. The vertical rate has to be lower than 2000 fpm.
Over reaction	Follows the RA as if it was a positive one (e.g., descends for a “Don’t climb” RA)
Weak reaction	Not applicable[6]
No reaction	Vertical rate unchanged and below 4000fpm
Opposite reaction	Vertical rate increases in the wrong direction or remains very high (>4000fpm)

Table 2: Reaction types for adjust vertical speed RAs

[6] This is because, for most RAs, RA downlink does not provide RA strength.

Reaction Type	Identification
Complied	Vertical rate between 750 fpm and 2500 fpm
Over reaction	Vertical rate over 2500 fpm
Weak reaction	Vertical rate below 750 fpm
No reaction	Vertical rate maintained, in a wrong sense (e.g., continues to descend with a climb RA), including level
Opposite reaction	Vertical rate changes and in the wrong sense

Table 3: Reaction types for positive RAs

4.2.3.6. It must be mentioned that the RAs were processed one by one, and not using an automatic filter.

4.2.3.7. The following figures summarise the results of this analysis.

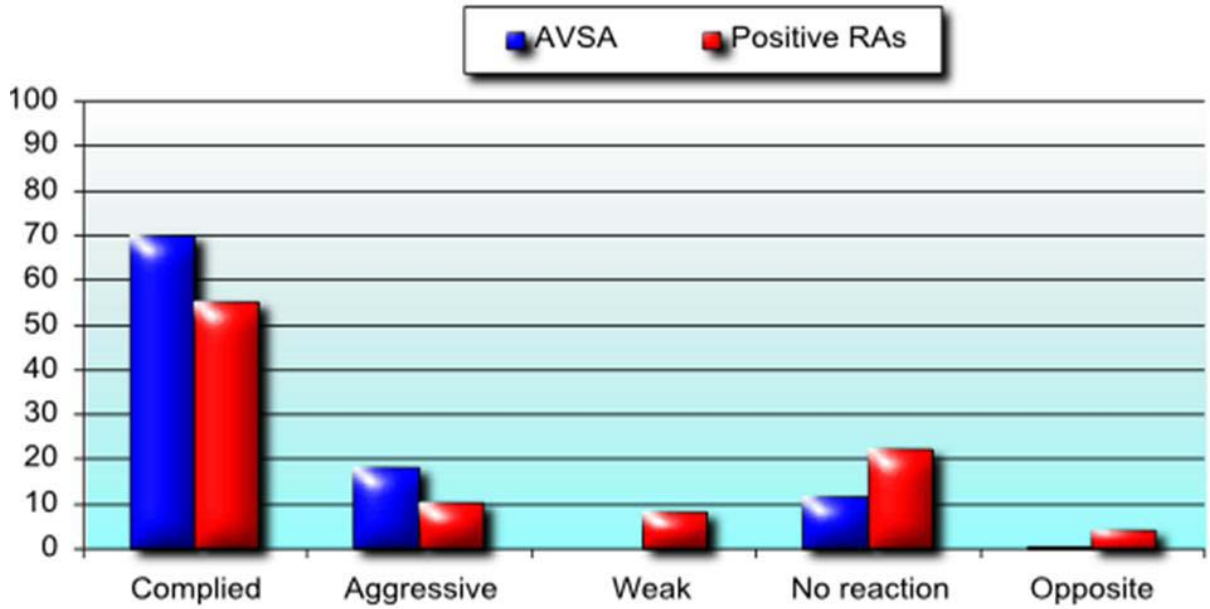


Figure 13: Response to RAs below FL135

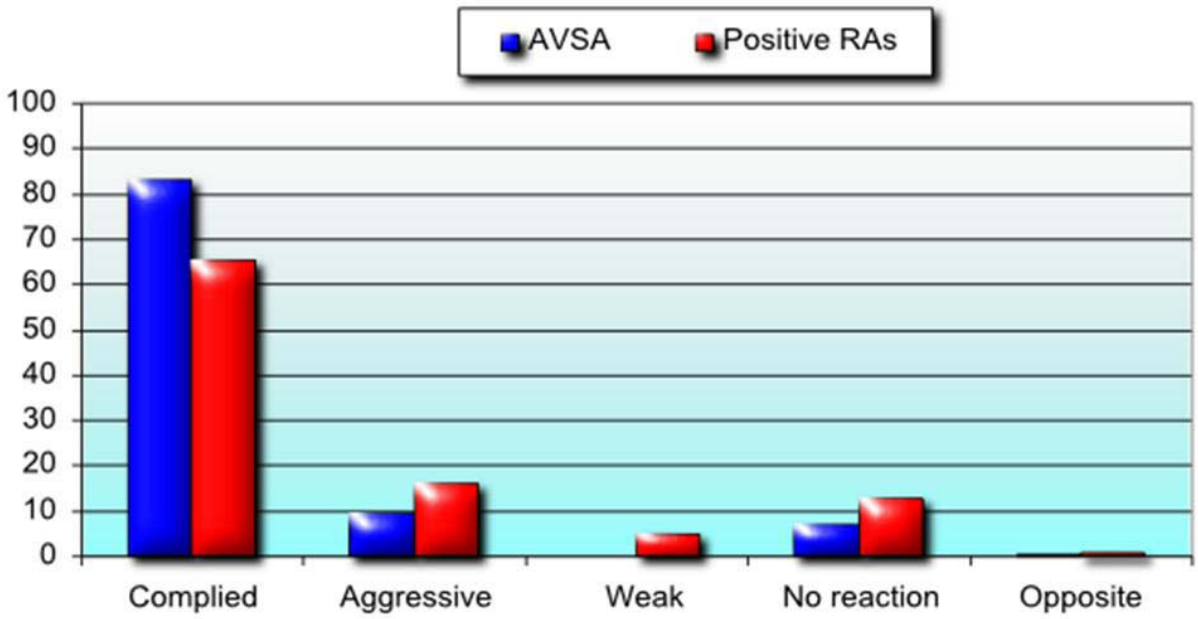


Figure 14: Response to RAs above FL135

4.2.3.8. Adjust vertical speed RAs are complied with a rate of 70% in TMA and 83% in En-route airspace. They are sometimes followed with an over reaction, meaning that the aircraft descends following a “don’t climb” RA, or climbs after a “don’t descend” RA. More rarely, there is no reaction from the crew. In addition, a few cases (0.4% below FL135 and 0.3% above) with opposite reactions were found. However, overall, adjust vertical speed RAs are often followed correctly by crews.

4.2.3.9. Positive RAs are followed correctly with a rate of 55% in TMA and 65% in En-route airspace. In 19% of the cases in TMA and 21% in En-route airspace, they are followed, but with an inappropriate vertical rate, either too high or too low. In 26% of the cases in TMA and 14% in En-route airspace, there is no reaction from the crew or an opposite response. It is noticeable that in TMA, 35% of the positive RAs are either not followed, followed with an opposite response, or followed weakly, which also significantly cuts the benefits brought by TCAS. This confirms observations from [SIRE+4].

4.3. Geometry of the encounters

4.3.1. Introduction

4.3.1.1. This part aims at describing the geometries of the encounters in which an RA has been issued. This is mainly done using the altitude, the Horizontal Miss Distance (HMD), and the Vertical Miss Distance (VMD).

4.3.2. Altitude

4.3.2.1. The following table shows the distributions of altitude for each type of RA.

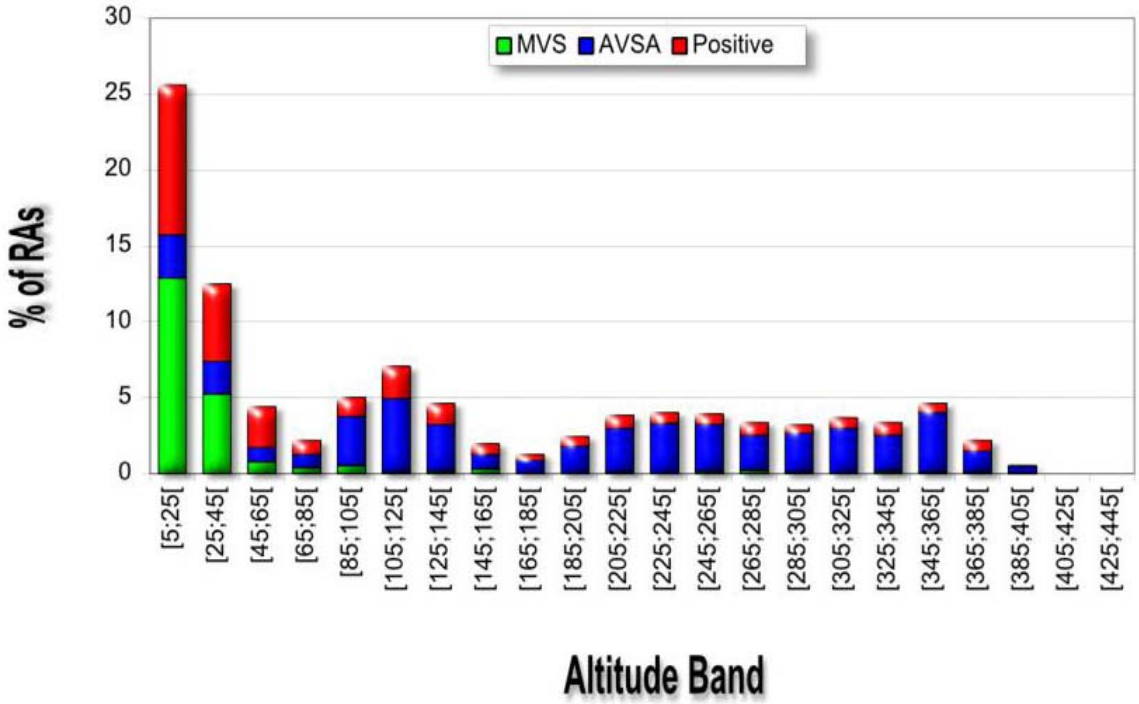


Figure 15: Altitude distribution

4.3.2.2. The altitude distribution has one major peak below 5000 ft. This peak corresponds to encounters involving IFR versus VFR aircraft. Another peak can be observed around FL100/120, which corresponds to 1000 ft level-off encounters between departures and arrivals near TMAs.

4.3.2.3. An important part of adjust vertical speed RAs were triggered around FL110 between arrivals and departures in TMAs. A noticeable part of these RAs also occurred above FL200.

4.3.2.4. Most monitor vertical speed RAs occurred in TMA, below 5000 ft between arrivals and VFR aircraft.

4.3.3. Horizontal Miss Distance

4.3.3.1. The following figure shows the distributions of Horizontal Miss Distance for each type of RA.

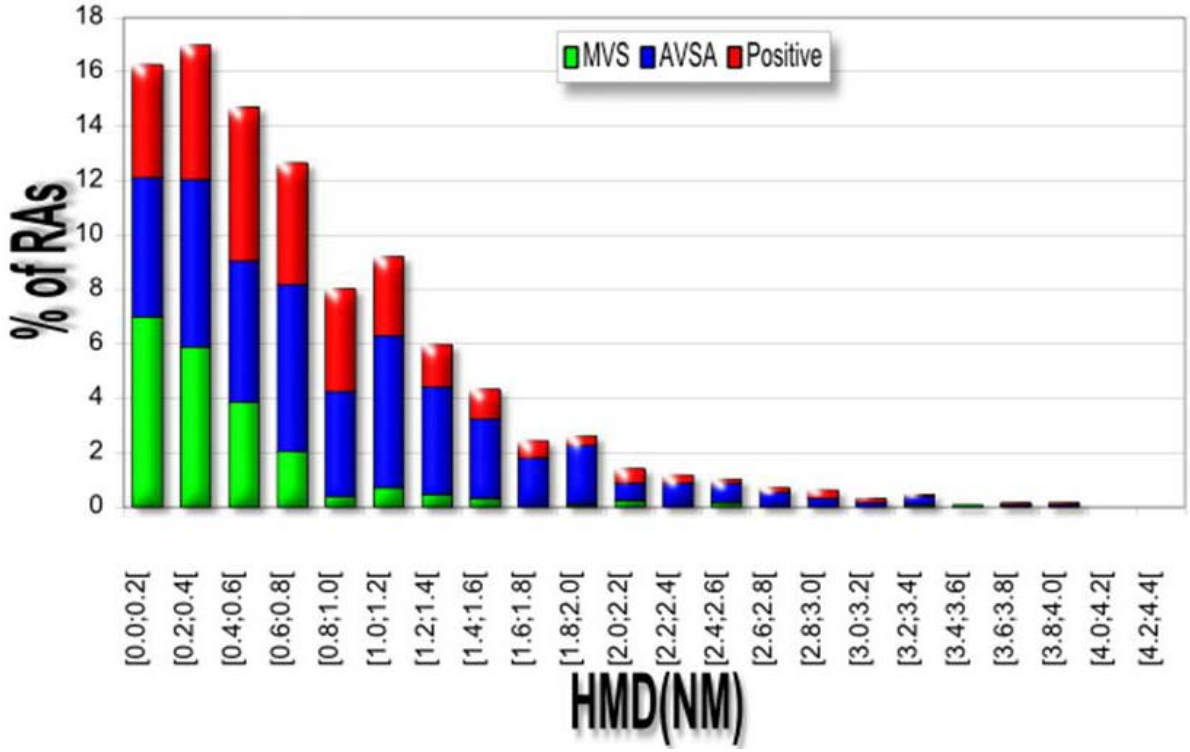


Figure 16: HMD distribution

4.3.3.2. 60% of RAs are triggered in encounters with an Horizontal Miss Distance below 1 NM. In encounters with large HMDs, TCAS estimates that there is no risk of collision and therefore does not trigger RAs.

4.3.3.3. The distribution for Adjust Vertical Speed RAs is widespread up to 2 NM, whereas that of monitor vertical speed RAs is concentrated below 1 NM. Positive RAs stand in between AVSA RAs and monitor vertical speed RAs.

4.3.4. Vertical Miss Distance

4.3.4.1. The following table shows the distributions of Vertical Miss Distance for each type of RA.

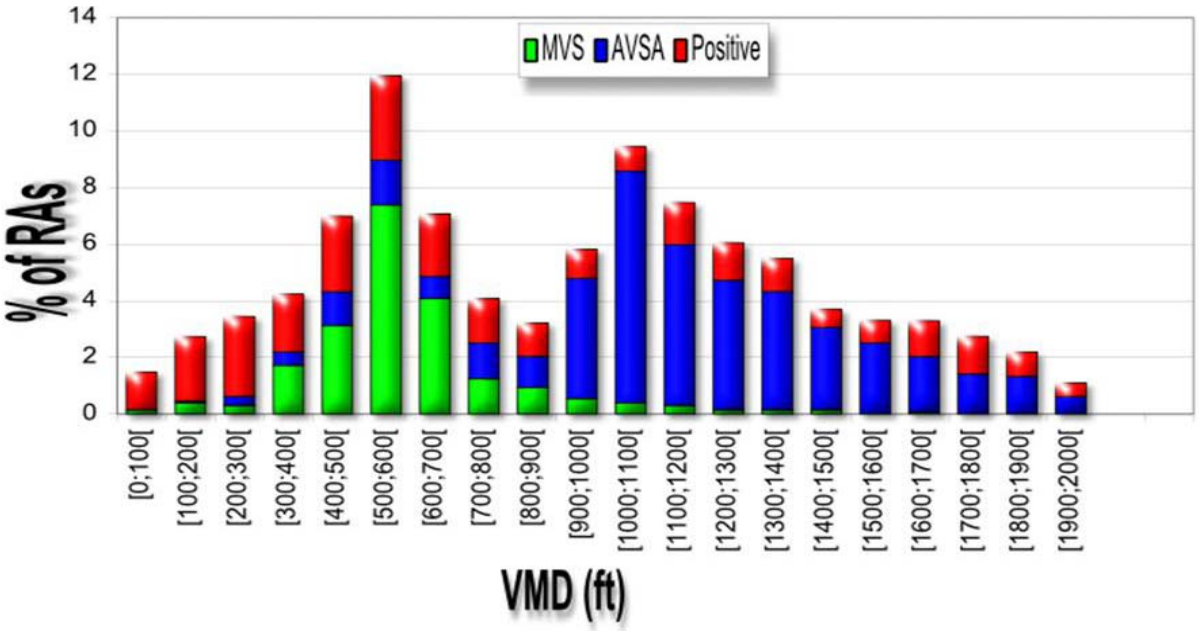


Figure 17: VMD distribution

4.3.4.2. The distribution for all the RAs shows two peaks, one around 500 ft, and the second one around 1000 ft. The former stands for encounters involving IFR and VFR aircraft, with a majority of monitor vertical speed RAs, whereas the second stands for 1000 ft level-off geometries, with a majority of adjust vertical speed RAs.

4.3.4.3. It is noticeable that the lowest VMDs are mostly for positive RAs. This was expected as in the closest encounters, such RAs are typically triggered. Depending on the way the pilot follows the RA, the VMD remains low, or can be pretty high in case of aggressive responses, which explains the way the VMDs for positive RAs are widespread.

4.3.5. Combined perspective

4.3.5.1. The following table shows the distributions of Vertical Miss Distance for all the RAs, versus the Horizontal Miss Distance.

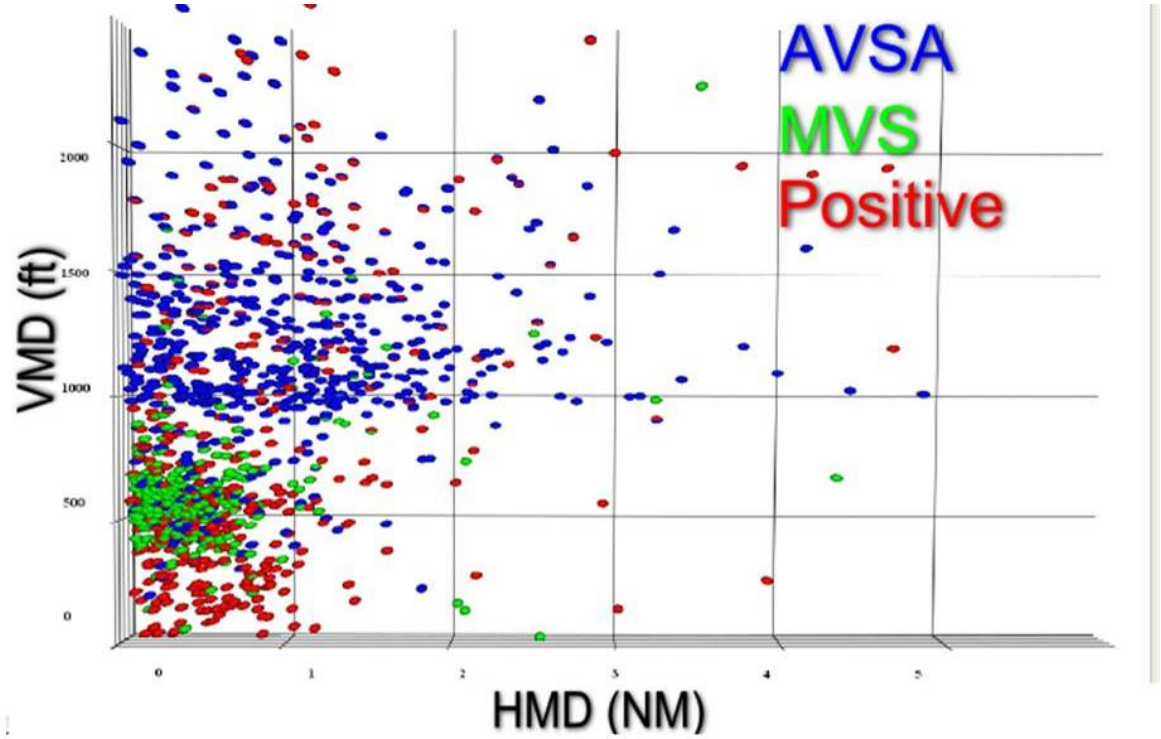


Figure 18 : VMD vs HMD

4.3.5.2. Two main clusters appear on this figure:

- monitor vertical speed RAs concentrated around 500 ft of VMD, and below 1 NM of HMD.
- adjust vertical speed RAs, around 1000 ft of VMD and below 2 NM of HMD.

4.3.5.3. The following figure shows an example of low altitude encounter with monitor vertical speed RAs triggered.

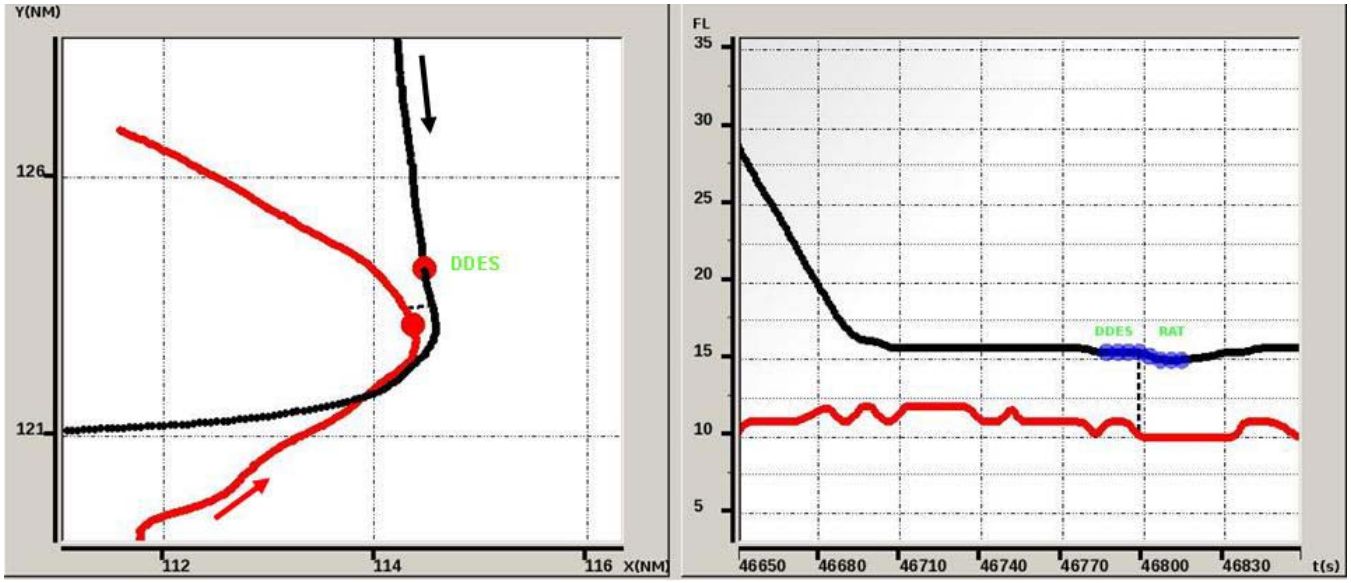


Figure 19: Low level encounter with a monitor vertical speed RA
DDES: "Monitor vertical speed" RA, **RAT**: RA terminated
The red circles on the horizontal trajectories show where the aircraft were at the time of the initial RA

4.3.5.4. In this encounter, the black aircraft receives a monitor vertical speed RA, requesting not to descend, against a VFR traffic 500 ft below. The pilot complies with the RA by not changing its trajectory. As a result, the VMD is 500 ft and the HMD is 0.27 NM.

4.3.5.5. Positive RAs are more widespread. One notices a cluster of such RAs for the smallest of the VMDs. Indeed, such RAs are triggered in the closest of encounters, the climb and descend RAs being the strongest initial RAs which can be triggered. Depending on the pilot reaction, the resulting VMD can be pretty high or very low when the response of the pilot is inadequate.

4.3.5.6. The following figure extends this view by adding the altitude component.

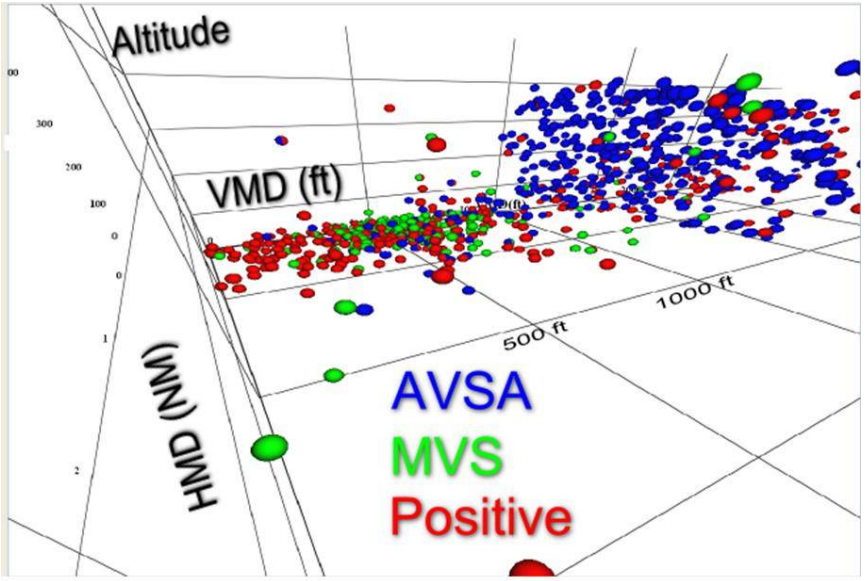


Figure 20 : VMD vs HMD

4.3.5.7. This view confirms what was observed from the previous figure. It also shows a significant number of encounters with a very small VMD, with an HMD below 1 NM, and always below 5000 ft. These encounters are VFR/IFR encounters, in which RAs are not necessarily followed appropriately. The following figure shows such an encounter.

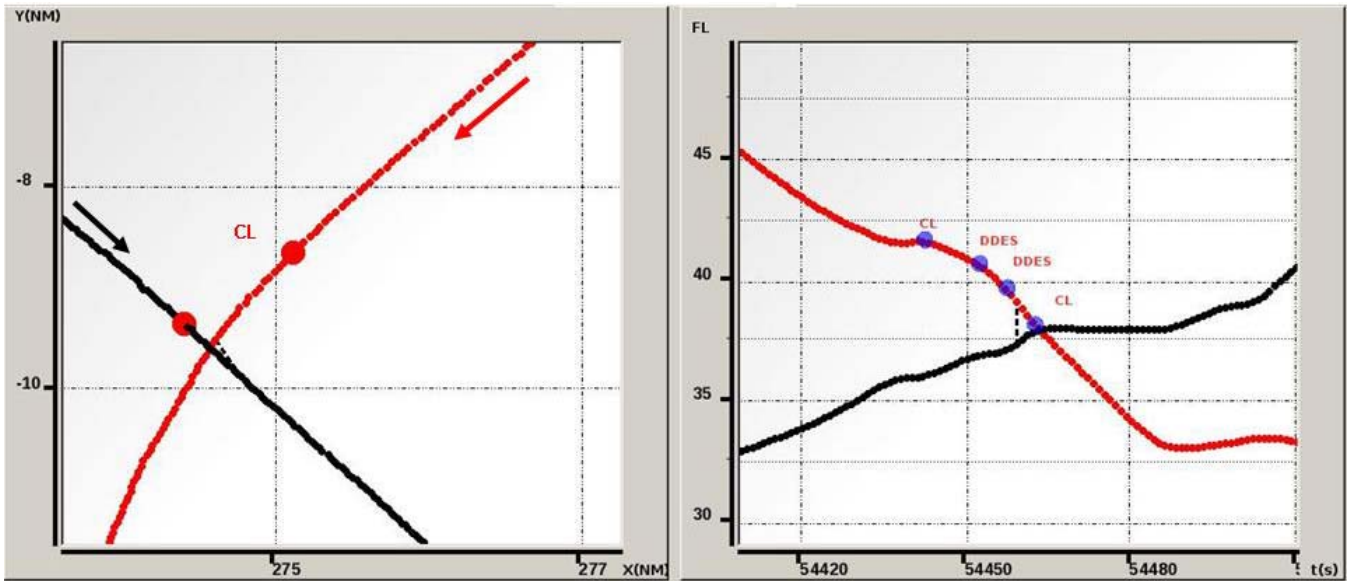


Figure 21: Low level encounter with a Positive RA not complied
CL: Climb RA, **DDES**: "Adjust vertical speed, Adjust"
The red circles on the horizontal trajectories show where the aircraft were at the time of the initial RA

4.3.5.8. In this encounter, the descending aircraft, while at 4200 ft, receives a Climb RA, which it does not follow and continues its descend, despite subsequent RAs requesting not to descend being triggered. As a result, the VMD is 100 ft and the HMD is 0.4 NM.

4.3.5.9. It can not be excluded that in this encounter, there was a visual acquisition and separation.

5. Issues SA01 and SA-AVSA monitoring

5.1. Introduction

5.1.1. The main objective of this study is to track issues SA01 and SA-AVSA, in order to determine if they are still occurring in the European airspace, and to update the risk of collision with these two issues [SIRE+8].

5.1.2. This part first shows SA01 and SA-AVSA events found during this study, and proposes an update of the initial risk of collision with these issues [SIRE+8] (i.e., one collision every 3 years).

5.1.3. The computations made in this part were performed using a methodology accepted at the RTCA [DO298] and EUROCAE [ER-1] level. This methodology consists in computing a probability of occurrence of the issues, knowing a number of events with the issues and a number of corresponding flight hours, and multiplying this figure by the severity of the issues (i.e., the probability that, knowing that an event is an occurrence of issue SA01 or SA-AVSA, it will lead to a collision).

5.1.4. Two computations were made. One is an update of the initial computation proposed in [SIRE+8]. It consists in taking into account all the known SA01 and SA-AVSA events, including those found in this study.

5.1.5. The second computation takes into account only recent SA01 and SA-AVSA events. In particular, it takes into account the SA01 and SA-AVSA events found in this study, and adds a recent (2008) SA01 event [SIRE+7]. The goal of having this second computation is to assess the evolution of the risk of collision versus time.

5.2. SA01 events

5.2.1. SA01a event

5.2.1.1. The following figure shows a SA01a event found in the data analysed. It involves two military transport aircraft. The aircraft type involved (Beechcraft twinprop) in this encounter is mostly used in commercial aviation, and were used under procedures similar to those used in civil aviation (i.e., approach training). For this reason, this event was used for the probability computation.

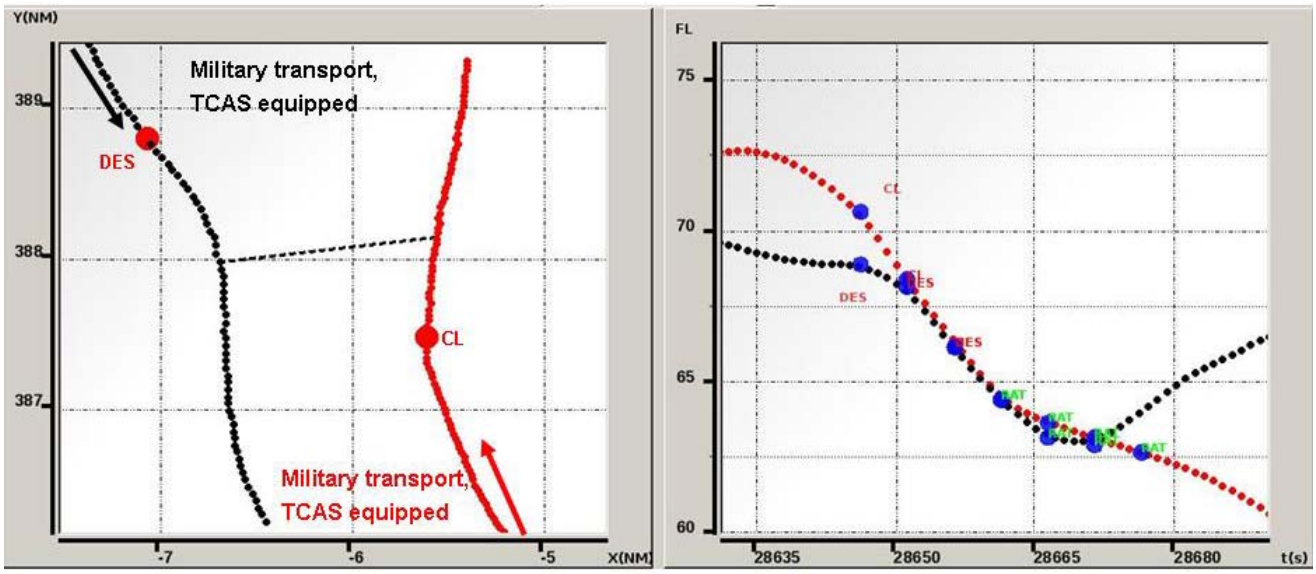


Figure 22: SA01a encounter between military controlled aircraft
CL: Climb RA, **DES**: Descend RA, **RAT**: RA terminated
The red circles on the horizontal trajectories show where the aircraft were at the time of the initial RA

5.2.1.2. The black aircraft received a descend RA, which it followed. The intruder received a climb RA which it did not follow and went opposite to it.

5.2.1.3. As a result, both aircraft descended at the same vertical rate, with 0 ft of vertical separation. During this descent, both aircraft were head on, and both performed a late right turn just before CPA.

5.2.1.4. The vertical separation at CPA was 0 ft, and the horizontal separation at CPA was 1.13 NM.

5.2.2. SA01b event

5.2.2.1. The following figure shows a SA01b event found in the data analysed within this study. It involves a civilian aircraft versus a military aircraft.

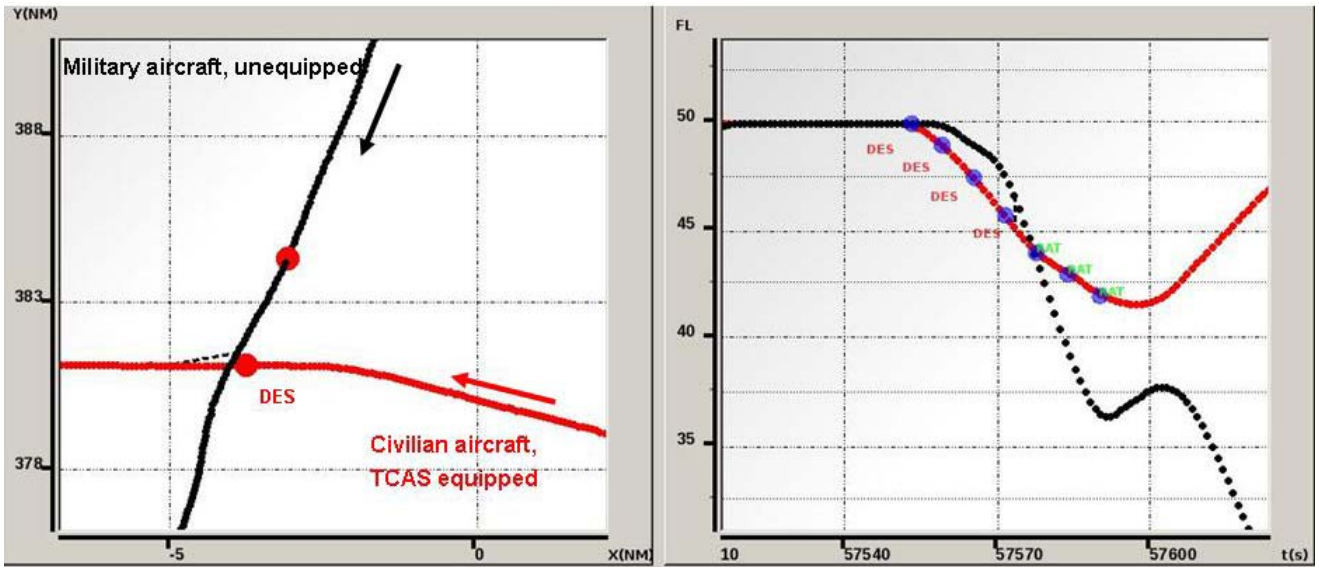


Figure 23: SA01b encounter
DES: Descend RA, **RAT**: RA terminated
The red circles on the horizontal trajectories show where the aircraft were at the time of the initial RA

5.2.2.2. The red aircraft, at 5000 ft, was on a radar heading of 300 degrees when it received information from ATC about a traffic in the 12 o'clock, with no height information. ATC asked this aircraft to turn onto 270 degrees, which it did.

5.2.2.3. The red aircraft received a descend RA, which it followed. However the intruder dived from above and both aircraft descended, close vertically, while converging horizontally.

5.2.2.4. The military aircraft had visual with the TCAS equipped aircraft and made a left turn to avoid it. It reported not having been advised about the presence of this aircraft.

5.2.2.5. The vertical separation at CPA was 100 ft, and the horizontal separation at CPA was 1.38 NM.

5.3. SA-AVSA events

5.3.1. Event 1

5.3.1.1. The following figure shows an example of encounter with an opposite reaction to an adjust vertical speed RA.

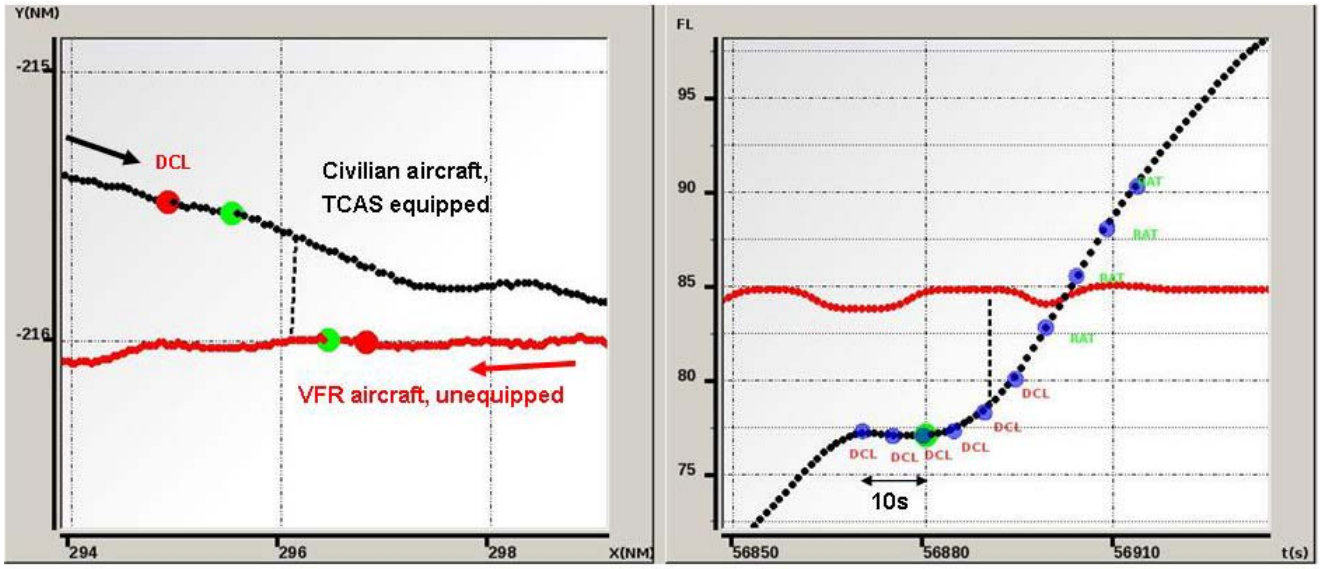


Figure 24: Possible SA-AVSA
DCL: "Adjust vertical speed, Adjust" RA, **RAT**: RA terminated
The red circles on the horizontal trajectories show where the aircraft were at the time of the initial RA

5.3.1.2. The climbing aircraft started a level-off, then received an adjust vertical speed RA against an aircraft at FL85.

5.3.1.3. A few seconds after, it started to accelerate upwards to 3500 fpm, in the opposite direction to the TCAS RA instruction. At this moment (shown with a green mark on the figure), the aircraft had not crossed yet. It seems unlikely that it decided to pass above. In addition, it seems to have decreased the rate of climb after the end of the RA.

5.3.1.4. As a result, the vertical separation at CPA was 600 ft, and the horizontal separation at CPA was 0.4 NM.

5.3.2. Event 2

5.3.2.1. The following figure shows an example of encounter with an opposite reaction to an adjust vertical speed RA.

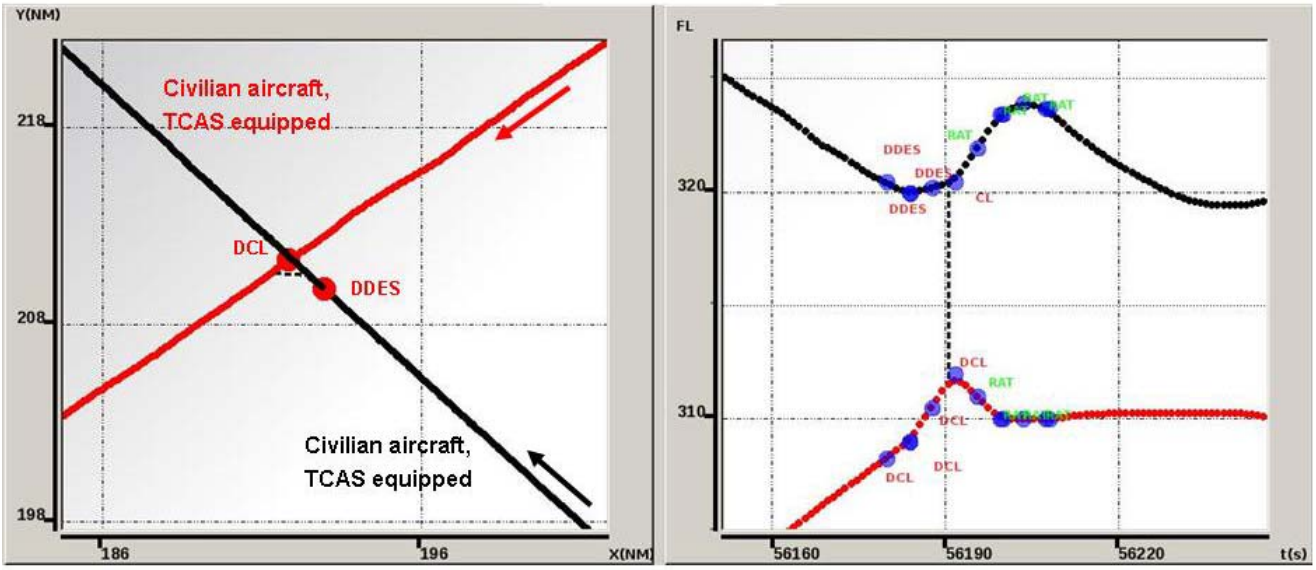


Figure 25: Possible SA-AVSA
DCL and DCL: "Adjust vertical speed, Adjust" RA, **CL**: Climb RA, **RAT**: RA terminated
The red circles on the horizontal trajectories show where the aircraft were at the time of the initial RA

5.3.2.2. The climbing aircraft received an adjust vertical speed RA while at 1000 fpm.

5.3.2.3. A few seconds after, it started to accelerate upwards to 2300 fpm, in the opposite direction to the TCAS RA instruction.

5.3.2.4. A climb RA was triggered onboard the black aircraft because of this opposite reaction.

5.3.2.5. As a result, the vertical separation at CPA was 800 ft, and the horizontal separation at CPA was 1.2 NM.

5.4. Methodology to compute the probability of collision

5.4.1. In order to derive a risk of collision for issue SA01 or issue SA-AVSA, the same methodology as used in [DO-298] for the evaluation of safety issue SA01 severity has been applied. It consists in determining the probability of collision with issues SA01 or SA-AVSA and combining this probability with the frequency of these issues. For issue SA01, the computation is as follows:

$$P(\text{SA01 and collision}) = P(\text{SA01}) \times P(\text{collision} \mid \text{SA01})$$

with

$$P(\text{Collision} \mid \text{SA01}) = \frac{\text{Vertical NMAC box}}{\text{Vert.SA01 miss distance}} \times \frac{\text{Horiz. NMAC box}}{\text{Horiz.SA01 miss distance}} \times P(\text{Collision} \mid \text{NMAC})$$

5.4.2. The formula for SA-AVSA is similar.

$$P(SA\text{AVSA and collision}) = P(\text{SAAVSA}) \times P(\text{collision} \mid \text{SAAVSA})$$

with

$$P(\text{Collision} \mid \text{AVSA}) = \frac{\text{Vertical NMAC box}}{\text{Vert.SA - AVSA miss distance}} \times \frac{\text{Horiz. NMAC box}}{\text{Horiz.SA - AVSA miss distance}} \times P(\text{Collision} \mid \text{NMAC})$$

5.4.3. The probability that a collision occurs is obtained knowing that ([ACA1]): $P(Collision \mid NMAC) = 0.1$

5.4.4. The frequency of occurrence of the two issues is computed knowing the number of the observed events, and the number of flight hours corresponding.

5.4.5. Another method of computation exists, which gives different results [MITLL]. Applying this method results in probabilities 4 times lower than those presented in this report, given the specificities of the European airspace.

5.5. Update of the probability of collision due to SA01 and SA-AVSA

5.5.1. The update of the computation was made using the additional SA01a and SA01b events and the 2 SA-AVSA events discovered in the analysed data. These events were discovered analysing events found in recordings with 3,400,000 flight hours of traffic.

5.5.2. These SA-AVSA events add to the 15 SA-AVSA events found in a monitoring conducted in 2004 and 2005, for a total of 3.92×10^6 flight hours.

5.5.3. Regarding SA01 events, a total of 12 events were known before this study. On these 12 events, a probability of occurrence can be updated using 10 of them:

- 2 SA01 events were found through analysing the Air Safety Reports of a major European airline in 2001 and 2002, over a total of 422,661 flight hours;
- 1 event found in the French airspace in 2001, over a total of 1,900,000 flight hours in the French airspace;

- 6 events were found through a DSNA monitoring in 2004 and 2005, over a total of 3,920,000 flight hours.
- 1 event was found in 2008 through a DSNA monitoring, over a total of 2,000,000 flight hours.

5.5.4. For the 2 other SA01 events, it is not possible to know precisely a number of flight hours to use for the computation of a probability of occurrence, as no specific monitoring was put in place to track them (Überlingen collision and Yaizu accident).

5.5.5. However, all 14 events (including the Überlingen collision and the Yaizu accident) can be used to update the severity of issue SA01, as the VMDs and HMDs are known.

5.5.6. The following figures shows the VMDs and HMDs of all the known SA01 and SA-AVSA events.

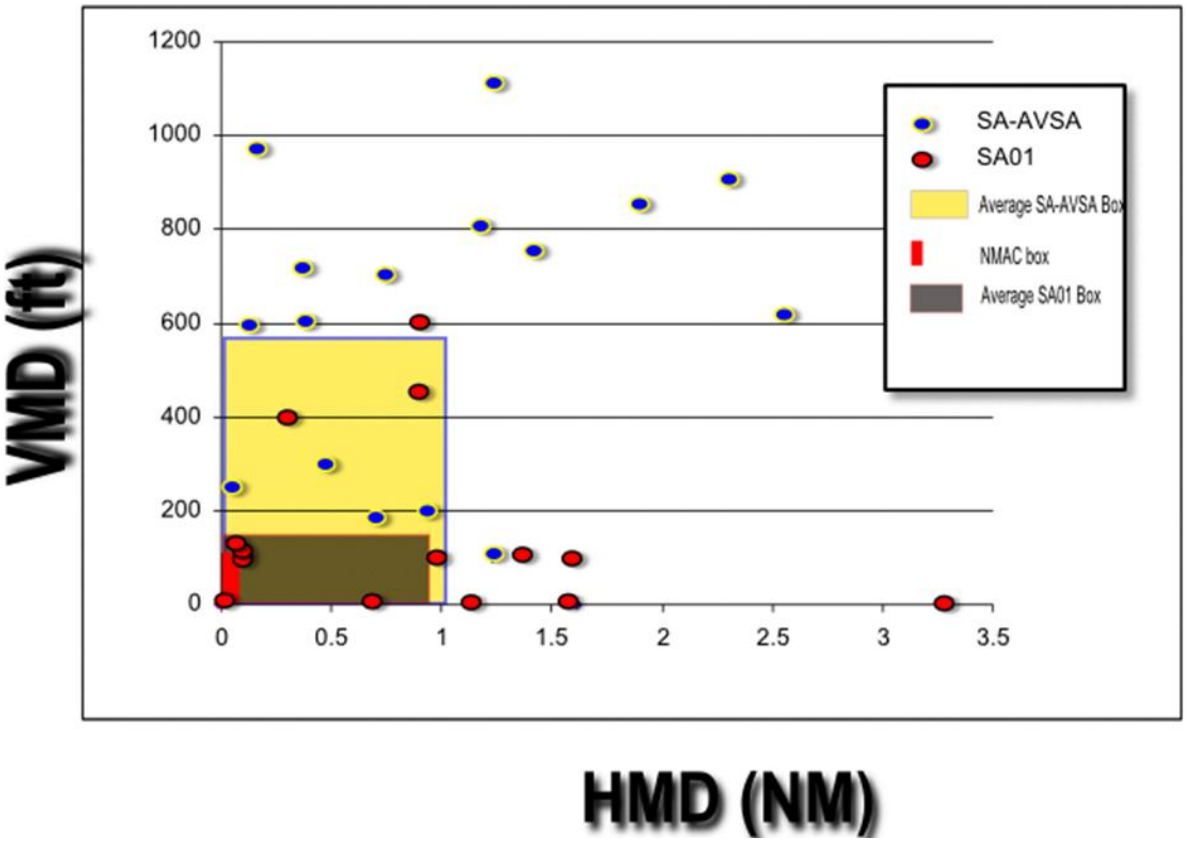


Figure 26: HMDs and VMDs of SA01 and SA-AVSA events

5.5.7. On average, SA01 events have a VMD of 150 ft and an HMD of 0.9NM. SA-AVSA events have a VMD of 570 ft and an HMD of 1.0 NM.

5.5.8. One notices on this figure that some SA-AVSA events have a VMD which is pretty high. This results from the intruder aircraft complying to its own RA, which does not remove the hazardous character of these encounters.

5.5.9. The resulting probabilities are summarised in the following table for SA01, and then for SA-AVSA.

5.5.10. One is an update of the initial computation proposed in [SIRE+8]. It consists in taking into account all the known SA01 and SA-AVSA events, including those found in this study.

5.5.11. The second computation takes into account only the SA01 and SA-AVSA events found in this study, and adds a recent (2008) SA01 event [SIRE+7].

	Initial computation	**Update of the initial computation**	**Computation based on last events only**
Probability of occurrence (per flight hour)	4.7×10^{-6}	1.2×10^{-6}	5.6×10^{-7}
Severity	4.7×10^{-3}	5.9×10^{-3}	1.3×10^{-2}
Probability of collision (per flight hour)	2.2×10^{-8}	7.2×10^{-9}	7.1×10^{-9}

Table 4: SA01 probabilities

	Initial computation	**Update of the initial computation**	**Computation based on last events only**
Probability of occurrence (per flight hour)	3.8×10^{-6}	1.8×10^{-6}	3.7×10^{-7}
Severity	1.4×10^{-3}	1.4×10^{-3}	1.5×10^{-3}
Probability of collision (per flight hour)	5.4×10^{-9}	2.6×10^{-9}	5.6×10^{-10}

Table 5: SA-AVSA probabilities

5.5.12. It is noticeable that the probabilities of occurrence of issues SA01 and SA-AVSA have decreased when compared to the initial computation. This can be explained by the fact that the tracking of the issues is maybe less aggressive than in the past, leading to some SA01/SA-AVSA going unnoticed and by the fact that there is certainly a better awareness of these issues among the pilot community.

5.5.13. The severity has not changed for issue SA-AVSA, and has slightly increased for issue SA01.

5.5.14. As a result, the probabilities of collision have decreased for both issues.

5.5.15. As a result, the probability of collision with SA01 or SA-AVSA is:

- Making the computation with all the known events: 9.8×10^{-9}, between 6.5×10^{-9} and 1.4×10^{-8} at the 95% confidence level. This corresponds, assuming that the number of flight hours in the European airspace is 14,000,000 flight hours per year [PRR], to one collision because of issue SA01 or issue SA-AVSA every 7.5 years, and between 5 years and 11 years with a confidence of 95%. This probability exceeds the tolerable rate for catastrophic events caused by equipment related hazards (10^{-9} per flight hour) by a factor of about 10;
- Making the computation with only recent events: 7.6×10^{-9}, between 2.5×10^{-9} and 1.8×10^{-8} at the 95% confidence level. This corresponds, assuming that the number of flight hours in the European airspace is 14,000,000 flight hours per year [PRR], to one collision because of issue SA01 or issue SA-AVSA every 9.5 years, within a range of 4 to 28 years at the 95% confidence level. This probability exceeds the tolerable rate for catastrophic events caused by equipment related hazards (10^{-9} per flight hour) by a factor of more than 7;

5.5.16. This is summarised in the following figure, which shows the probability to have a collision, assuming a poisson process.

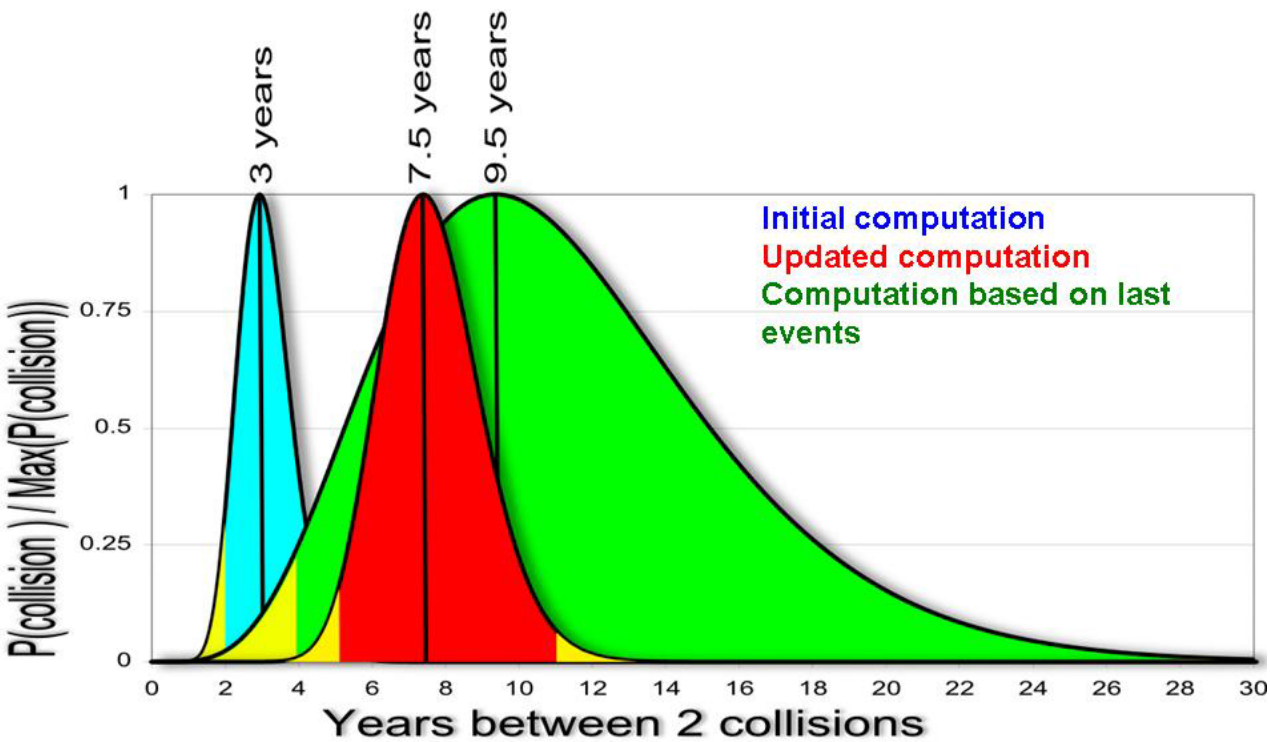


Figure 27: Probability of collision

5.5.17. It appears that taking into account only recent events leads to risks of collision somewhat lower than when taking into account all the events. As explained above, this certainly results by the fact that the tracking of the issues is maybe less aggressive than in the past, leading to some SA01/SA-AVSA going unnoticed and by the fact that there is certainly a better awareness of these issues among the pilot community

5.5.18. However, it must be mentioned that the computation on the last events only provides an estimate of the risk of collision (the 95% confidence interval provides figures ranging from 4 to 28 years between 2 collisions) as it has been computed on few

events, but is nonetheless unacceptably high when compared to the tolerable rate of catastrophic events.

5.5.19. The following curve is extracted from [IATA].

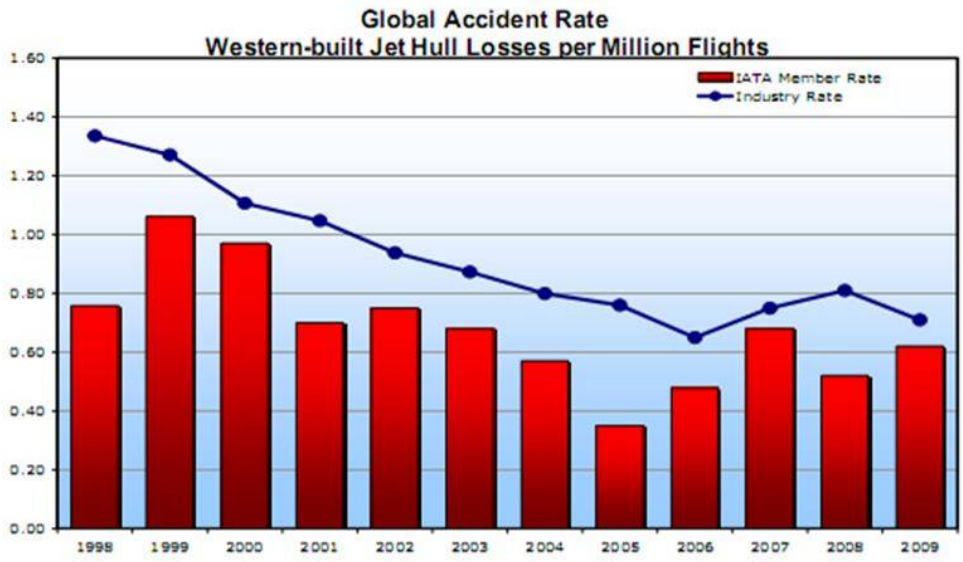


Figure 28: Global Accident rate : Western-built Jet Hull Losses per Million Flights [IATA]

5.5.20. According to this figure [IATA], the order of magnitude of the accident rate is in the order of one per million of flight in 2009.

5.5.21. The rate of collision due to issue SA01 or SA-AVSA is in the order of one per 100 million flight hours. Knowing that on average, a flight can be estimated as lasting one hour this means that losses of aircraft due to issues SA01 or SA-AVSA are in the order of 1% of the total.

6. Conclusion

6.1.1. 6 months of French radar data, and 7 months of UK data were analysed. 1268 RAs were analysed.

6.1.2. Two SA01 events and two SA-AVSA events were found during the monitoring of French and UK data.

6.1.3. The risk of collision with safety issues SA01 and SA-AVSA, initially estimated as 1 collision every 3 years, was updated using the events found during this monitoring. The probability of collision due to issues SA01 and SA-AVSA is equal to 9.8×10^{-9} per flight hour, which is equivalent to one collision every 7.5 years in the European airspace, within a range of 5 to 11 years at the 95% confidence level. This exceeds the tolerable rate for catastrophic events caused by equipment related hazards (10^{-9} per flight hour) by a factor of about 10.

6.1.4. The risk of collision computed only on the last events is equal to 7.6×10^{-9} per flight hours, which is equivalent to one collision every 9.5 years in the European airspace, within a range of 4 to 28 years at the 95% confidence level. This exceeds the tolerable rate for catastrophic events caused by equipment related hazards (10^{-9} per flight hour) by a factor of more than 7.

6.1.5. In summary, this study shows once again that looking for issues SA01 and SA-AVSA in a monitoring leads to finding them, even over a short period of time.

6.1.6. The severity of these two issues continues to call for a rapid implementation of the solution, TCAS II logic version 7.1.

7. References

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[DO-298] RTCA – 'Safety Analysis of Proposed Change to TCAS RA Reversal Logic' – November 2005

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[EMO1] EMOTION-7, WP5 – 'EMOTION-7 Final Report' – EUROCONTROL ACAS Programme – EMOTION7/WP5/107/D, Version 2.0, January 2003.

[EMO2] EMOTION-7, WP3 – 'Issue SA01a – Probability of occurrence of late reversal RAs' – EUROCONTROL ACAS Programme – EMOTION7/WP3/091/D, Version 1.1, June 2002

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[IATA] 2009 Aviation safety performance

[PASS] 'Monitoring report of SNET performance in Europe, PASS/WA1/WP6/64/D, version 1.3, April 2009'

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[SIRE] 'SIRE Project Final Report - EUROCONTROL Mode S & ACAS Programme – SIRE/WP4/58/D – version 1.0, December 2005

[SIRE+1] ‘Operational performance of CP115 in Boston airspace’ – EUROCONTROL MSA Programme, Sofréavia & DSNA – SIRE+/WP5/37/D – Version 1.0, March 2007

[SIRE+2] ‘Operational performance of CP115 in New York airspace’ – EUROCONTROL MSA Programme, Sofréavia & DSNA – SIRE+/WP6/59/D – Version 1.1, December 2007

[SIRE+3] ‘Comparison of “TCAS Simulation” and “RA downlink” processes based on Dutch airspace data’ – EUROCONTROL MSA Programme, Sofréavia & DSNA – SIRE+/WP8/74/D – Version 1.0, September 2008

[SIRE+4] ‘TCAS II performance in European TMAs” – EUROCONTROL Mode S Programme, Sofréavia & DSNA – SIRE+/WP8/84/D – Version 1.1, February 2009

[SIRE+5] ‘Operational performance of TCAS in Paris area’ – EUROCONTROL Mode S Programme, Sofréavia & DSNA – SIRE+/WP8/80/W – Version 1.2, December 2008

[SIRE+6] ‘Operational performance of TCAS in London area’ – EUROCONTROL Mode S Programme, Sofréavia & DSNA – SIRE+/WP8/79/W – Version 1.1, December 2008

[SIRE+7] ‘19 June 2008 SA01 event’ – EUROCONTROL Mode S Programme, Sofréavia & DSNA – SIRE+/WP8/73/W – Version 1.0, September 2008

[SIRE+8] 'Decision criteria for regulatory measures on TCAS II version 7.1’ – EUROCONTROL Mode S Programme - SIRE+/WP7/69/D – version 1.0 – 27/06/2008

8. Appendix A : Localisation of events

8.1. Localization of the events

8.1.1. Introduction

8.1.1.1. This part aims at describing where the RAs occurred, so as to try to find trends in the areas where RAs are triggered, and also in the time when they are triggered.

8.1.2. Date and Time

8.1.2.1. This part presents some information about the time the RAs were triggered, the day, and the month.

8.1.2.2. The following figure shows the distribution of the RAs per month.

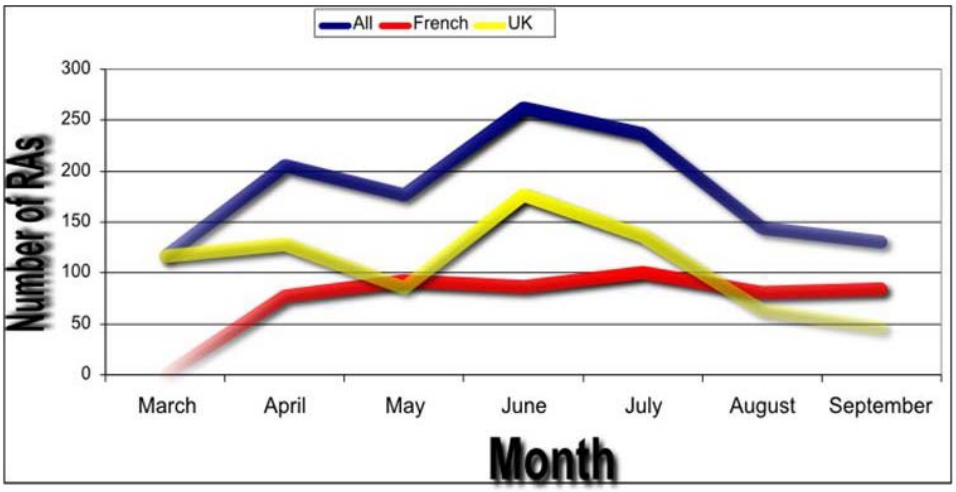

Figure 29 : RAs per month

8.1.2.3. The availability of the French data was assessed versus the months, and was found to be constant on the time period analysed. Therefore any variation on the French curve can not be explained by variations in the number of days available.

8.1.2.4. This availability figure is not available for the UK data, however it is assumed that NATS record data on a regular basis.

8.1.2.5. A peak is noticeable in the UK data in June and July. Such a peak is also present in the French data in July, even though much less noticeable. These peaks correspond to the periods during which the traffic is maximum, with peaks of GA traffic.

8.1.2.6. The following figure shows the distribution of the RAs per hour in the day (UTC).

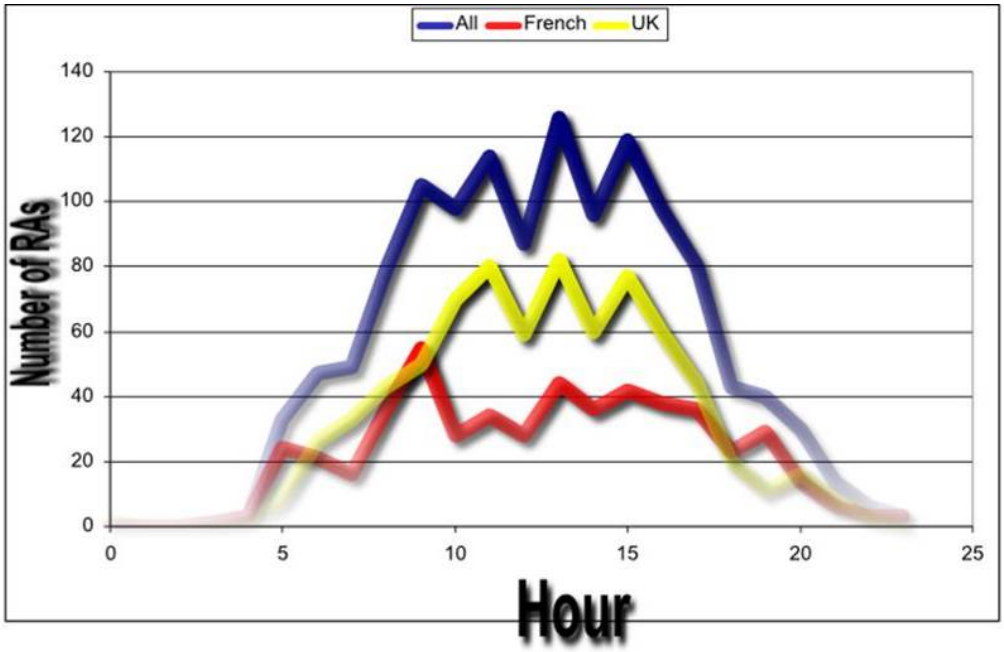

Figure 30 : RAs per hour

8.1.2.7. One observes a peak around 12 o'clock. In the French data, one also observes a peak at 9 o'clock. These peaks correspond to peaks in the traffic.

8.1.3. Hot spots

8.1.3.1. The following figure shows where RAs events occurred. Red colour is used for positive RAs, blue colour for AVSA RAs, and green colour for monitor vertical speed RAs.

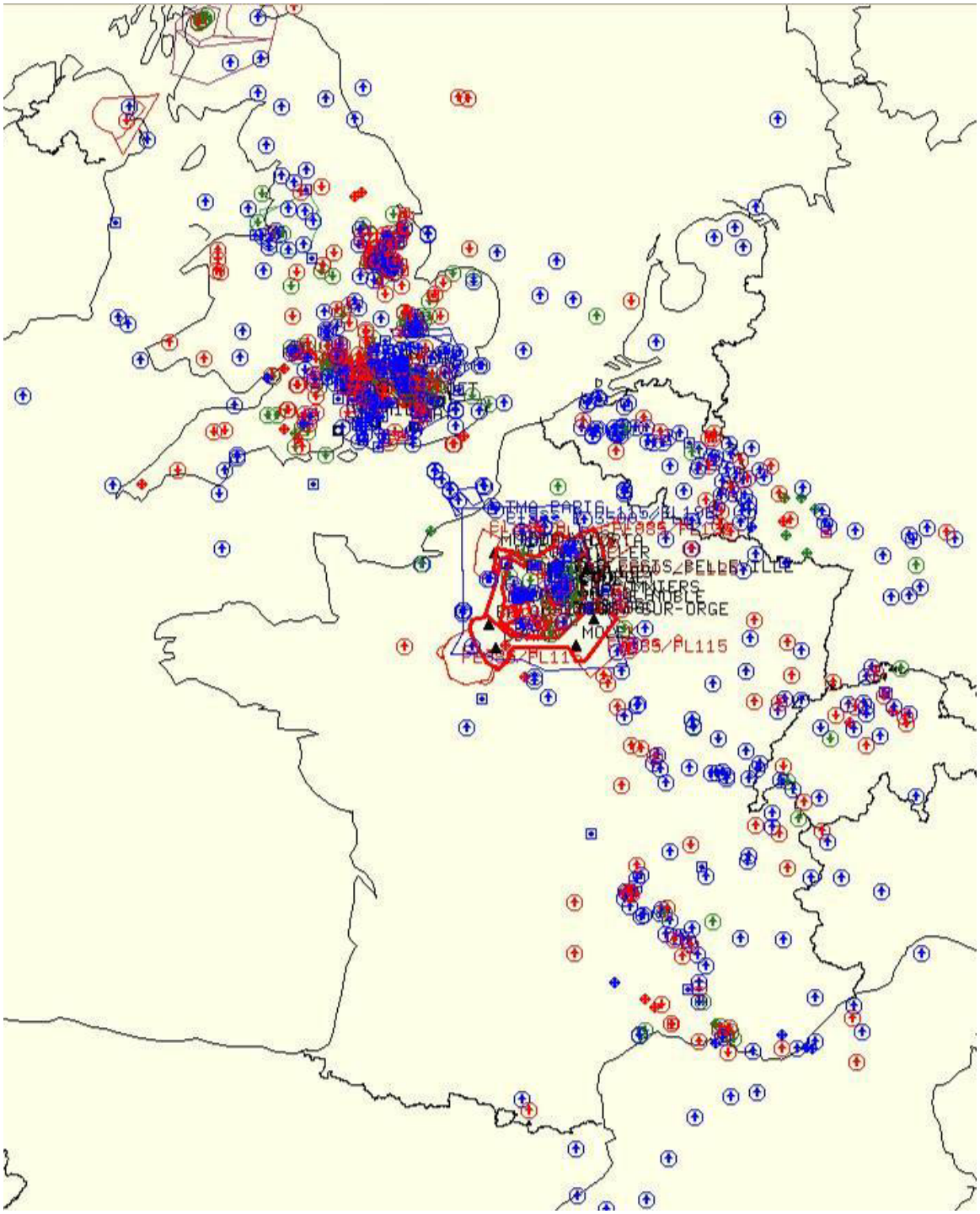

Figure 31: RA location
⬇ stands for RAs below 5000 ft, ⬩ stands for RAs between 5000 ft and FL90, ☒ stand for RAs between FL90 and FL135, ⬆ stands for RAs above FL135
Red colour is used for positive RAs, blue colour for AVSA RAs, and green colour for monitor vertical speed RAs

8.1.3.2. One notices that the two main areas where RAs occur are Paris TMA and London TMA.

8.1.3.3. In addition to that, the Maastricht enroute airspace is also a zone where many RAs are triggered. Marseille and Zurich are also areas where RAs are triggered on a regular basis. A few RAs were also found in Glasgow and Belfast TMAs.

8.1.3.4. The following figure shows a zoom on Paris TMA. Hotspots are shown with a red ellipse.

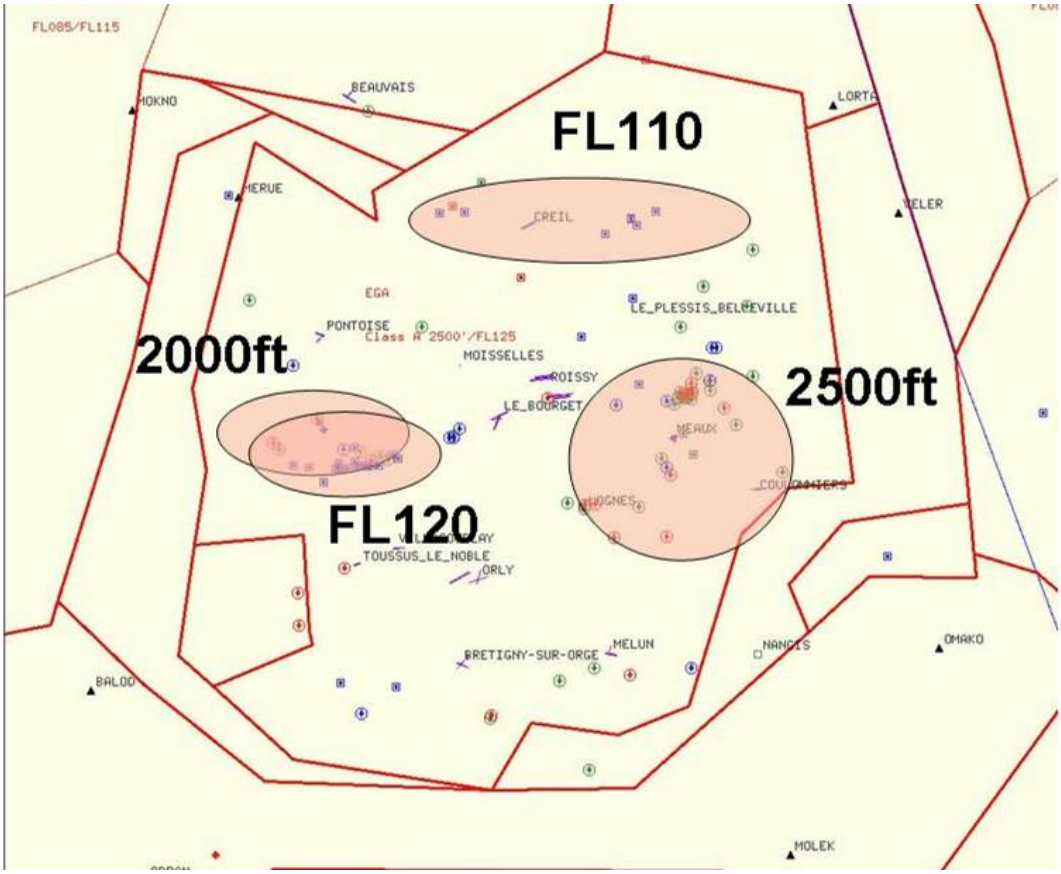

Figure 32: RA location in Paris TMA
stands for RAs below 5000 ft, ⬩ stands for RAs between 5000 ft and FL90, ☒ stand for RAs between FL90 and FL135, stands for RAs above FL135
Red colour is used for positive RAs, blue colour for AVSA RAs, and green colour for monitor vertical speed RAs

8.1.3.5. Two first hotspots can be highlighted, one to the west of Roissy and of Le Bourget, around FL120, and another to the North of Roissy, around FL110. The two hot spots correspond to crossings between IFR arrivals and departures from CDG.

8.1.3.6. Two hotspot around 2000/2500 ft can be highlighted East and West of Roissy. These hotspots corresponds to areas where IFR and VFR traffic cross at 500 ft (VFR fly in class G airspace beneath IFRs in adjacent class A airspace).

8.1.3.7. The 2000 ft and the FL110 hotspots correspond to the easterly landing and take-off configuration, whereas the 2500 ft and the FL120 hotspots correspond to the westerly landing and take-off configuration.

8.1.3.8. These hotspots were already highlighted in [SIRE+5].

8.1.3.9. It is noticeable that the hotspot below 5000 ft encompasses encounters with VMDs around 500 ft, which means there are mainly encounters with VFR and IFR traffic in this area.

8.1.3.10. On the contrary, the hotspots above 5000 ft encompass encounters with VMDs above 1000 ft.

8.1.3.11. The following figure shows a zoom on London TMA. Hotspots are shown with a red ellipse.

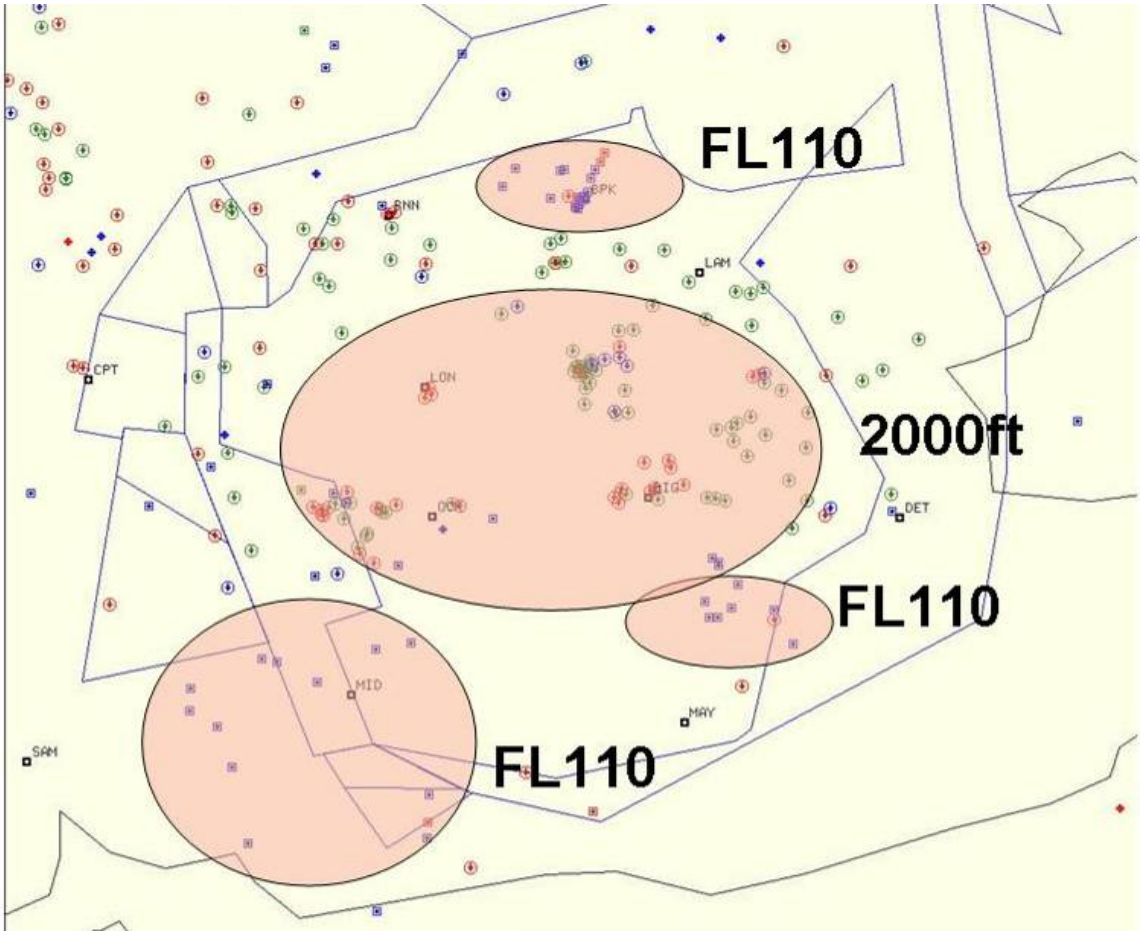

Figure 33: Zoom on London TMA
stands for RAs below 5000 ft, ♦ stands for RAs between 5000 ft and FL90, ☒ stand for RAs between FL90 and FL135, stands for RAs above FL135
Red colour is used for positive RAs, blue colour for AVSA RAs, and green colour for monitor vertical speed RAs

8.1.3.12. Several hot spots can be highlighted, below 5000 ft, and around FL110-120. The hotspots above FL110 correspond to crossing between arrivals and departures. These hotspots are close to those highlighted in [SIRE+6].

8.1.3.13. A concentration of RAs can be observed around BIG, and 12NM to the North of it, with crossing between arrivals to Heathrow and London city traffic pattern. These RAs all occur below 5000 ft.

8.1.3.14. As for Paris, it is noticeable that the hotspot below 5000 ft encompasses encounters with VMDs around 500 ft, which means there are mainly encounters with VFR and IFR traffic in this area. And again, as for Paris, the hotspot above 5000 ft encompasses encounters with VMDs above 1000 ft.

8.1.3.15. The following figure the same view but this time for the enroute airspace, with shown in yellow the main flows of traffic.

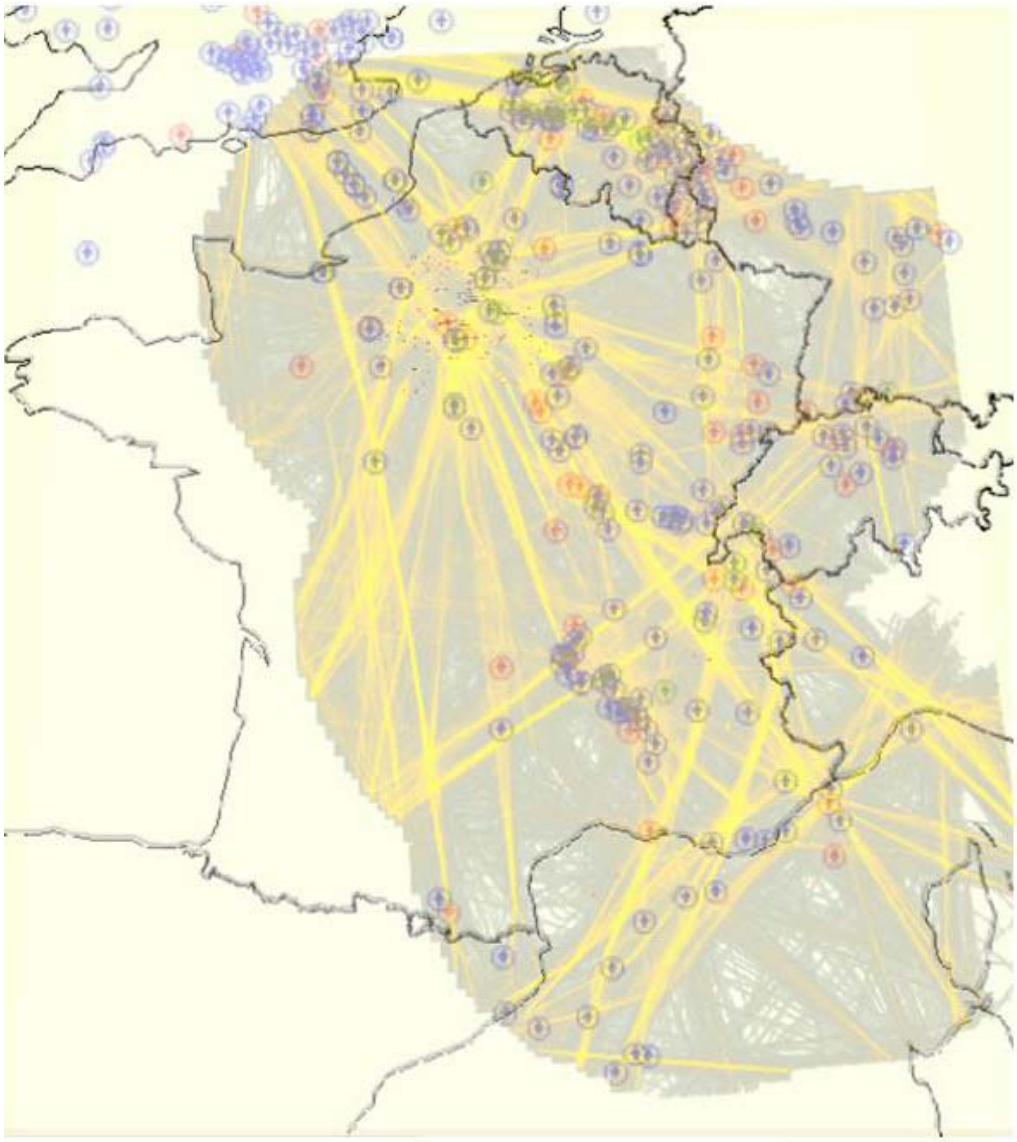

Figure 34: RA location Enroute

8.1.3.16. The zones where RAs occur correspond to areas where the main flows of traffic cross.

8.1.4. Combined perspective

8.1.4.1. The following figure shows a view of the European airspace. Monitor vertical speed RAs are shown in green, adjust vertical speed RAs in blue, and positive RAs in red. The yellow zone shows the limit between TMA and Enroute.

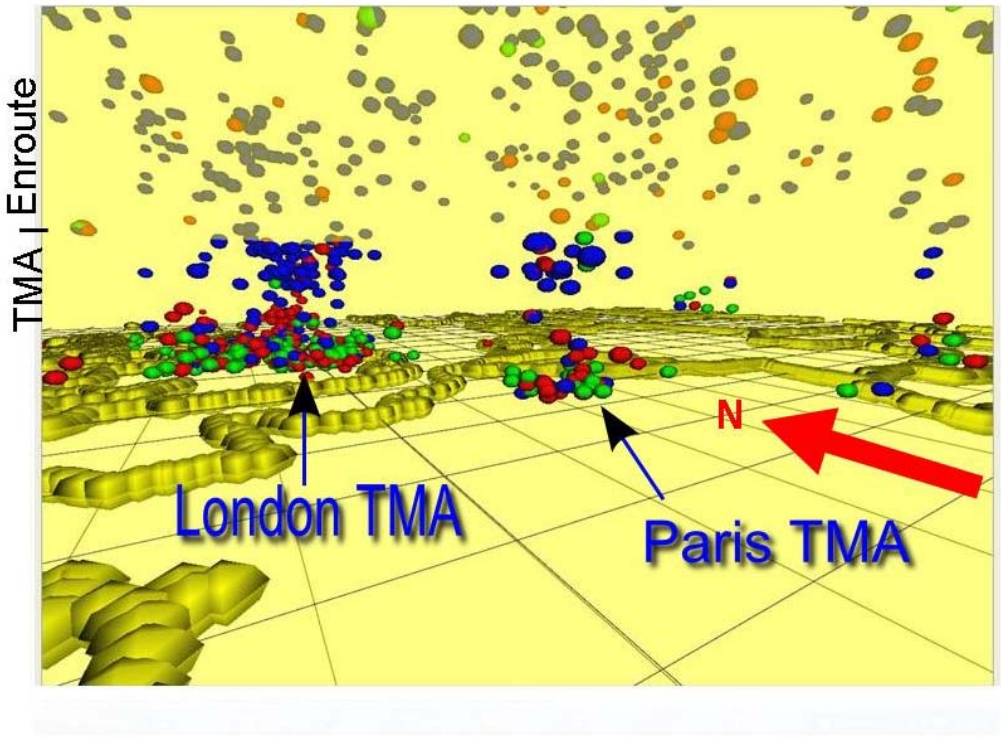

Figure 35: RAs in the European airspace

8.1.4.2. Monitor vertical speed RAs are concentrated in TMAs, close to the ground. Among RAs triggered close to the ground, one also finds a noticeable part of positive RAs.

8.1.4.3. Adjust vertical speed RAs are triggered in TMAs, but close to the upper limit of the TMAs, and also enroute, but here, they are widespread in the airspace.