ACAS PROGRAMME

EMOTION-7 Final Report
European Maintenance of TCAS II version 7.0
Project EMOTION-7

ACAS/03-003

Edition	**:**	**1**
Edition Date	**:**	**January 2003**
Status	**:**	**Released Issue**
Class	**:**	**EATMP**

DOCUMENT IDENTIFICATION SHEET

DOCUMENT DESCRIPTION

Document Title
ACAS PROGRAMME
EMOTION-7 Final Report
European Maintenance of TCAS II version 7.0
Project EMOTION-7

EWP DELIVERABLE REFERENCE NUMBER:

PROGRAMME REFERENCE INDEX:	**ACAS ref.:**	ACAS\03-003 Version 2.0
	EATMP Infocentre ref. :	030218-01
	EDITION DATE:	January 2003

Abstract

The ACAS II implementation by the ECAC Member States was the fist widespread operational implementation of TCAS Version 7. The EMOTION 7 project was established to provide an appropriate framework to minimise the risks associated with potential TCAS II Version 7 operational, safety, and technical issues, particularly in the European airspace environment.

Keywords

ACAS TCAS RVSM TA RA

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DOCUMENT STATUS AND TYPE

STATUS		CLASSIFICATION	
Working Draft	☐	General Public	☐
Draft	☐	EATMP	☑
Proposed Issue	☐	Restricted	☐
Released Issue	☑		

ELECTRONIC BACKUP

INTERNAL REFERENCE NAME:

HOST SYSTEM	MEDIA	SOFTWARE
Microsoft Windows	Type: Hard disk	
	Media Identification:	

DOCUMENT APPROVAL

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

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Acting Director Infrastructure, ATC Systems & Support	 Wolfgang PHILIPP	17/02/03

Document control sheet

Title:	**EMOTION-7 Final Report** **European Maintenance of TCAS II version 7.0** **Project EMOTION-7**	
Author:	Thierry Arino	
Reference:	EMOTION-7 Final Report	
Pages:	Cover & reverse + iv + 118	

Version	Date issued	comments
1.0	27-11-2002	Draft Version Review by T.A., E.V. and C.A. Changes in the structure of the document, editorial changes
1.1	19-12-2002	Second Draft version Review by J.L., J.M.L., B.R. and F.C. Editorial changes
1.2	13-01-2003	Third Draft version Review by J.L., E.V. and B.H Editorial changes, addition of the executive summary, rephrasing of conclusion and recommendations
1.3	21-01-2003	Fourth Draft version Review by E.V. and B.H. Editorial changes to executive summary, conclusion and recommendations
2.0	24-01-2003	First version delivered to EUROCONTROL

EMOTION-7 Final Report

European Maintenance of TCAS II version 7.0

Project EMOTION-7

Drafted by: EMOTION-7 project team

Authorised by: Thierry Arino on 24/01/2003

RECORD OF CHANGES

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Executive summary

The EMOTION-7 project took place between January 2000 and December 2002 within the framework of the EUROCONTROL ACAS Programme. It addressed the European maintenance of TCAS II logic version 7.0. The project was set up to provide EUROCONTROL with the adequate tool and structure to minimise any possible risk associated with the ACAS II implementation in Europe.

The project was issue resolution oriented. The EMOTION-7 work consisted firstly in identifying potential issues, secondly assessing their severity, and finally in rectifying them, if required.

The identification of twelve potential issues and the investigation of six of these issues were facilitated by a specific EMOTION-7 monitoring but also by other means such as the EMOTION-7 Team expertise, the EMOTION-7 Steering Committee (including European CAA representatives, JAA representatives, TCAS manufacturers, aircraft manufacturers, aircraft operators) inputs, national operational monitoring programmes and the former ACASA project of the EUROCONTROL ACAS Programme.

The EMOTION-7 monitoring was based on two very close cooperations with British Airways and Airbus Transport International. In addition to issue identification, it provided statistics on the improvements brought by TCAS II version 7.0.

In summary, a reduction by two of the number of reported RAs was observed with both airlines. The analysis of the 1000ft level-off encounters, which represent half of the reported encounters, confirmed that TCAS II version 7.0 has a better handling of these encounters than the previous version 6.04a. It triggers less RAs, which are also more compatible with ATC clearances.

Out of the twelve potential issues, six issues were investigated in depth. The selection of these six issues was based on both the EMOTION-7 Team expertise and EMOTION-7 Steering Committee advice. The selection took into account both the potential for operational and/or safety implications and the constraint related to the effort available within the project.

Issues with the potential to debase the safety performance of TCAS were classified as safety issues, whereas issues that had no safety consequences, but, which could be disturbing for ATC and pilots were classified as operational issues.

The severity of the six investigated issues was evaluated using operational and safety performance indicators. The output of these analyses was to decide whether a rectification of the issue was required.

The first step of an issue rectification consisted in deciding whether or not a technical solution was the most relevant option to resolve the issue. Both the operational and technical aspects were considered. In a second step, a technical solution or an operational procedure modification was proposed to rectify the issue. A third step consisted in verifying that the solution was relevant. Then it consisted in verifying that the TCAS logic performance was not affected by the modification or that the operational procedure modification was acceptable for both flight crew and ATC perspectives. A fourth step consisted in promoting the solution mainly to major European stakeholders for procedural solutions and to US experts for technical solutions.

In summary, the EMOTION-7 project permitted to rectify six issues through direct solutions proposals or through recommendations, and also permitted to gain a better knowledge of TCAS II version 7.0.

The EMOTION-7 monitoring was a very useful tool during the project. It should be maintained for the same reasons as creating the EMOTION-7 project and, also, because of potential future changes in the ATM operations, which may impact the performances of TCAS II.

The initial rectification of issue SA01 (Inappropriate reversal logic operation) was one of the major deliverable of the EMOTION-7 project. In a near future, it should be extended in scope in order to fully address all of the anomalies discovered to te in the TCAS reversal logic.

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Acronyms

ACAS	Airborne Collision Avoidance System
ACASA	ACAS Analysis
AD	Airworthiness Directive
APSG	ACAS Programme Steering Group
ASR	Air Safety Report
ATC	Air Traffic Control
CAS	Collision Avoidance System
CENA	Centre d'Etudes de la Navigation Aérienne
EMOTION-7	**E**uropean **M**aintenance **O**f **T**CAS II vers**ion 7**.0
FAA	Federal Aviation Administration
FL	Flight Level
GA	General Aviation
HMD	Horizontal Miss Distance
ICAO	International Civil Aviation Organization
MOPS	Minimum Operational Performance Standards
NM	Nautical Mile
NMAC	Near Mid-Air Collision
OMG	Operational Monitoring Group
OSCAR	Off-line Simulator for Collision Avoidance Resolution
QAR	Quick Access Recorder
RA	Resolution Advisory
RVSM	Reduced Vertical Separation Minimum
SB	Service Bulletin

SICASP	SSR Improvements and Collision Avoidance Systems Panel
SCRSP	Surveillance and Conflict Resolution Panel (successor to SICASP)
SSR	Secondary Surveillance Radar
TA	Traffic Advisory
TCAS	Traffic Alert and Collision Avoidance System
UK	United Kingdom
US	United States of America
VMD	Vertical Miss Distance
WP	Work Package

List of definitions

Double equipage encounter

Encounter involving two TCAS equipped aircraft.

Double level-off encounter

A level-off encounter in which both aircraft are levelling-off to reach flight levels 1000ft apart, one climbing and the other one descending.

Horizontal Miss Distance

The horizontal separation at the time of closest approach between the two aircraft in an encounter.

Level-off encounter, or 1000ft level-off encounter

Encounter during which two aircraft are levelling-off 1000ft apart, or during which one aircraft is levelling-off 1000ft apart from a level aircraft, with a simultaneous horizontal convergence.

Near Mid-Air Collision

An encounter in which horizontal separation is less than 500ft and vertical separation less than 100ft simultaneously. In this report, it is generally taken to be an encounter in which hmd < 500ft and vmd < 100ft (i.e. at closest approach).

Operational issue

An issue, which does not debase the safety benefits brought by ACAS, but which is disturbing for the flight crews and/or ATC.

Positive RA

An RA requesting a climb or descend at 1500ft/mn.

Reversal RA

RA that reverses the sense of the initial RA. For example, an RA requesting the aircraft to climb at 1500fpm, while an initial RA was previously requesting a descent at 1500fpm.

Risk Ratio

The risk of collision in an airspace for a given ACAS equipage scenario divided by the risk of collision in that airspace in the absence of ACAS.

Safety issue

An issue, which has the potential to debase the safety benefits brought by ACAS, possibly leading to reduced vertical separations, or even to NMACs.

Single equipage encounter

Encounter involving a TCAS equipped aircraft and an aircraft not equipped with TCAS.

Single level-off encounter

A level-off encounter in which one aircraft is levelling-off to reach a flight level 1000ft apart from a level aircraft.

Split TA

A TA is called a split TA, if it occurs once, disappears and, then, reoccurs for the same intruder a few seconds later while the aircraft are still converging in range.

Vertical Miss Distance

The vertical separation at the time of closest approach between the two aircraft in an encounter.

1. Introduction

1.1. Context

1.1.1. The carriage and operation of the ACAS II compliant equipment TCAS II version 7.0 has been mandatory in Europe since the 1st January 2000 for all civil turbine-engined aircraft with more than 30 passenger seats or more than 15,000 kg. Due to the late availability of TCAS II version 7.0, an ACAS II implementation transition period was scheduled from 1 January 2000 until 31 March 2001. In order to permit resolution of difficulties related to supply, installation and certifications of TCAS II version 7.0, some exemptions were made available until the 30th September 2001.

1.1.2. The development of TCAS II version 7.0 was carried out in the US and was completed in December 1998. TCAS II version 7.0 is not mandatory in the US, whereas it is recognized that this major update addresses several issues identified with TCAS II version 6.04a. As a result, Europe was the first to undertake an operational widespread implementation of TCAS II version 7.0. Therefore, the EUROCONTROL ACAS Programme decided to set up the EMOTION-7 project, which stands for **E**uropean **M**aintenance **O**f **TCAS II version 7.0**. It was based on a three-year schedule and was sponsored by the EUROCONTROL ACAS Programme from January 2000 to December 2002.

1.2. Scope and objectives

1.2.1. The main objective of the project was to provide EUROCONTROL with the adequate tool and the adequate structure to minimise the risks associated with the European ACAS implementation.

1.2.2. The further objectives of the project were to:

- Set in place an effective EMOTION-7 monitoring of TCAS II version 7.0 to permit identification and clear understanding of potential technical and operational issues and to ensure that the changes proposed in TCAS II version 7.0 were effective in an operational environment;
- Maintain the required level of TCAS II expertise to enable the rapid resolution of TCAS II version 7.0 CAS logic issues; and
- Enable maintenance of the technical co-operation on TCAS II version 7.0 between FAA, Sofréavia, CENA and EUROCONTROL, thereby providing the climate for rapid response to potential ACAS Programme change proposals to TCAS II version 7.0 CAS logic.

1.3. Document overview

1.3.1. The purpose of this document is to present the work achieved from January 2000 to December 2002 within the EMOTION-7 project.

1.3.2. This report is structured as follows:

- First, an overview of the project is provided in part 2;
- Part 3 presents the results of the EMOTION-7 monitoring;
- Part 4 provides a presentation of the analysed issues;
- Parts 5 and 6 provide respectively conclusions and recommendations;
- A brief presentation of all the issues is also presented in Appendix A.

2. Project overview

2.1. Maintenance process

2.1.1. It was decided that the EMOTION-7 project would provide an issue resolution oriented maintenance of TCAS II version 7.0.

2.1.2. This issue resolution oriented maintenance process is composed of three phases:

- **Issue identification** permitted by an EMOTION-7 monitoring.
- **Issue analysis**:
  - Assessing the severity, which consists in assessing the probability of occurrence of the issue, its causes and its consequences; and
  - Demonstrating the severity, which results in deciding to proceed or not with the issue rectification.
- **Issue rectification**:
  - Investigating the problem, which consists in deciding whether or not a technical solution is the most pertinent option to rectify the issue;
  - Proposing a solution to rectify the issue;
  - Validating the solution; and
  - Promoting the solution.

2.2. Project structure

2.2.1. To achieve an issue resolution oriented maintenance of TCAS II version 7.0, the structure of the project was split into complementary phases supported by specific Work Packages:

- Issue identification (WP-3);
- Issue analysis (WP-1);
- Issue rectification (WP-2);
- EMOTION-7 Steering Committee (WP-4);
- Project management (WP-5).

2.2.2. Work Packages one to four are described below.

2.3. WP-3 : issue identification

2.3.1. WP-3 consisted in an EMOTION-7 monitoring of TCAS II version 7.0, set up in order to identify potential issues, through a close cooperation with:

- Airbus Transport International, because this airline was planned to be among the first to implement version 7.0, and because of the possibility to have detailed data for TCAS II events; and
- A major European airline, British Airways.

2.3.2. The first step of the monitoring was to gather data related to the operations of Airbus Transport International and British Airways. Data were extracted from:

- Airborne data through Quick Access Recorder, which includes the TCAS II advisories, and TCAS II boxes with recordings capabilities;
- Pilot reports;
- ATC reports;
- Radar data recorded at CENA or obtained from EUROCONTROL.

2.3.3. ACAS event reports were usually composed of information from several sources. Therefore the different sources of data available for a given event had to be correlated in order to facilitate data analysis.

2.3.4. The results of the analyses of events were sent to EUROCONTROL, British Airways and Airbus Transport International. The statistical analyses and the analyses of significant events were detailed in reports provided on a 6-month basis to EUROCONTROL, British Airways and Airbus Transport International.

2.3.5. The analysis of the data recorded during the monitoring provided information on TCAS alerts onboard the aircraft, and provided statistical figures such as the number of RAs per flight hour for aircraft in the European Airspace, the altitude distribution of the events, pilot appreciation, etc. However, the main objective of the monitoring was to permit the identification of potential issues. This issue identification was also permitted by other means:

- EMOTION-7 team expertise;
- EMOTION-7 Steering Committee inputs;
- National operational performance monitoring;
- The ACASA project.

2.3.6. The output of this issue identification was a clear understanding of the issues being considered, before entering into the phases of issue analysis and issue rectification, if the issue was considered worth investigating. Technical issues with the potential to debase the safety performance of TCAS were classified as safety issues, whereas issues that had no safety consequences, but, which could be disturbing for ATC and pilots were classified as operational issues. **Safety issues were referenced as**

SAxx, while operational issues were referenced as OPxx, where xx is the number of the issue.

2.3.7. The analysis of data from the monitoring provided an initial estimate of the severity of some issues and helped in the decision to investigate them in details or not.

2.3.8. The decision to proceed to the analysis of an issue was exercised 6 times:

- Issue SA01: Inappropriate reversal logic operation (see §4.3):
- Issue SA07: Discrepancy between altitude quantization and altitude reporting capability announcement (see §4.4);
- Issue SA10: Inappropriate RAs due to incorrect altitude reporting (see §4.5);
- Issue OP06: Unnecessary RAs in 1000-ft level-off geometries (see §4.6);
- Issue OP08: Operational implications for ACAS due to proposed ground movement control techniques utilising Mode S multilateration (see §4.7);
- Issue OP09: TAs for intruders on the ground (see §4.8).

2.3.9. The following issues were identified, but not analysed either because it was concluded from the EMOTION-7 team expertise and from the Steering Committee judgement that they would not have significant operational implications, or they were identified late (e.g., SA11):

- Issue SA02: Inappropriate RAs against glider clusters;
- Issue SA11: RA display misinterpretation;
- Issue SA12: Inappropriate RAs in multiple aircraft encounters;
- Issue OP03: Split TAs in converging situations;
- Issue OP04: Green arc symbology for weakening RAs;
- Issue OP05: Nuisance TA aural annunciations at low altitudes.

2.4. WP-1 : issue analysis

2.4.1. When an issue was to be investigated, analysis had to determine whether the issue was related to a specific encounter geometry, flight phase, altitude layer or operational procedure.

2.4.2. When possible, figures on the probability of occurrence of the issues were provided, using inputs from the EMOTION-7 monitoring.

2.4.3. The output of the issue analysis was an accurate estimate of the severity of the issue. The severity of safety issues was illustrated using risk ratios to show whether the issue was affecting the safety performance of TCAS. A risk ratio is an indicator of the benefit brought by TCAS: a risk ratio of x% means that for a given airspace, the risk of collision if aircraft are equipped with TCAS is x% of the risk of collision in that airspace if aircraft are not equipped with TCAS.

2.4.4. The severity of operational issues was demonstrated using operational performance indicators such as ATC or pilot complaints, or deviations caused by RAs.

2.4.5. Following this, the Steering Committee recommended to proceed or not with the issue rectification by the project. The decision to proceed with issue rectification was taken twice, for issues SA01 (Inappropriate reversal logic operation) and OP06 (Unnecessary RAs in 1000-ft level-off geometry).

2.5. WP-2 : issue rectification

2.5.1. The first step of rectification consisted in deciding whether or not a technical solution (e.g., logic modification) was the most relevant option to resolve the issue. Both the operational and technical aspects were considered.

2.5.2. In a second step, a technical solution (e.g., issue SA01) or an operational procedure modification (e.g., issue OP06) was proposed to rectify the issue.

2.5.3. The third step of the rectification phase consisted in verifying that the solution was relevant, that the CAS logic performance was not affected by the modification or that the operational procedure modification was acceptable for both pilot and ATC controller perspectives. This was performed using:

- The European real encounter data base (a set with over 500 radar data encounters) extracted from radar data recordings to perform operational performance simulations. These data were used to compute performance indicators (e.g., deviations caused by RAs), in order to demonstrate that the proposed solutions would be acceptable for ATC and pilots. This data base had already been used in pre-implementation studies of TCAS II version 7.0, such as [QUAT];
- The ICAO ACAS safety standard encounter model [SARPS] and the European ACAS Safety encounter model [ACA2] to perform ACAS safety simulations (i.e., risk ratio computations). The main safety indicator used to demonstrate the safety benefits of the proposed solutions was the risk ratio, which was computed with and without the TCAS II modification.

2.5.4. The fourth step consisted in :

- Demonstrating the European view of the severity of the issues mainly to a US audience and in particular to the FAA. RTCA SC-147 was involved because TCAS is an equipment manufactured in the USA and certified by the FAA, and because no modification is possible without an FAA agreement;
- In promoting the solution mainly to major European stakeholders for procedural solutions (issue OP06), and to US experts for technical solutions (issue SA01).

2.6. WP-4 : EMOTION-7 Steering Committee

2.6.1. An EMOTION-7 Steering Committee was setup to support the decision process related to each identified issue. The Steering Committee was composed of major ACAS stakeholders:

- European CAA representatives;
- JAA representatives;
- TCAS manufacturers;
- Aircraft manufacturers;
- Aircraft operators (British Airways, Lufthansa and Airbus Transport International).

2.6.2. The EMOTION-7 findings were presented to the EMOTION-7 Steering Committee on a six month basis. Using this information, the Steering Committee provided recommendations and guidelines.

3. EMOTION-7 monitoring

3.1. Scope and objectives

3.1.1. Within the scope of the EMOTION-7 project, Work Package 3 addressed the EMOTION-7 monitoring of TCAS II version 7.0 **with the specific objective to highlight as soon as possible potential issues**. This task involved a major European airline (British Airways) and a smaller aircraft operator (Airbus Transport International).

3.1.2. Through these close co-operations, all the TCAS II reports of both airlines were available and enabled to assess TCAS II version 7.0 operational performances. This also enabled a statistical analysis and the possibility to identify relevant TCAS II events that required specific investigation.

3.1.3. In addition, both airlines provided airborne recorded data that enabled a detailed technical and operational investigation of possible TCAS II version 7.0 issues and a statistical analysis of TCAS II version 7.0 performances.

3.1.4. Finally, some radar recordings were performed so as to extract trajectories of aircraft for relevant events. Some detailed analyses were then performed based on these radar data and if available, on the airborne TCAS data and pilots' reports.

3.1.5. The statistical results shown in this part are trends, which were observed during the EMOTION-7 monitoring. These results enable to have a better picture of what improvements are brought by TCAS II version 7.0, therefore they are presented. However, **the reason why an EMOTION-7 monitoring was set up was to permit issue identification.** Therefore, concentrating on trends rather than on specific events was not the primary purpose of the EMOTION-7 monitoring, but only an output of it.

3.2. *British Airways*

3.2.1. Type of operations

3.2.1.1. British Airways is a major European airline, which operates worldwide. The British Airways fleet encompasses three types of fleet, for several types of operations:

- The Regional Fleet includes turboprops and short range commuter aircraft;
- The Short Haul Fleet includes Airbus and Boeing types of airframe for European and UK services;
- The Long Haul Fleet for Worldwide services.

3.2.2. ASRs investigation

3.2.2.1. During 2 years and a half, a copy of all the ASRs related to TCAS filled in by pilots of British Airways has been received and processed by the project team.

3.2.2.2. The following presents the main results of the statistical analysis performed on a total of 1059 ASRs received and processed.

3.2.2.3. Number of ASRs per month

3.2.2.3.1. The following figure presents the ASR breakdown per month for 2000, 2001 and 2002. The 2000 figures only takes into account the second semester for 2000.

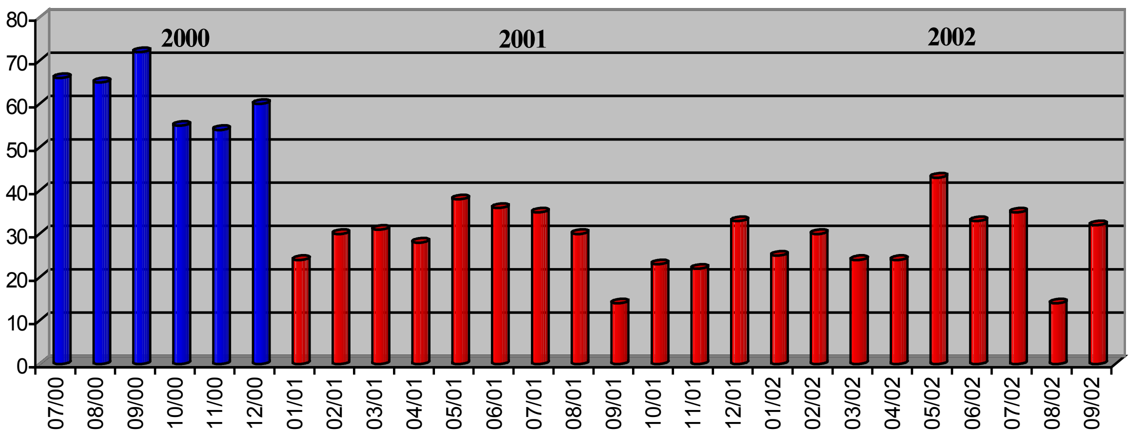

Figure 1: Number of ASRs received each month

3.2.2.3.2. **The number of ASRs received per month has been reduced by more than half since the beginning of 2001**. During the second half of 2000, an average of 62 ASRs per month was received. This average has decreased to 29 in 2001 and 2002.

3.2.2.3.3. **This reduction of the number of received ASRs is attributed to the implementation of TCAS II version 7.0.** A 50% reduction of the number of RAs triggered with TCAS II version 7.0 in comparison with TCAS II version 6.04a was expected and is in line with the studies performed during the development and validation of the new TCAS II version [QUAT].

3.2.2.3.4. Level-off encounters represent about 50% of the ASRs. They represent 55% of the ASRs in 2000, and 49% for 2001 and 2002. A decrease in the proportion of level-off encounters was expected [WP1/045], due to the improvements included in TCAS II version 7.0 for the treatment of 1000ft level-off encounters.

3.2.2.3.5. Nevertheless, these figures are based on reported events and there could be some differences with the overall number of RAs. However, the trend is well established.

3.2.2.4. Pilot appreciation

3.2.2.4.1. In the ASRs, pilots fill in a field entitled pilot appreciation. They have the choice to classify the event as necessary, useful or unnecessary. This perception is therefore very subjective. The purpose of this part is to present the trends observed in the ASRs, keeping in mind that only rough trends can be taken into account, due to the subjectivity of the pilot appreciation of the events.

3.2.2.4.2. The following figure presents the pilot appreciation, when this information was available (77% of the ASRs), as reported in the ASRs describing encounters that occurred in 2000, and encounters that occurred in 2001&2002.

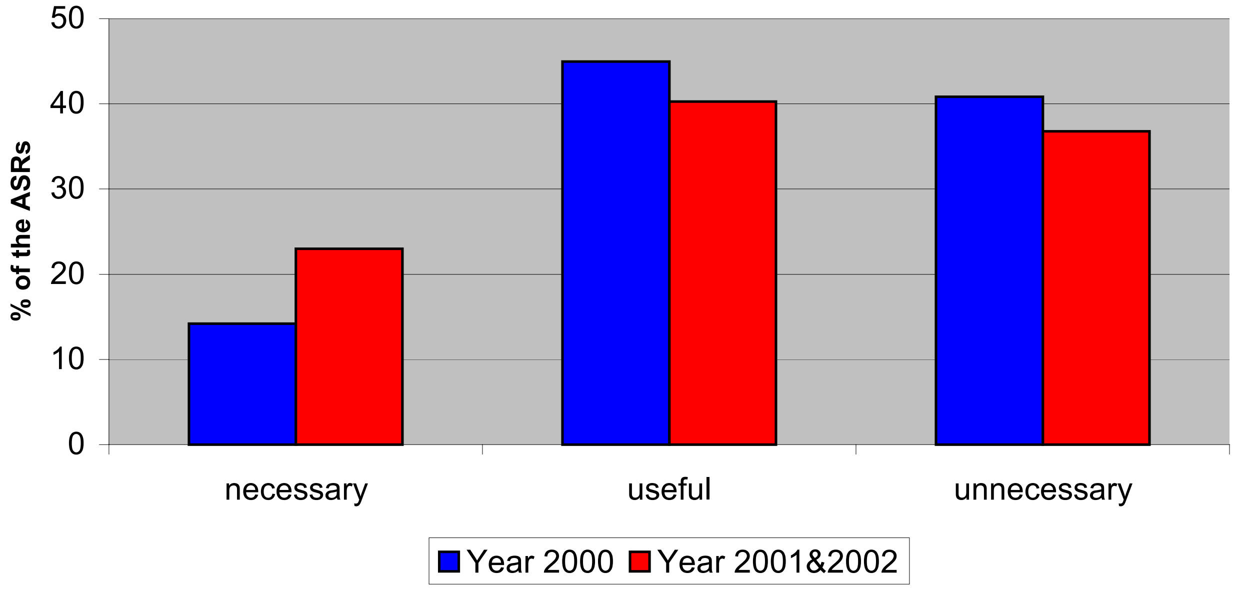

Figure 2: 2000 vs. 2001&2002 (% of ASRs)

3.2.2.4.3. The two distributions are slightly different. **The reported RAs are more often perceived as necessary** since the introduction of TCAS II version 7.0 (23% instead of 14%). They are less often perceived as unnecessary (37% instead of 41%). This trend is a **good point for TCAS II version 7.0**, because it brings improvements, and because the overall pilot appreciation is positive, with more than 50% of the RAs classified as necessary or useful.

3.2.2.4.4. The following figure presents the pilot appreciation as reported in the ASRs describing 1000ft level-off encounters. The specific figures for 2000 and 2001&2002 are not shown, as they are equivalent.

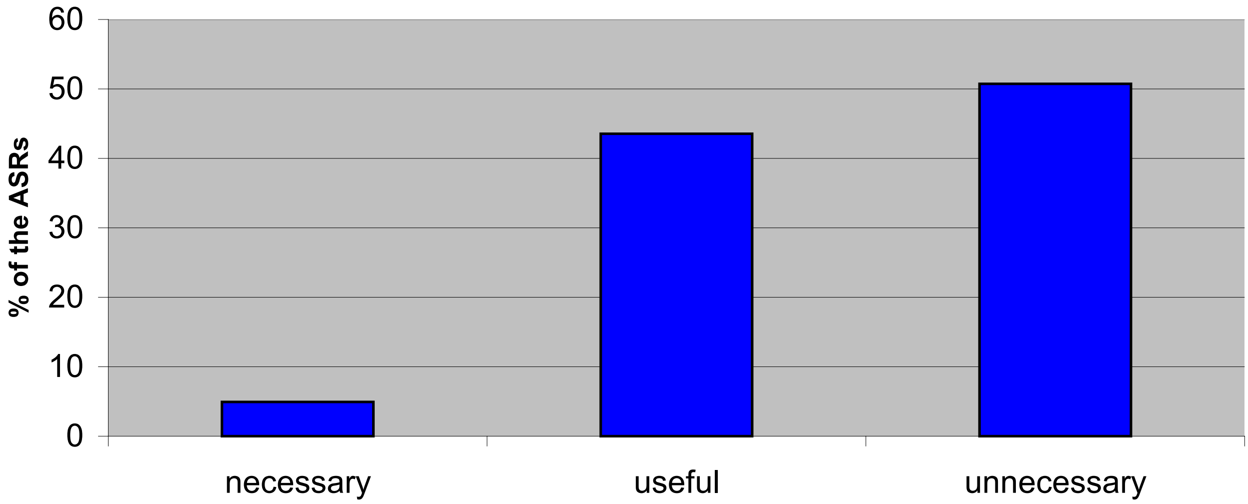

Figure 3: Level-off encounters

3.2.2.4.5. RAs triggered during level-off encounters are seldom perceived as necessary (i.e. 5% instead of 19% for all the RAs). They are often perceived as useful (44% of the ASRs).

3.2.2.4.6. One half of the RAs triggered in level-off encounters are perceived as unnecessary. This does not mean that all these RAs perceived as unnecessary were incompatible and disruptive for pilots or ATC: the analysis of Issue OP06 [WP1/045] (see §4.6) and analysis of events from the EMOTION-7 monitoring demonstrate that, especially with TCAS II version 7.0, **RAs triggered during level-off encounters are often compatible with ATC clearances**.

3.2.2.4.7. The following figure presents the pilot appreciation as reported in the ASRs describing encounters with VFR intruders. The specific figures for 2000 and 2001&2002 are not shown, as they are equivalent.

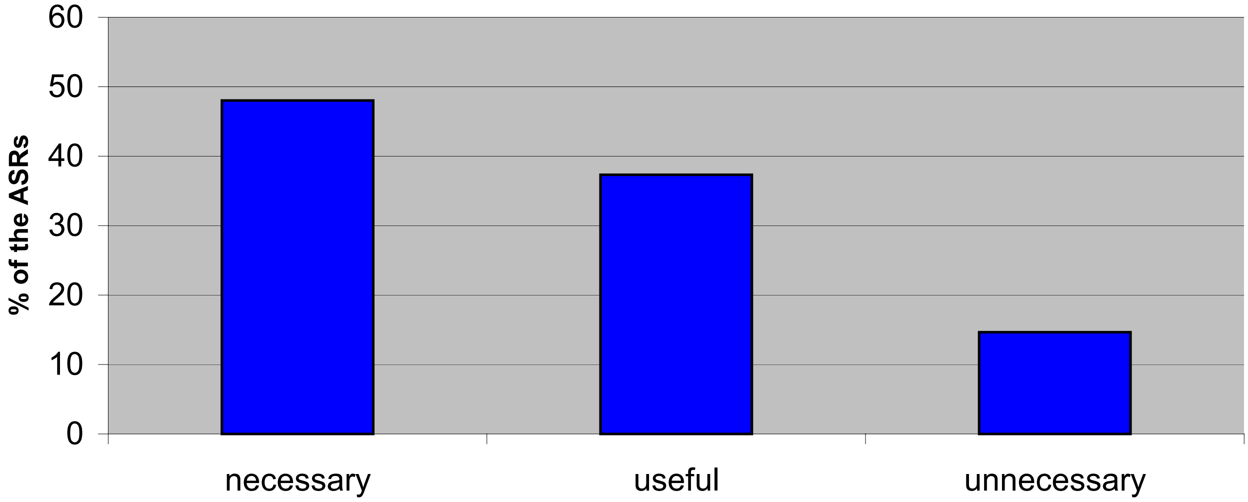

Figure 4: Encounters with VFR aircraft

3.2.2.4.8. **The vast majority of RAs triggered against VFR intruders (8.3% of the ASRs) seems to be necessary or useful** (85% of the encounters). This underlines the fact that encounters involving VFR intruder would often result in vertical separation at CPA estimated as lower than 500ft without TCAS. **TCAS helps to address the issue of incompatibility between IFR and VFR flights**.

3.2.2.5. Altitude breakdown

3.2.2.5.1. The following figure presents the altitude distribution of the events reported in the ASRs, for all the encounters and for the subset of ASRs corresponding to 1000ft level-off encounters.

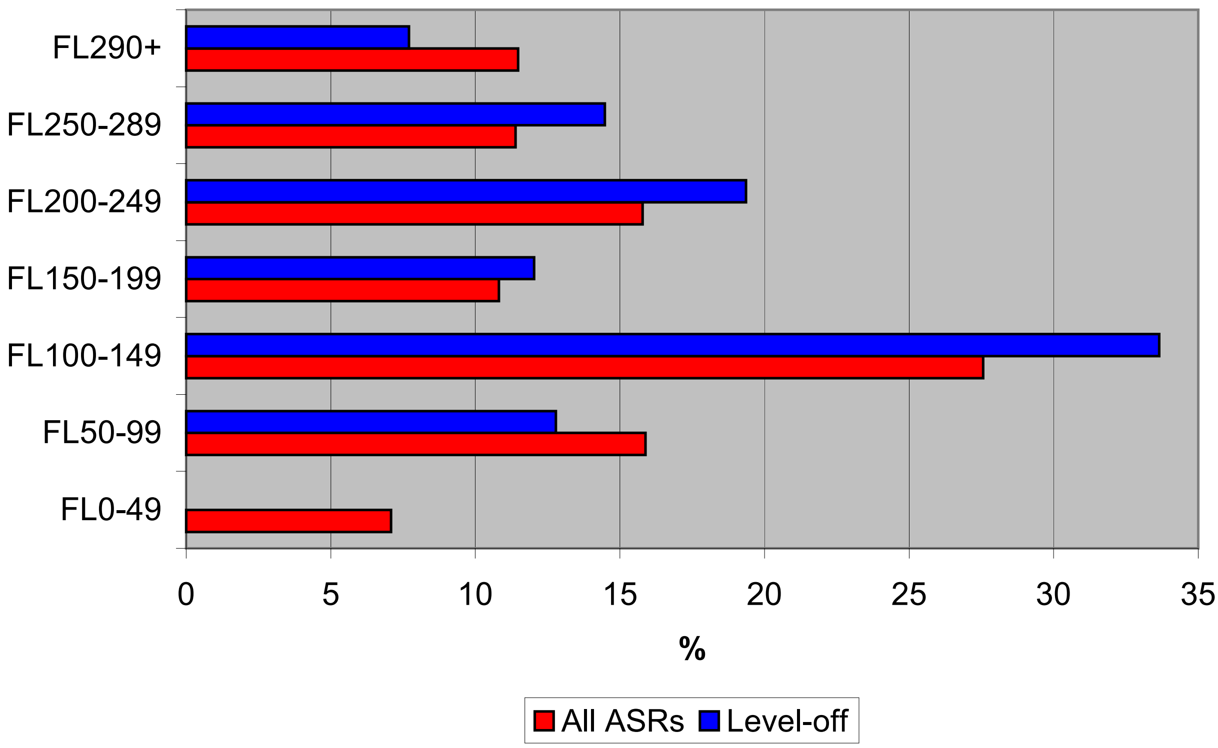

Figure 5: All encounters vs. level-off encounters

3.2.2.5.2. There are differences between the altitude breakdown of all the ASRs and of the level-off encounters:

- The lack of level-off encounters below FL50;
- **The greater proportion of level-off encounters in the FL100-FL149 altitude band, which is mainly due to the departure and arrival procedures in place in major airports**, like Heathrow and Gatwick. Actually, and as highlighted in the issue OP06 analysis, this peak corresponds to locations where RAs occur frequently, and, which are known as hot spots [WP2/064]. The procedural solutions proposed for issue OP06 address this peak.

3.2.2.5.3. The following figure presents the altitude distribution of the events reported in the ASRs, for all the encounters that occurred before the introduction of RVSM in the European airspace and for all the encounters that occurred after (24th January 2002).

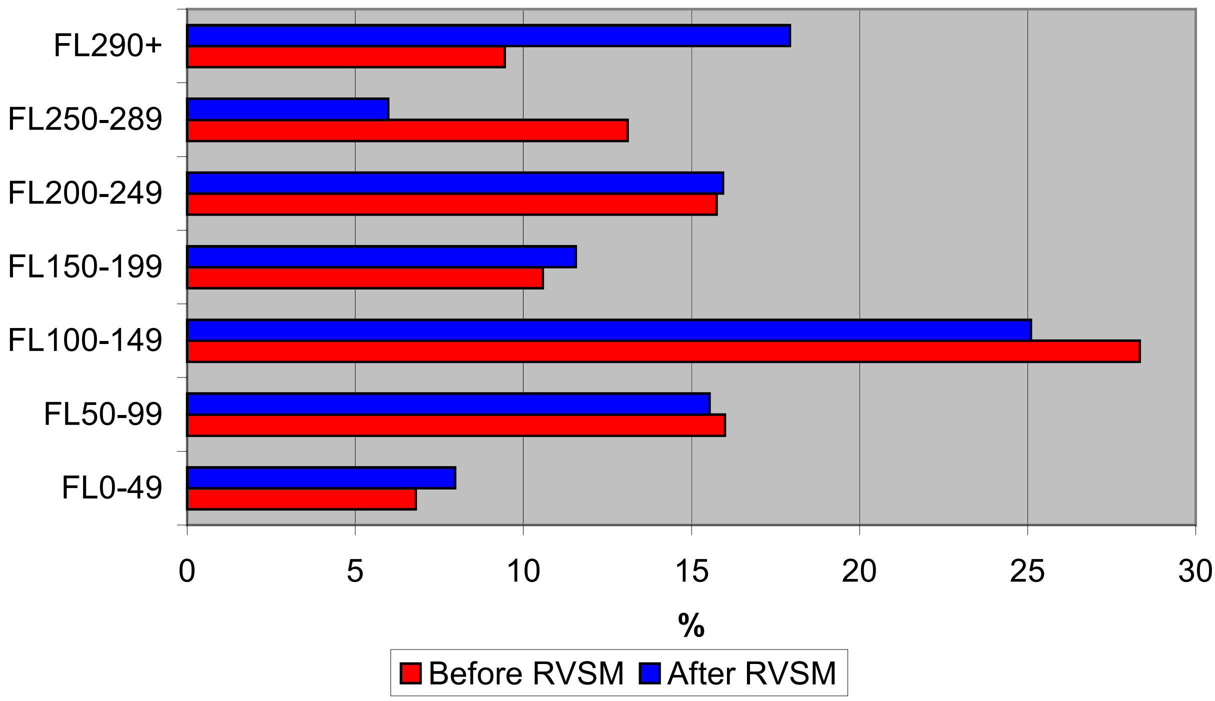

Figure 6: Encounters before RVSM introduction vs. Encounters after RVSM introduction

3.2.2.5.4. The distributions are very close from 0ft to FL250. An inversion appears above FL250, as the proportion of reported RAs is two time higher above FL290, and two times lower between FL250 and FL290 after RVSM introduction than before.

3.2.2.5.5. This is linked to the introduction of RVSM in the European Airspace, as there are more aircraft in closer proximity above FL290.

3.2.3. Airborne data investigation

3.2.3.1. A total number of **50 TCAS data dumps** have been received from April 2001 to October 2002. They all address TCAS II version 7.0. This data includes a total of 52 RAs and separately 2228 TAs. **The ratio between RAs and TAs computed on this set of data is therefore 1 RA every 43 advisories**.

3.2.3.2. Data is mainly available for level-off encounters (59.6%). A significant proportion of the RAs are classified as necessary (30.7%) in the corresponding ASRs.

3.2.3.3. Only 9.7% of the RAs triggered during level-off encounters are positive RAs (i.e., climb or descend at 1500ft/mn). No positive RAs have been triggered during single level-off encounters (i.e., one aircraft levelling-off 1000ft apart from a level intruder). Despite the still significant proportion of RAs generated during level-off encounters, it should be noted from the EMOTION-7 monitoring of British Airways that with TCAS II version 7.0, a very large part of them are compatible with the ATC clearance only demanding a reduction of the vertical rate.

3.2.4. Radar data investigation

3.2.4.1. A total number of 66 events were analysed through radar data recordings.

3.2.4.2. For each of these events, simulations were performed on the radar data, and a feedback was made to British Airways, with an analysis.

3.3. Airbus Transport International

3.3.1. Type of operations

3.3.1.1. The fleet of Airbus Transport international is composed of 5 Belugas, which fly in Europe, between non major airports such as Toulouse, Hamburg, Manchester, etc.

3.3.1.2. Their cruise flight levels of these aircraft are usually ranging between FL260 and FL290.

3.3.2. General results

3.3.2.1. Number of TAs

3.3.2.1.1. At the initiation of the EMOTION-7 monitoring, Airbus Transport International's aircraft were equipped with TCAS II version 6.04a. Therefore, during about one year, TAs generated with TCAS II version 6.04a have been analysed to enable a comparison with the TAs generated by TCAS II version 7.0.

3.3.2.1.2. Airborne recordings have been received since the first flights with TCAS II version 7.0 from late October 2000 to late September 2002.

3.3.2.1.3. The table below presents the number of TAs for both TCAS II versions based on the available airborne recordings.

	TCAS II v6.04a	TCAS II 7.0
Number of days of recordings	937	2203
Number of flight hours during these days	2043	4698
Number of TAs	249	486
1 TA every X days of operations	3.8	4.5
1 TA every X flight hours	8.2	9.7

Table 1: Number of TAs for both TCAS II versions

3.3.2.1.4. The TA generation rates are roughly equal. There is **1 TA every 9.7 flight hours** and it corresponds to 1 TA every 4.5 days of operations.

3.3.2.2. Number of RAs

3.3.2.2.1. The following table presents the number of flight hours and RAs for both TCAS II versions. The estimated TA/RA ratios are computed by dividing the rate of each of them per flight hour.

	TCAS II version 6.04a	TCAS II version 7.0
Number of flight hours	4898	5755
Number of RAs	24	7
1 RA every X flight hours	204	822
Estimated TA/RA ratio	25	85

Table 2: Number of RAs for both TCAS II versions

3.3.2.2.2. **The expected reduction in the RA generation rate is confirmed by these results**. Only 7 RAs have been generated by TCAS II version 7.0 during about 5800 flight hours. The reduction rate observed on Airbus Transport International fleet is in the order of four.

3.3.2.2.3. This ratio is very low and even lower than expected. This high reduction rate is likely linked to Airbus Transport International operations. Based on the various studies performed prior to the TCAS II version 7.0 implementation, a reduction by two of the number of RAs was anticipated. This reduction rate seems to be operationally confirmed by other sources (e.g. SCTA[1] and the monitoring of British Airways presented in §3.2.).

3.3.2.2.4. For the RAs, and when possible, simulations were performed on radar data, and a feedback was made to Airbus Transport International, with an analysis.

[1] Air Traffic Control Services, a DGAC service in charge of the monitoring of TCAS II in France.

3.3.3. TA monitoring

3.3.3.1. Altitude breakdown

3.3.3.1.1. The following figure shows the altitude distribution of the TAs, given in percentages of the total number of TAs.

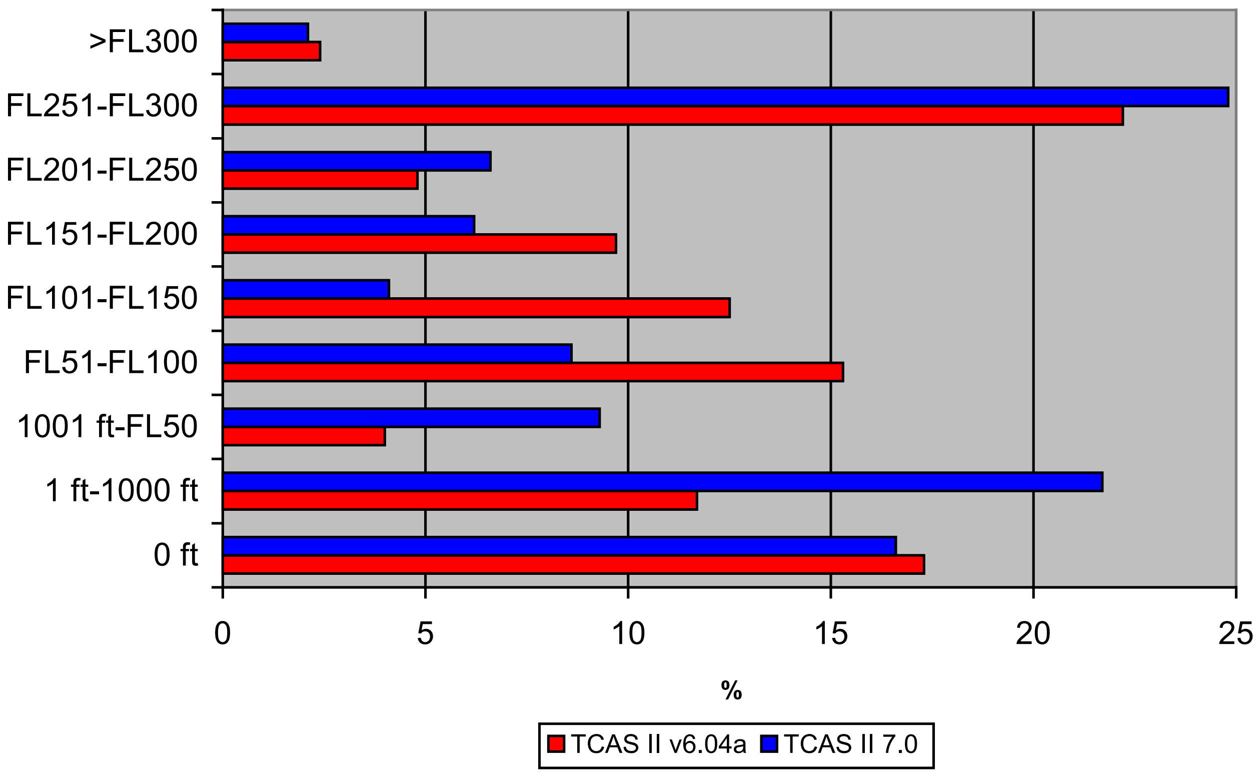

Figure 7: Altitude distribution of TAs

3.3.3.1.2. Both distributions have a peak between FL250 and FL300. This peak is due to the cruise flight levels of Airbus Transport International aircraft, which are usually ranging from FL260 to FL290.

3.3.3.1.3. Both distributions have a peak for TAs on the ground: the proportion of such TAs is around 17% with both versions.

3.3.3.1.4. The major difference between version 6.04a and version 7.0 can be observed at low altitudes as 9.3% of the TAs with version 7.0 are observed between 1001ft and FL50, whereas they are only 4.0% with version 6.04a. Most of these TAs are triggered for intruders on the ground. The specific issue Of TAs for intruders on the ground is analysed within issue OP09 [WP1/075].

3.3.3.2. Low altitude TAs

3.3.3.2.1. The following figure shows the altitude distribution of low altitude TAs with TCAS II version 7.0. This figure is interesting, as a low altitude TA accompanied with an aural message is disturbing for the crew.

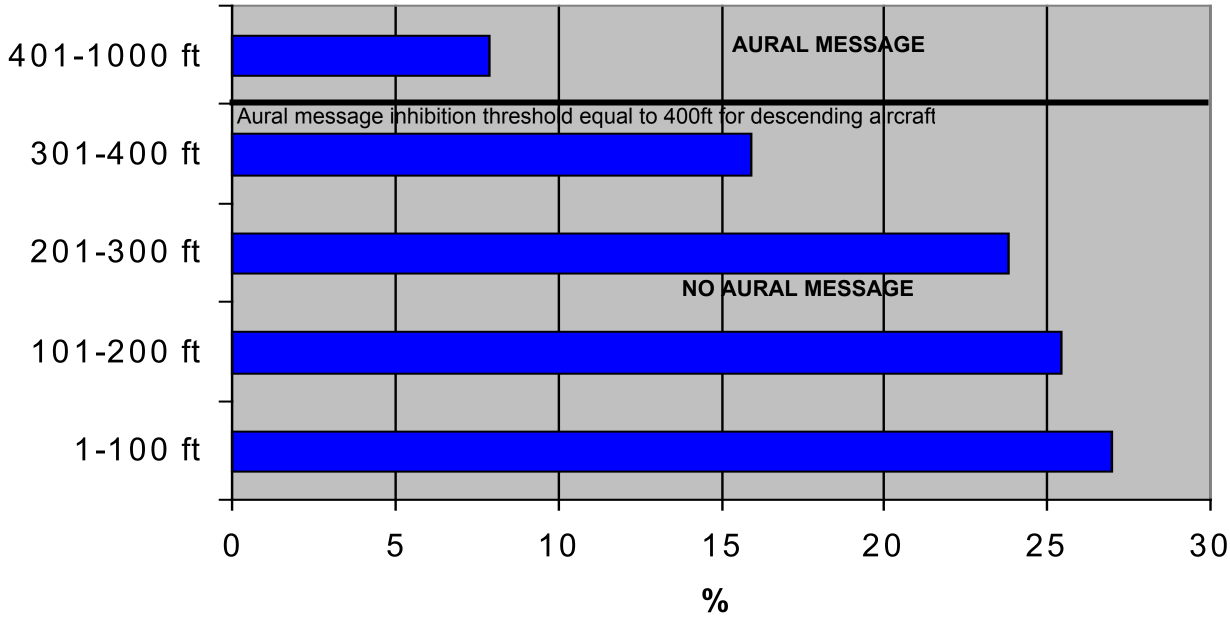

Figure 8: Altitude distribution of low altitude TAs

3.3.3.2.2. This figure shows that actually only 7.9% of the TAs generated below 1000ft while airborne have induced an aural message.

3.3.3.2.3. The remaining 92.1% have been generated below 400ft and have therefore not been accompanied by an aural message.

3.3.3.2.4. Therefore, despite the fact that 21.7% of the TAs were triggered below 1000ft, **very few aural alerts have been announced because of the inhibition altitude threshold provided by TCAS II version 7.0**, which is 400ft for the descending aircraft.

3.3.3.3. Split TAs

3.3.3.3.1. A TA is called a split TA, if it occurs once, disappears and, then, reoccurs for the same intruder a few seconds later while the aircraft are still converging in range. Such a TA can be disturbing for a crew, because of the repetitive aural annunciations associated.

3.3.3.3.2. The analysis of TAs showed that 9.7% of the airborne TAs were split TAs with TCAS II version 7.0, which corresponds to 1 airborne split TA every 131 flight hours. This is more than what was observed with version 6.04a (i.e., 4.4% of airborne split TAs and 1 airborne split TA every 227 flight hours).

3.3.3.3.3. Nevertheless, this difference was not judged to be an issue because:

- The monitoring of British Airways has shown that some split TAs in converging situations are triggered, but actually, in a lower proportion (5.1%);
- No specific complaints from pilots were received.

3.4. Concluding remarks on the EMOTION-7 monitoring

3.4.1. General

3.4.1.1. The EMOTION-7 monitoring was a very useful source of data in the scope of the European maintenance of TCAS II version 7.0. Its relevance in the investigation of potential issues has been highlighted in several occasions.

3.4.1.2. It provided statistical and operational inputs for the analysis and rectification of several issues. It also enabled to confirm the operational realism of some issues (e.g., Issue SA01, issue OP03).

3.4.1.3. The EMOTION-7 monitoring was also a useful tool as it made possible the identification of the following issues:

- Issue SA10: Inappropriate RAs due to incorrect altitude reporting;
- Issue SA11: RA display misinterpretation;
- Issue OP04: Green arc symbology for weakening RAs;
- Issue OP06: Unnecessary RAs in 1000-ft level-off geometries;
- Issue OP09: TAs for intruders on the ground;

3.4.2. Issue SA01: Inappropriate reversal logic operation

3.4.2.1. The EMOTION-7 monitoring enabled to find three events, during which reversal RAs were triggered. These events were initially found by the analysis of ASRs.

3.4.2.2. In these events, one aircraft manoeuvred opposite to the RAs while the crew of the other aircraft followed the RAs. This resulted in both aircraft descending towards the same location, and in the issuance of very late reversal RAs. These events are real examples of issue SA01a (see §4.3).

3.4.2.3. Airborne and radar data were available for these events. These data enabled to provide operational examples of issue SA01.

3.4.3. Issue SA10: Inappropriate RAs due to incorrect altitude reporting

3.4.3.1. Data were available for events during which inappropriate RAs were triggered because incorrect altitude data were provided to TCAS, leading to inappropriate or even dangerous RAs.

3.4.3.2. This data enabled to underline the operational relevance of issue SA10 [WP1/093] (see §4.5) by showing that the probability of having potentially dangerous events caused by incorrect altitudes could not be ignored.

3.4.4. Issue OP06: Unnecessary RAs in 1000ft level-off geometries

3.4.4.1. The analysis of 1000ft level-off encounters confirmed once again that TCAS II version 7.0 triggers RAs, which are more compatible with ATC clearances when compared with version 6.04a.

3.4.4.2. These encounters were seen as a useful source of data for the analysis of issue OP06 (see §4.6), together with the statistical results brought by the analysis of ASRs.

3.4.5. Other lessons learnt

3.4.5.1. The analysis of events involving VFR aircraft proved that TCAS helps to address the issue of incompatibility between IFR and VFR traffic.

3.4.5.2. Analysis showed that these events often occur in the USA (76% of the ASRs dealing with VFR intruders) and the vertical CPA reported by the pilot is often lower than 500ft (70% of the ASRs dealing with VFR intruders). The airspace structure is such that these encounters occur more often in the USA, however, such encounters also occur in the European airspace.

3.5. Other sources of data

3.5.1. The EMOTION-7 monitoring was useful to permit identification of issues and to provide data that were used to investigate the issues. However, several other sources were used:

- Issue identification was helped by the participation to the OMG of the APSG. The OMG is considered as the main European forum, where States bring issues to the attention of the TCAS community;
- Issue SA01 (i.e., Inappropriate reversal logic operation) was identified during a safety study, through simulations performed on theoretical encounters extracted from encounter models such as the ICAO ACAS safety standard encounter model or the European safety encounter model;
- Other issues were identified by creating theoretical encounters with the OSCAR tool in order to reproduce a behaviour of the CAS logic (e.g., issue SA12, Inappropriate RAs in multiple aircraft encounters), or in order to prepare a glider trial (issue SA02, Inappropriate RAs against glider clusters);
- The performance of the European ACASA project permitted identification of issues SA07 (i.e., Discrepancy between altitude quantization and altitude reporting capability announcement) and of issue OP03 (i.e., split TAs in converging situations);
- The EMOTION-7 Steering Committee permitted to identify, by anticipation, issue OP08 (i.e., Operational implications for ACAS due to proposed ground movement control techniques utilizing Mode S multilateration);
- Direct feedbacks from Airbus or British Airways enabled to identify issue OP05 (i.e., TA aural annunciations at low altitudes).

4. Presentation of the issues addressed by WP1 and WP2

4.1. Introduction

4.1.1. The goal of this part is to present the main results achieved during the investigation of the 6 issues analysed during the project.

4.1.2. Safety issues are referenced as SAxx, while operational issues are referenced as OPxx, where xx is the number of the issue.

4.1.3. In addition, a brief summary of all the EMOTION-7 issues is provided in Appendix A.

4.1.4. A table summarising the work performed is shown hereafter.

Issue	Name	Identified/confirmed through					Analysed	Rectified
		E7 monitoring	E7 team expertise	E7 Steering Committee	National operational monitoring programmes	ACASA project		
SA01	SA01a: Late reversal RAs or no reversal RAs in coordinated encounters	✓	✓				✓	✓
	SA01b: Late reversal RAs or no reversal RAs in uncoordinated encounters		✓					
	SA01c: Undesirable reversal RAs in coordinated encounters		✓				✓	✓
SA02	Inappropriate RAs against glider clusters		✓					
SA07	Discrepancy between altitude quantization and altitude reporting capability announcement				✓	✓	✓	✓
SA10	Inappropriate RAs due to incorrect altitude reporting	✓			✓		✓	
SA11	RA display misinterpretation	✓			✓			
SA12	Inappropriate RAs in multiple aircraft encounters		✓					
OP03	Split TAs in converging situations					✓		
OP04	Green arc symbology for weakening RAs	✓						
OP05	Nuisance TA aural annunciations at low altitudes	✓			✓			✓
OP06	Unnecessary RAs in 1000-ft level-off geometries	✓			✓		✓	✓
OP08	Operational implications for ACAS due to proposed ground movement control techniques utilising Mode S multilateration			✓			✓	
OP09	TAs for intruders on the ground	✓			✓		✓	✓

Table 3: EMOTION-7 issues

4.2. *General description of OSCAR displays*

4.2.1. The OSCAR simulation tool is a set of integrated tools to prepare, execute and analyse scenarios of encounters involving TCAS II equipped aircraft. It includes an implementation of the TCAS II version 7.0.

4.2.2. For each encounter, the most relevant results of the TCAS II simulations are provided by screen dumps of OSCAR windows. Several types of information are displayed:

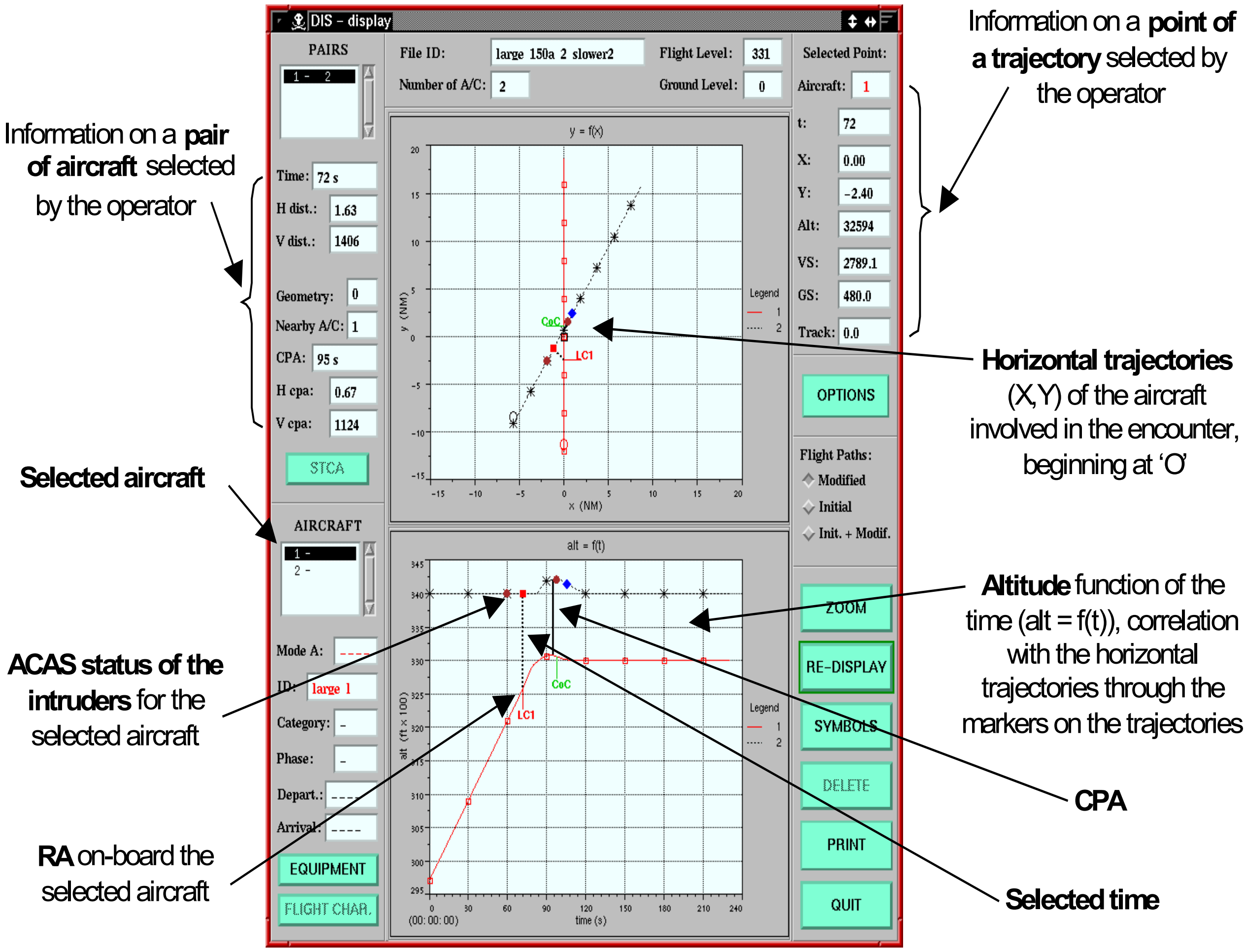

Figure 9: OSCAR display

4.2.3. TCAS II simulation results are displayed on the horizontal and vertical trajectories. RAs are displayed on the trajectory of the selected aircraft and ACAS status of the intruders on their respective trajectories, according to the symbols and labels described hereafter:

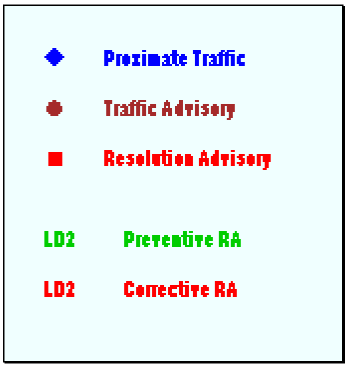

Figure 10: OSCAR symbols

Label	Advisory
CoC	Clear of Conflict
Cl	Climb (1500 fpm)
DDes	Don't Descend
LD5 / LD1 / LD2	Limit Descent 500 / 1000 / 2000 fpm
Des	Descend (1500 fpm)
DCl	Don't Climb
LC5 / LC1 / LC2	Limit Climb 500 / 1000 / 2000 fpm
CCl	Crossing Climb (1500 fpm)
RCl	Reverse Climb (1500 fpm)
ICl	Increase Climb (2500 fpm)
MCl	Maintain Climb
CDes	Crossing Descend (-1500 fpm)
RDes	Reverse Descent (-1500 fpm)
IDes	Increase Descent (-2500 fpm)
MDes	Maintain Descent

Figure 11: OSCAR labels

4.3. *Issue SA01 : Inappropriate reversal logic operation*

4.3.1. Issue identification

4.3.1.1. When compared with the previous TCAS II (i.e., version 6.04a), one significant change included in TCAS II version 7.0 is that sense reversals RAs are now permitted in TCAS-TCAS coordinated encounters. This change was introduced to cope with changing situations where the initial RA sense has clearly become the wrong thing to do, in particular when one of the pilots decides not to follow the RAs but manoeuvres contrary instead.

4.3.1.2. The EMOTION-7 Project has identified in early 2000 areas of improvements for the reversal logic. These areas of improvement were documented in [WP1/012] and referenced as issue SA01. Issue SA01 consists in 3 issues, which deal with the reversal logic: Issues SA01a, SA01b and SA01c.

4.3.1.3. Issue SA01a is referred to as **Late reversal RAs or no reversal RAs in coordinated encounters**. This issue deals with the fact that the reversal logic does not trigger on time some reversal RAs, which would be useful to avoid NMACs, in coordinated encounters during which one pilot does not follow his RAs. Issue SA01c is referenced as **Undesirable reversal RAs in coordinated encounters**. This issue deals with the fact that the reversal logic sometimes triggers reversal RAs, which lead to NMACs, when both pilots follow their RAs during coordinated crossing encounters.

4.3.1.4. A rectification referenced as CP112 (i.e., Change Proposal 112) in the RTCA arena was proposed to rectify these two issues ([WP2/024]&[WP2/028]). Work was undertaken between 2000 and 2002 in order to demonstrate the operational realism of issues SA01a and SA01c to the FAA and to demonstrate that CP112 brings significant benefits.

4.3.1.5. Work underway in the CAS logic area identified in September 2002 a new issue with the reversal logic. The reversal logic sometimes fails to trigger reversal RAs in single equipage encounters or similarly in double equipage encounters but with one TCAS II either in stand-by mode or in TA-only mode. This new area of improvement was referenced as issue SA01b, which is entitled **Late reversal RAs or no reversal RAs in uncoordinated encounters**.

4.3.2. Issue analysis

4.3.2.1. Issue SA01a: Late reversal RAs or no reversal RAs in coordinated encounters

4.3.2.1.1. The reversal logic is not performing as expected in scenarios in which one pilot does not follow his RAs, while the other pilot follows his RAs. In these scenarios where reversal RAs would be necessary to compensate an inadequate pilot response, the reversal logic can fail to trigger reversal RAs, or triggers them too late to be efficient.

4.3.2.1.2. The following figures show an example of encounter illustrating this issue. In figure 12, aircraft 1 and aircraft 2 are quite head on at the same altitude. Aircraft one starts a descent, possibly following an ATC instruction. The aircraft pass with 871ft of vertical separation at CPA. The hmd is 0ft. Figure 13 and 14 show this encounter with TCAS II version 7.0. The pilot of aircraft 1 has a climb RA, which he does not follow because he possibly follows the ATC instruction to descend. The pilot of aircraft 2 has a descend RA, which the pilot follows. This results in both aircraft descending towards the same location.

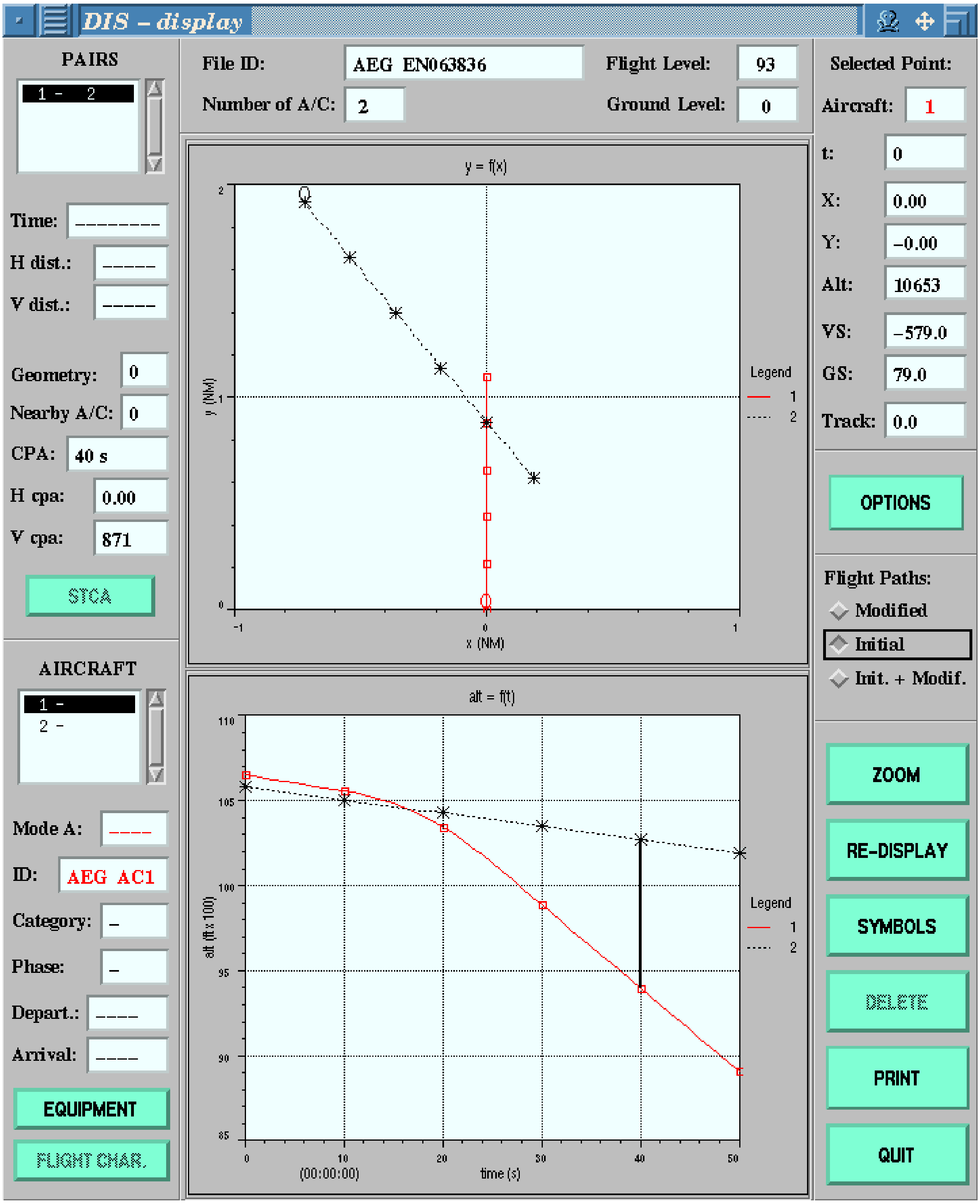

Figure 12: Issue SA01a - Encounter without TCAS contribution

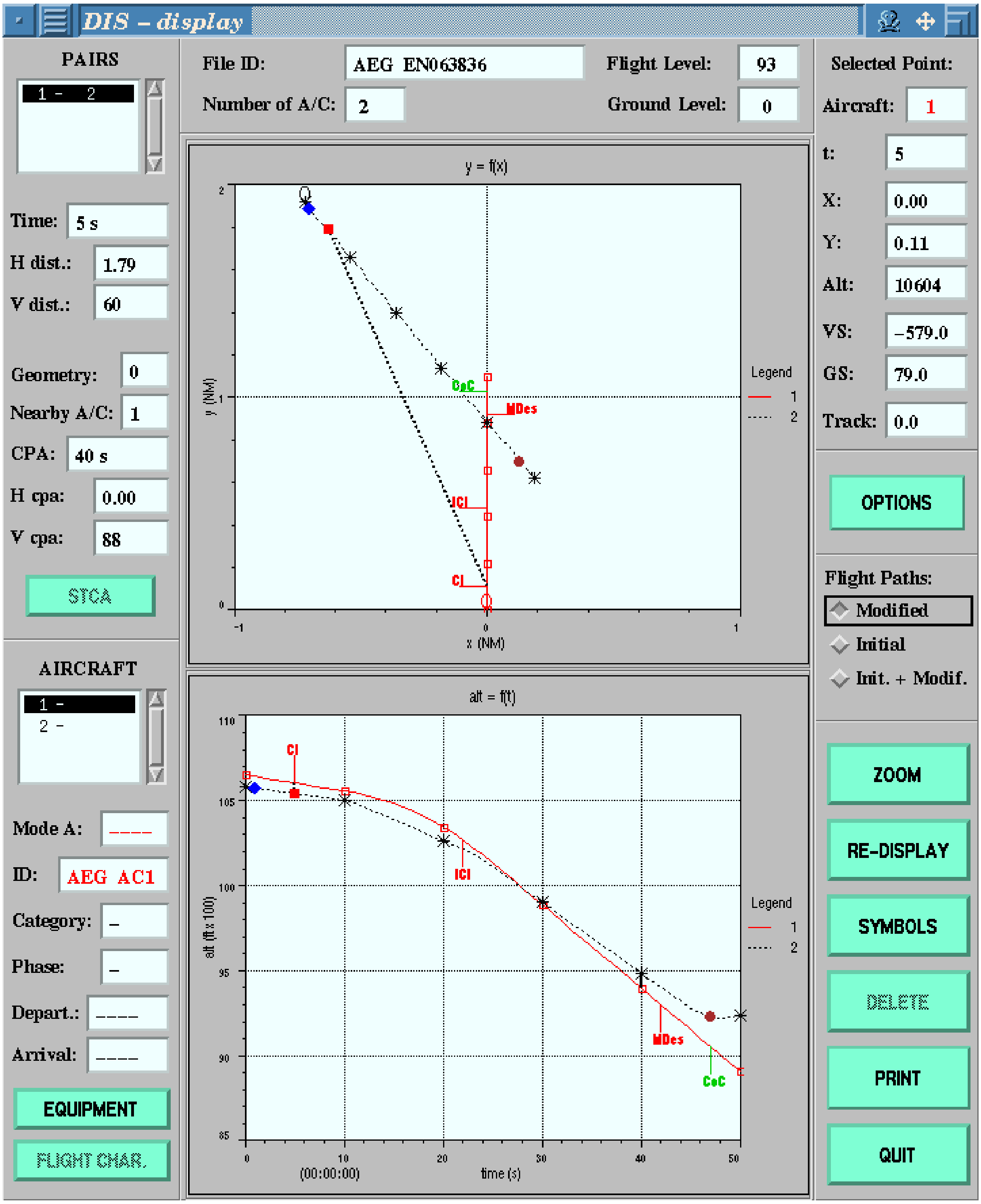

Figure 13: Issue SA01a - Encounter simulated with TCAS II version 7.0 RAs onboard aircraft 1

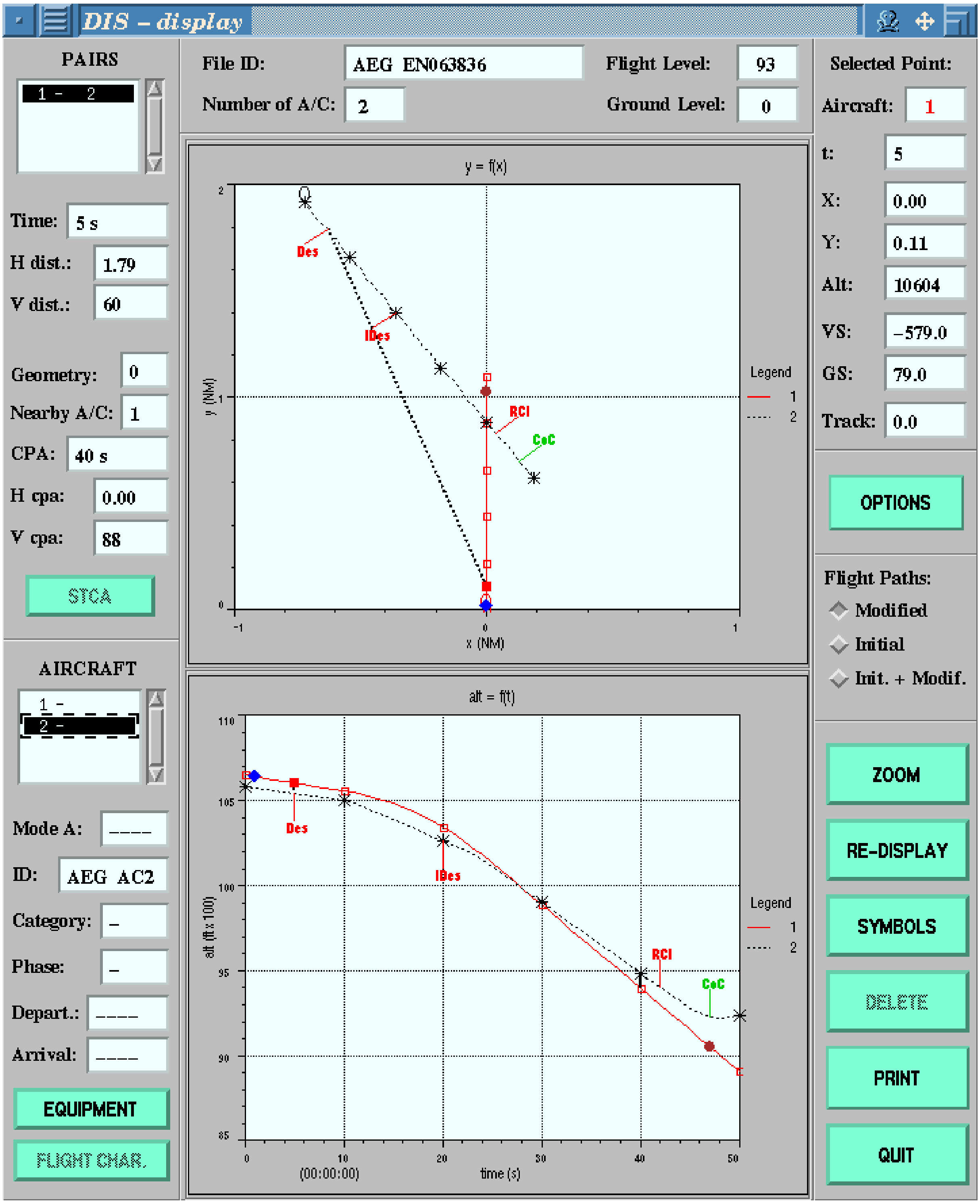

Figure 14: Issue SA01a - Encounter simulated with TCAS II version 7.0 RAs onboard aircraft 2

4.3.2.1.3. Both aircraft have reversing sense RAs. However, **these RAs are triggered too late to be efficient** (i.e., 2s after CPA). The resulting vertical separation at CPA is lower than 100ft. Reversal RAs triggered at least 10s before CPA would give time to the pilot to react.

4.3.2.1.4. An analysis [WP1/012] was performed in order to assess the severity of this issue. Simulations with one pilot not following his RAs in each encounter were performed on the ICAO ACAS safety standard encounter model and on the European ACAS safety encounter model.

4.3.2.1.5. Risk ratios were computed on the set of encounters, in which one pilot does not follow his RAs while the other does, extracted from these encounter models, and in which reversal RAs are triggered. These specific risk ratios are well over 100% (e.g., 224.6%[2], which means that the risk of collision with TCAS when one pilot does not follow RAs [ABUL] is higher than without TCAS, on these encounters).

4.3.2.1.6. Simulations were performed with the reversal logic disabled. The risk ratios are dramatically increased (e.g., 424.8% with the reversal logic disabled instead of 224.6% with the reversal logic enabled, see 4.3.2.1.5) for scenarios in which one pilot does not follow his RAs. These results show how **reversal RAs are necessary to solve some situations in which one pilot does not follow his RAs**.

4.3.2.1.7. Therefore, the analysis of issue SA01a underlined that when one pilot does not follow the RAs but manoeuvres contrary to the RAs, **the system solution introduced in the reversal logic does not perform as well as one can expect,** as it can fail to compensate an inadequate pilot response.

4.3.2.2. Issue SA01b: Late reversal RAs or no reversal RAs in uncoordinated encounters

4.3.2.2.1. The geometries involved in issue SA01b are comparable to those described for issue SA01a, but this time only one aircraft is equipped with TCAS, and the pilot follows his RAs. In particular, one geometry is for two aircraft flying at the same FL and converging in range with a late ATC instruction inducing an intruder manoeuvre that thwarts the initial RA issued onboard the TCAS equipped aircraft.

4.3.2.2.2. No severity analysis was performed because this issue is a recent one, which was identified at the end of the EMOTION-7 project in September 2002.

[2] A risk ratio of 224.6% does not mean that NMACs will be systematic. It only means that with the use of TCAS and when one pilot is manoeuvring contrary to the RAs, NMACs are 2.246 more frequent than when TCAS is not used, for a given airspace and for a given set of encounters.

4.3.2.3. Issue SA01c: Undesirable reversal RAs in coordinated encounters

4.3.2.3.1. In early 2000, studying subsets of reversing encounters with both pilots following their RAs, it was found that improvements are required especially when the following criteria are met:

- The initial RAs are crossing RAs, which the pilots of the two aircraft follow;
- The relative altitude rate is high;
- The reversal RAs are generated at a later stage, which mean 10s or less before CPA.

4.3.2.3.2. In this kind of encounter, the aircraft cross twice vertically because of the reversal RAs. This behaviour results in very low vertical separations at CPA.

4.3.2.3.3. The following figures present an example simulated with TCAS version 6.04a and then with TCAS II version 7.0. The encounter without TCAS II contribution is shown on figure 15. It is similar to an altitude bust, which is a possible scenario.

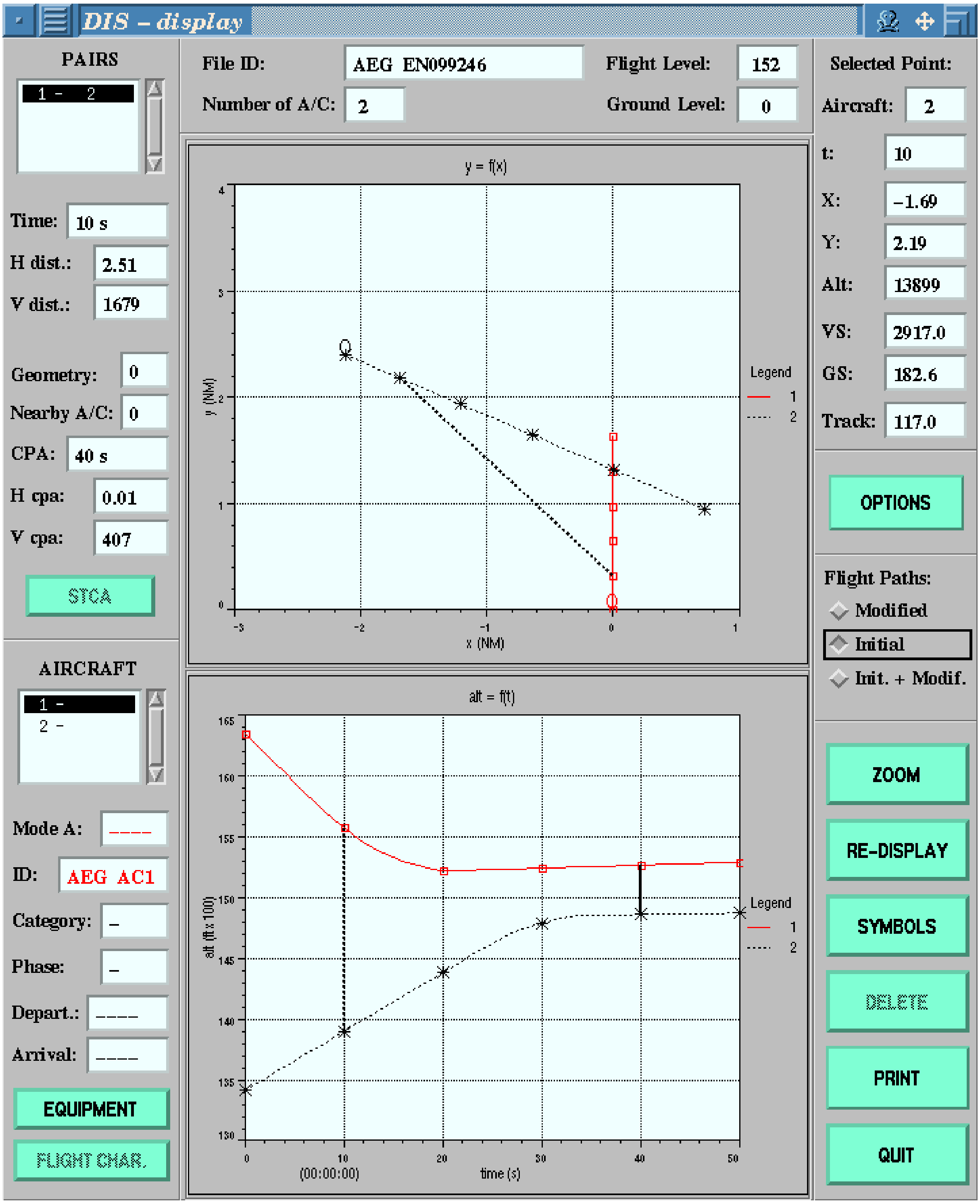

Figure 15: Issue SA01c - Encounter without TCAS contribution

4.3.2.3.4. The following figure shows the encounter simulated with TCAS II version 6.04a.

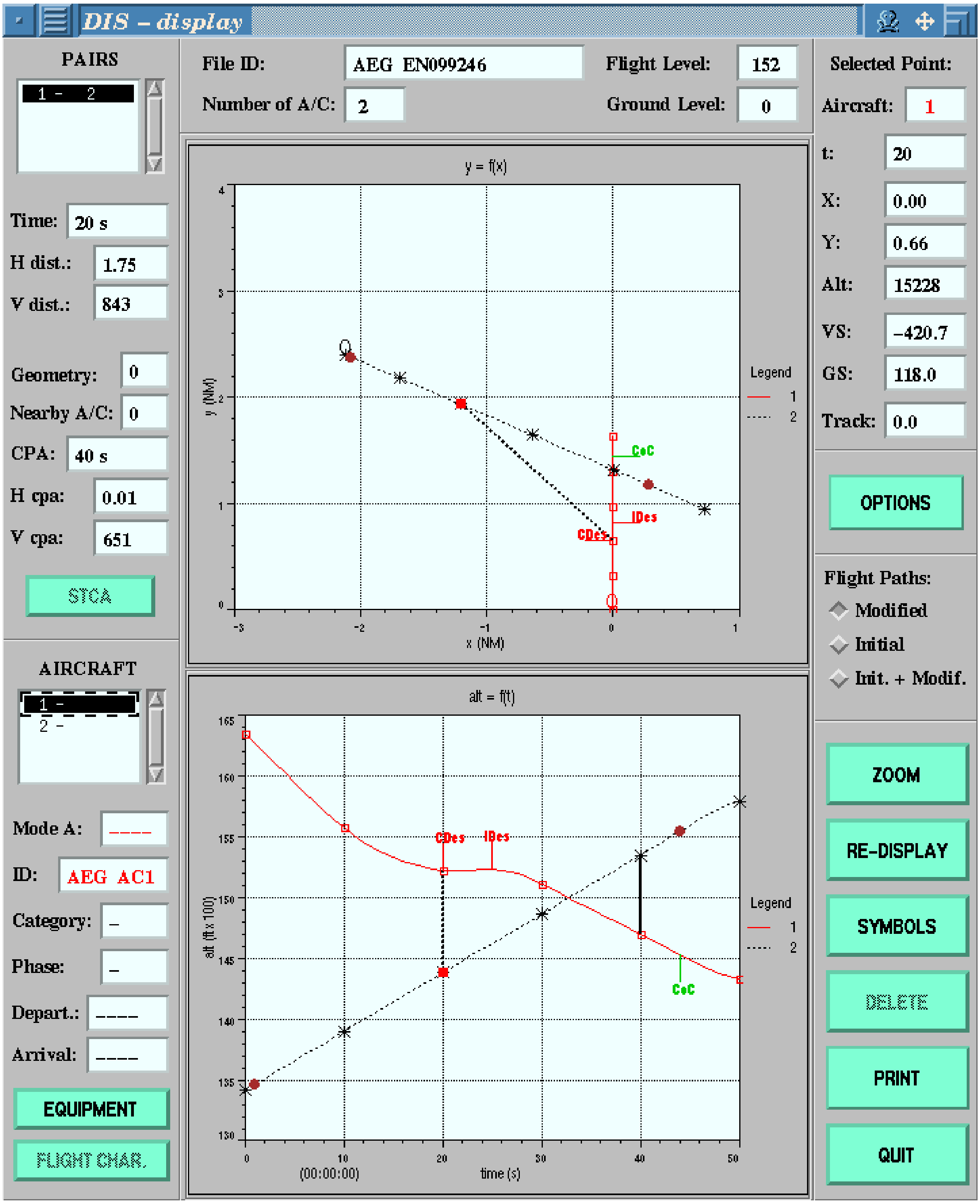

Figure 16: Issue SA01c - Encounter simulated with TCAS II version 6.04a RAs onboard aircraft 1

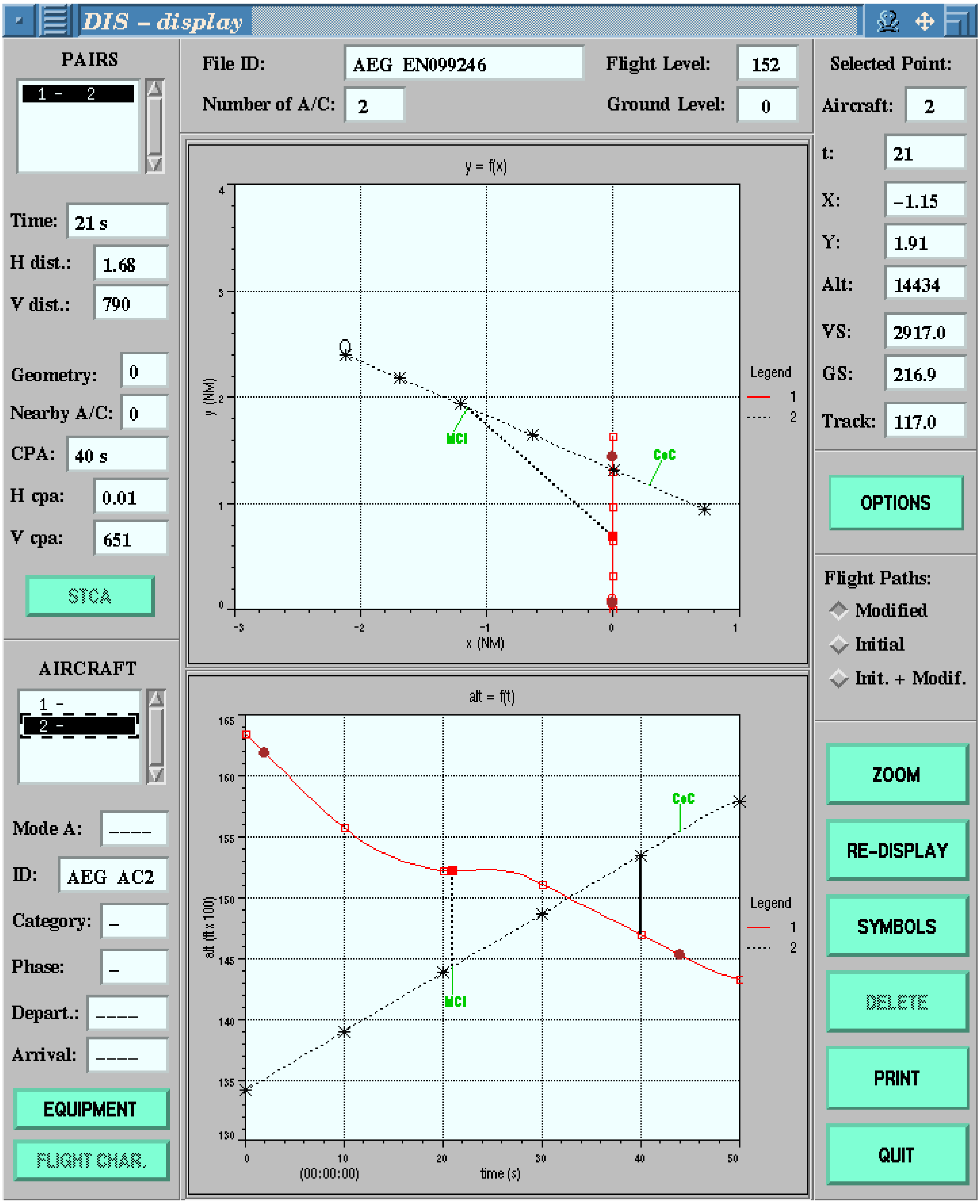

Figure 17: Issue SA01c - Encounter simulated with TCAS II version 6.04a RAs onboard aircraft 2

4.3.2.3.5. In this encounter, TCAS II version 6.04a performs well, as the **vertical separation at CPA is over 600ft**.

4.3.2.3.6. The following figures show the same encounter simulated with TCAS II version 7.0.

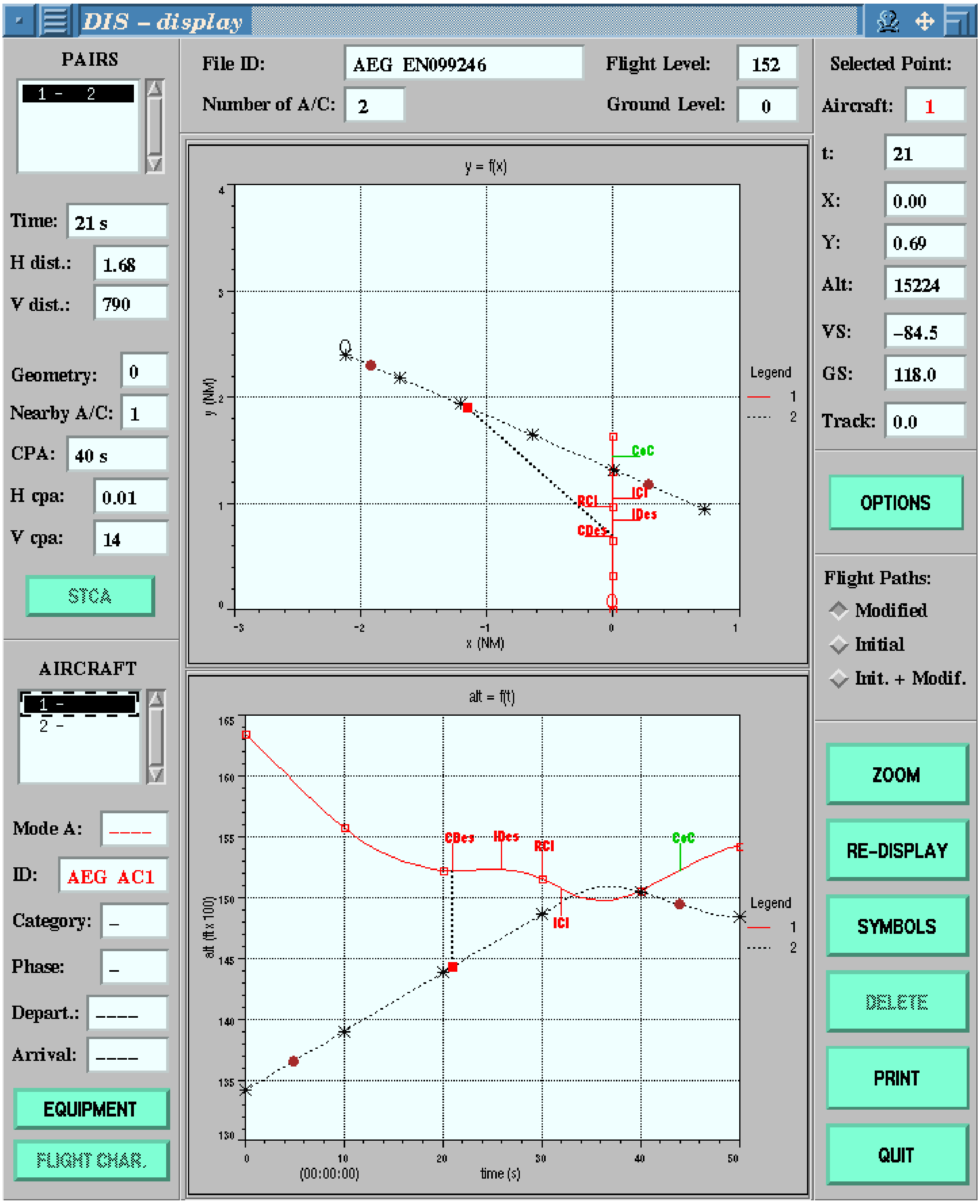

Figure 18: Issue SA01c - Encounter simulated with TCAS II version 7.0 RAs onboard aircraft 1

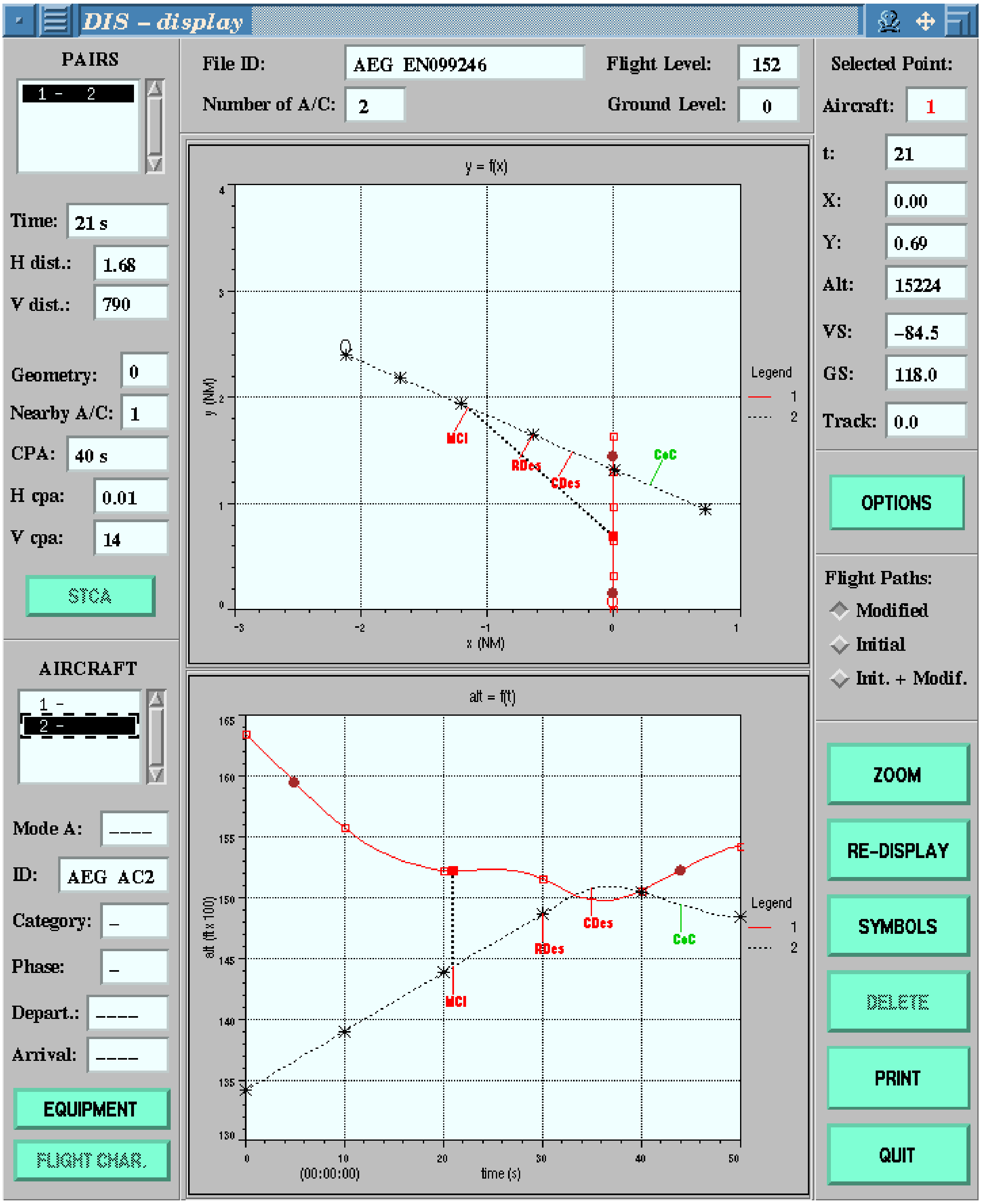

Figure 19: Issue SA01c - Encounter simulated with TCAS II version 7.0 RAs onboard aircraft 2

4.3.2.3.7. With TCAS II version 7.0, reversal RAs are triggered. However, they cause the aircraft to cross twice vertically, which leads to a **vertical separation at CPA below 100ft**.

4.3.2.3.8. An analysis [WP1/012] was performed in order to assess the severity of this issue. Simulations were performed on the ICAO ACAS safety standard encounter model and on the European ACAS safety encounter model. **This analysis of issue SA01c underlined that induced NMACs could be observed because of the new reversal mechanism, for geometries in which crossing RAs are triggered. These NMACs are not observed with version 6.04a of the logic.**

4.3.2.3.9. Simulations were performed with the reversal logic disabled. The risk ratios are very slightly modified. These results show that the impact of the reversal logic on the risk ratios is not highly significant when both pilots follow their RAs.

4.3.3. Issue rectification

4.3.3.1. Issue SA01a: Late reversal RAs or no reversal RAs in coordinated encounters

4.3.3.1.1. In October 2000, a logic rectification divided into two parts was proposed to correct issues SA01a and SA01c [WP2/024], and is referenced as CP112 in the RTCA arena [WP2/28]. Part 1 of this rectification deals with issue SA01a.

4.3.3.1.2. The goal of this rectification is to allow the logic to trigger a reversal RA earlier in coordinated encounters, if a lack of manoeuvre is detected for own aircraft [WP2/028].

4.3.3.1.3. The following figures show the encounter of §4.3.2.1 simulated with CP112.

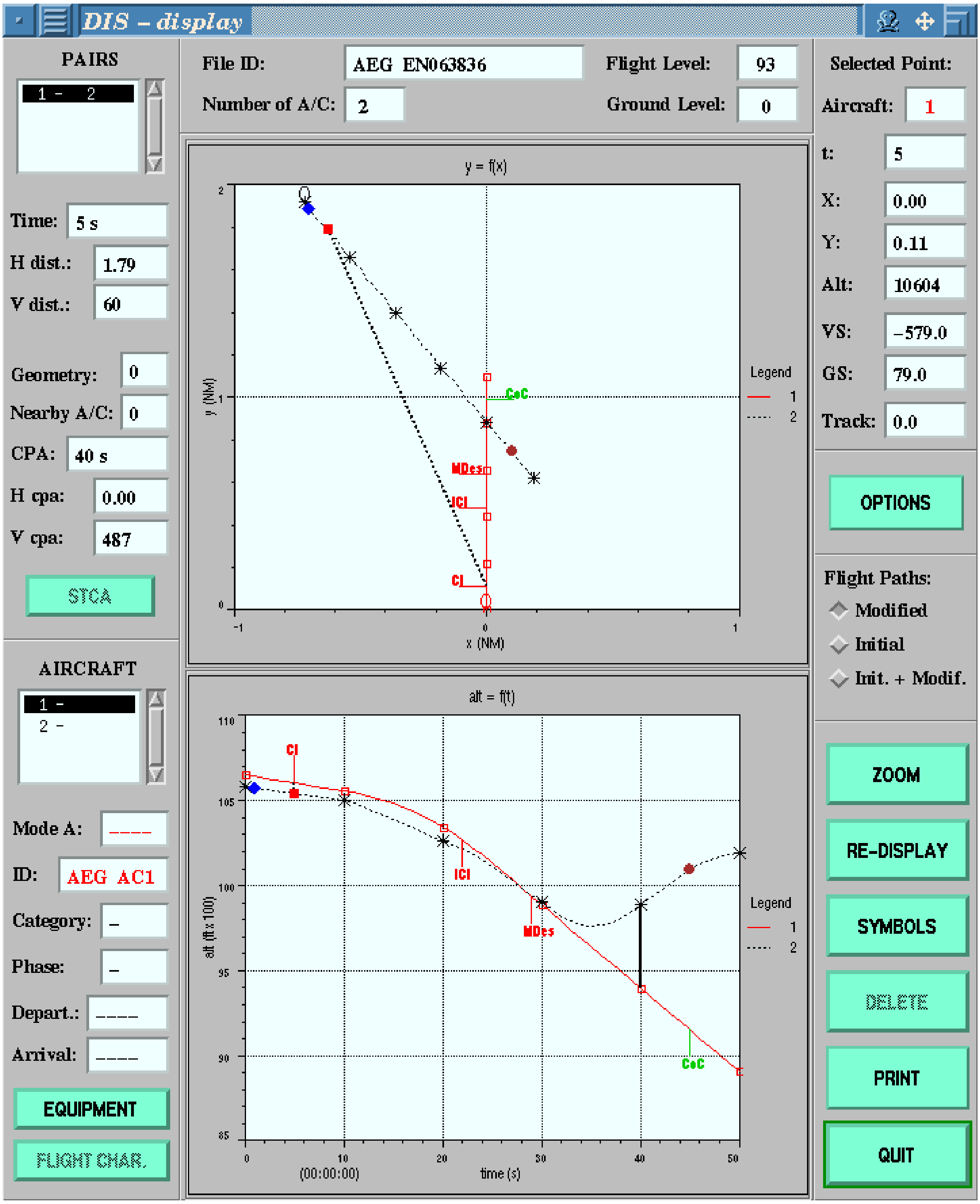

Figure 20: Issue SA01a - Encounter simulated with TCAS II version 7.0+CP112 - RAs onboard aircraft 1

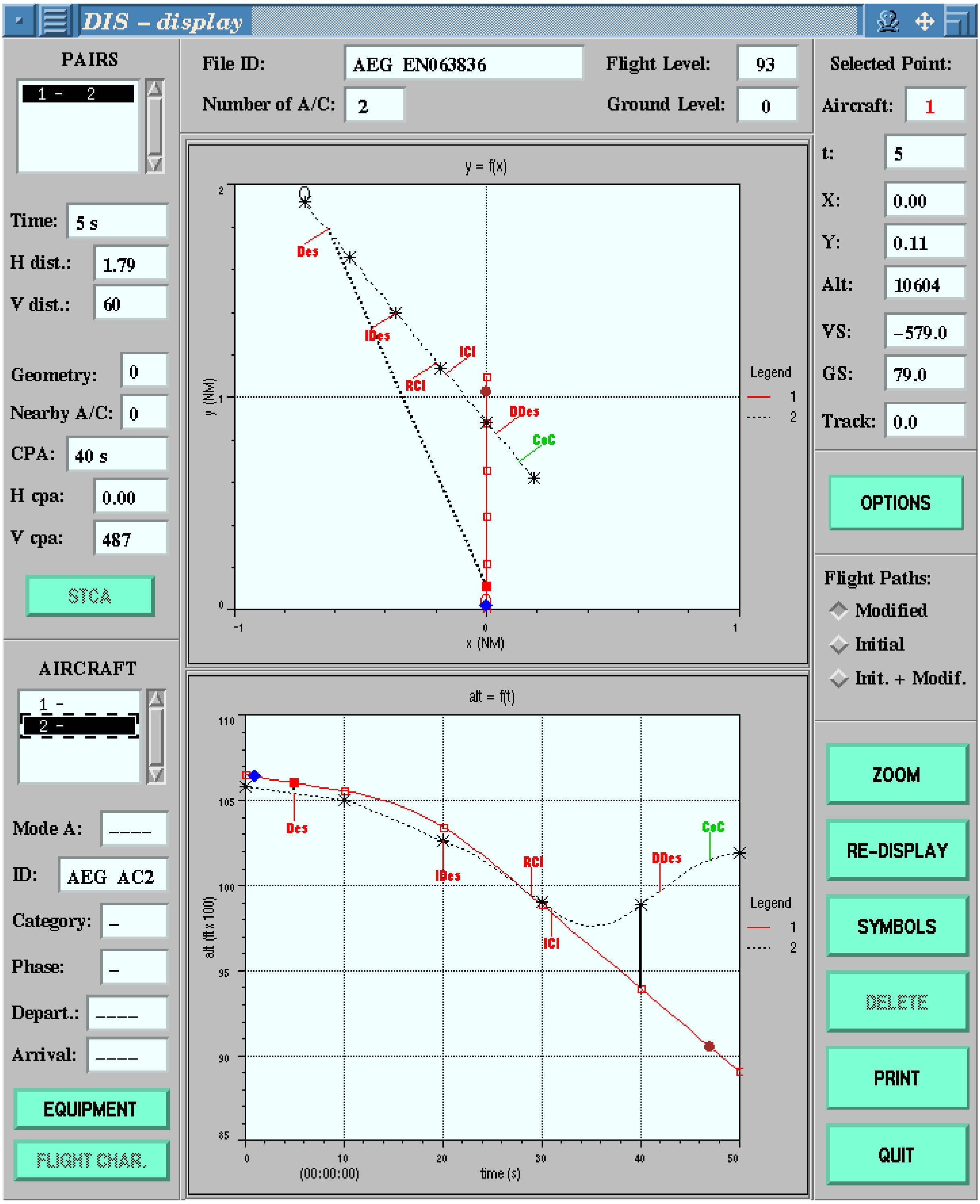

Figure 21: Issue SA01a - Encounter simulated with TCAS II version 7.0+CP112 - RAs onboard aircraft 2

4.3.3.1.4. With CP112, the reversal RA is triggered earlier than on figures 13 and 14, which results in a vertical separation at CPA close to 500ft, as the pilot has now the time to react.

4.3.3.1.5. Simulations performed on the ICAO ACAS safety standard encounter model and on the European ACAS safety encounter model showed that CP112 significantly improves the safety benefits brought by ACAS, for the encounters during which one pilot does not follow his RAs but manoeuvres contrary to them. With a standard configuration, CP112 decreases the risk ratios from 19.0% to 18.2% [WP2/047] when considering the European ACAS safety encounter model and from 11.0% to 9.8% [WP2/024] when considering the ICAO ACAS safety standard encounter model. Risk ratios computed on the reversal subsets confirmed the benefits brought by CP112 (i.e., risk ratio decreased from 224.6% to 129.3%).

4.3.3.1.6. Following a plenary RTCA SC147 meeting in June 2001, FAA J. Hughes Technical Center took the action to perform an analysis of issue SA01a [FAA1]. The goal of this analysis was to try to replicate the findings of the EMOTION-7 project on issue SA01a. This analysis was made possible by data sent to the FAA by the EMOTION-7 project, concerning real events from the EMOTION-7 monitoring and also theoretical encounters for which issue SA01a was observed. **The analysis performed by FAA confirms the EMOTION-7 findings, concerning the behaviour of the reversal logic, and concerning the benefits brought by CP112**.

4.3.3.1.7. Due to the Mode S priority rule included in the CAS logic, CP112 has the potential to improve the current logic behaviour in only 50% of the cases. Removing these limitations would enable to further improve CP112 performance. Work in this area is planned in 2003 under the auspices of the EUROCONTROL ACAS Programme.

4.3.3.2. Issue SA01b: Late reversal RAs or no reversal RAs in uncoordinated encounters

4.3.3.2.1. No rectification was proposed to issue SA01b, because this issue was discovered only after CP112 was developed. This issue is not addressed by CP112.

4.3.3.2.2. However, it is recommended that work on issue SA01 should be extended in scope to address fully all the anomalies in the CAS logic, among which issue SA01b.

4.3.3.3. Issue SA01c: Undesirable reversal RAs in coordinated encounters

4.3.3.3.1. Part 2 of CP112 deals with issue SA01c. The goal of the modification is to forbid reversal RAs when they are likely to generate two altitude crossings, as the ones described in figures 18 and 19 above. CP112 part 2 is, therefore, strengthening the conditions for issuing a reversal RA if the aircraft are converging in altitude following a crossing RA.

4.3.3.3.2. The following figure shows the encounter of §4.3.2.3 simulated with CP112, with both pilots following their RAs.

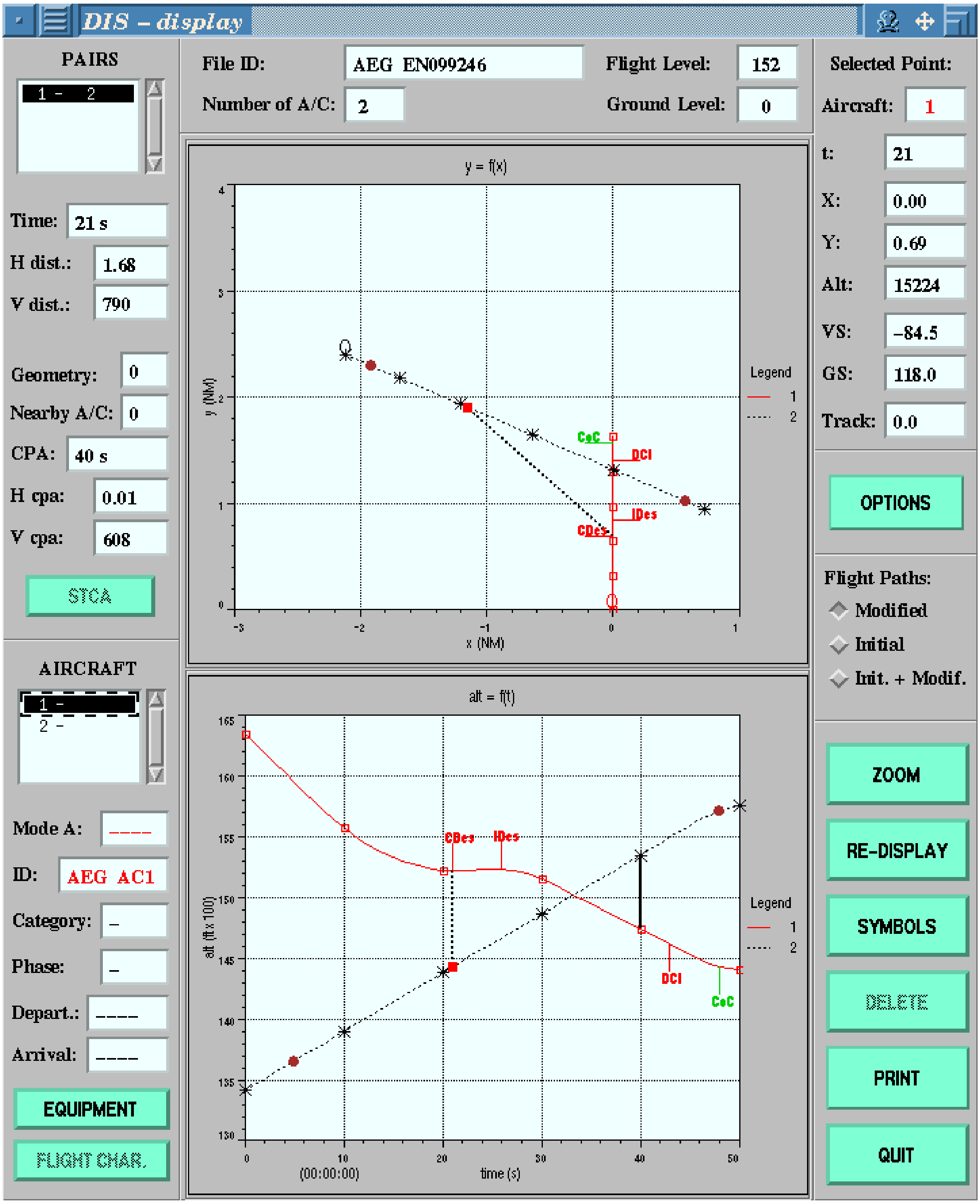

Figure 22: Issue SA01c - Encounter simulated with TCAS II version 7.0+CP112 - RAs onboard aircraft 1

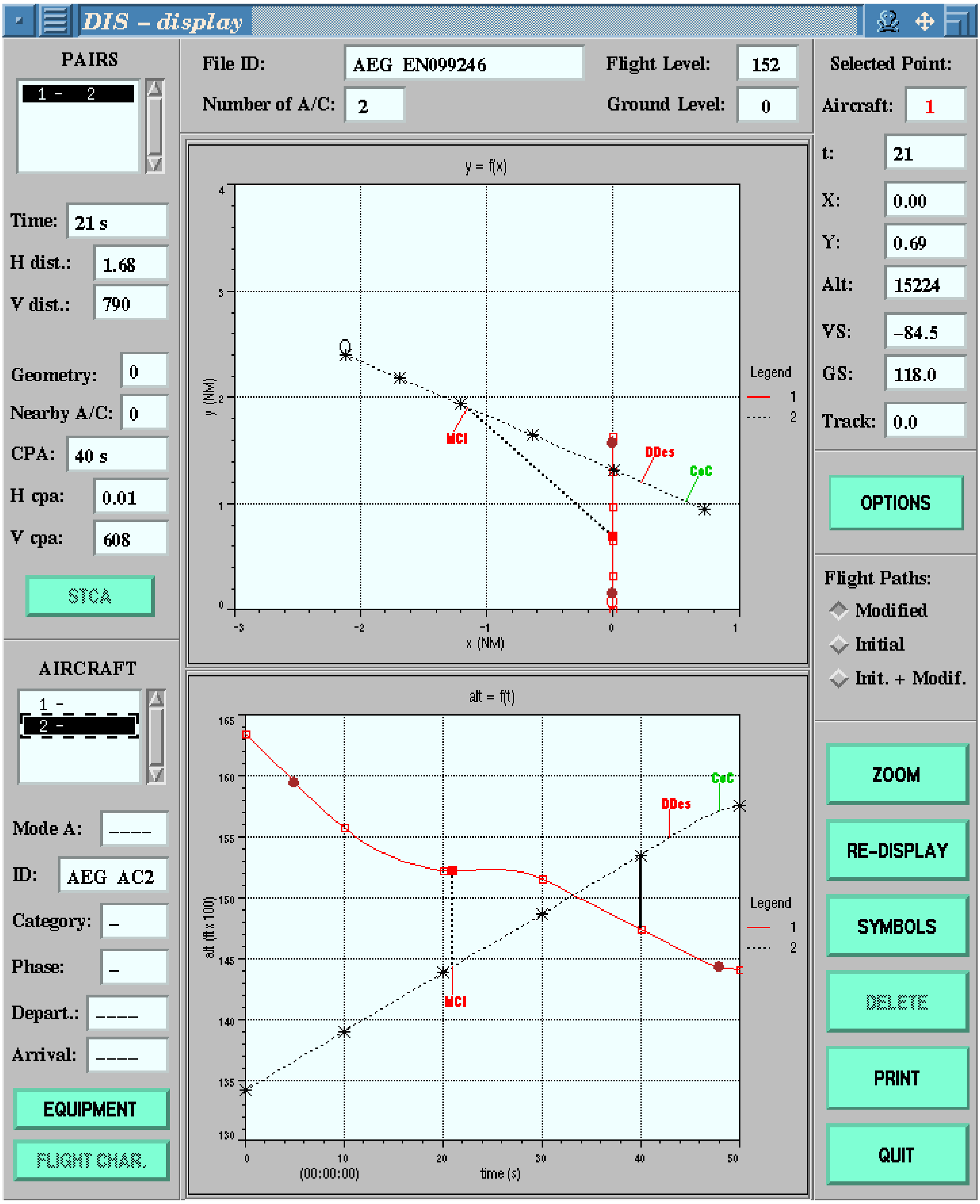

Figure 23: Issue SA01c - Encounter simulated with TCAS II version 7.0+CP112 - RAs onboard aircraft 2

4.3.3.3.3. With CP112, the reversal RAs are not triggered, which results in a vertical separation at CPA over 600ft.

4.3.3.3.4. The computation of risk ratios on the ICAO ACAS safety standard encounter model and on the European ACAS safety encounter model, with both pilots following their RAs confirms the benefits brought by CP112, with risk ratios significantly decreased (i.e., from 19.1% to 1.2%) on the reversal subsets. FAA also confirms the EMOTION-7 findings on issue SA01c [FAA1].

4.3.4. Operational considerations

4.3.4.1. General

4.3.4.1.1. Figures concerning the probability of occurrence of encounters leading to reversal RAs were initially provided in 2000 [WP2/024]. Simulations were made on around 600,000 flight hours extracted from French radar data recordings, representing 4 months of recording. **It was found that one encounter leading to reversal RAs should be expected every two months in the French airspace**. Therefore, such encounters should not be considered as rare events in the European airspace.

4.3.4.1.2. Six real occurrences of issue SA01a were found in 2001 and 2002, taking opportunity of the EMOTION-7 monitoring:

- Event in Japan in January 2001;
- Event in Belgium in July 2001 (described below in §4.3.4.2) found through the EMOTION-7 monitoring [WP3/062] of British Airways;
- Event in France in November 2001 found through the EMOTION-7 monitoring;
- Event in Germany in February 2002 found through the EMOTION-7 monitoring [WP3/091] of British Airways;
- Event in France in March 2002;
- Bodensee accident in July 2002.

4.3.4.1.3. Using the events involving British Airways aircraft, it was possible to estimate a more accurate probability, that an aircraft experiences issue SA01a in the European airspace. It was computed that this probability is equal to $4.7.10^{-6}$ per flight hour [WP3/091].

4.3.4.2. Event of July 20001

4.3.4.2.1. This event was identified through the EMOTION-7 monitoring. It involved two aircraft, which experienced issue SA01a, because one pilot did not follow his RAs and manoeuvred contrary to them. The event involved a level aircraft at FL280 (aircraft 1) and an aircraft cleared to climb to FL270 (aircraft 2). Both aircraft were in contact with the same controller.

4.3.4.2.2. The following figures show the radar data for this encounter, simulated with TCAS II version 7.0.

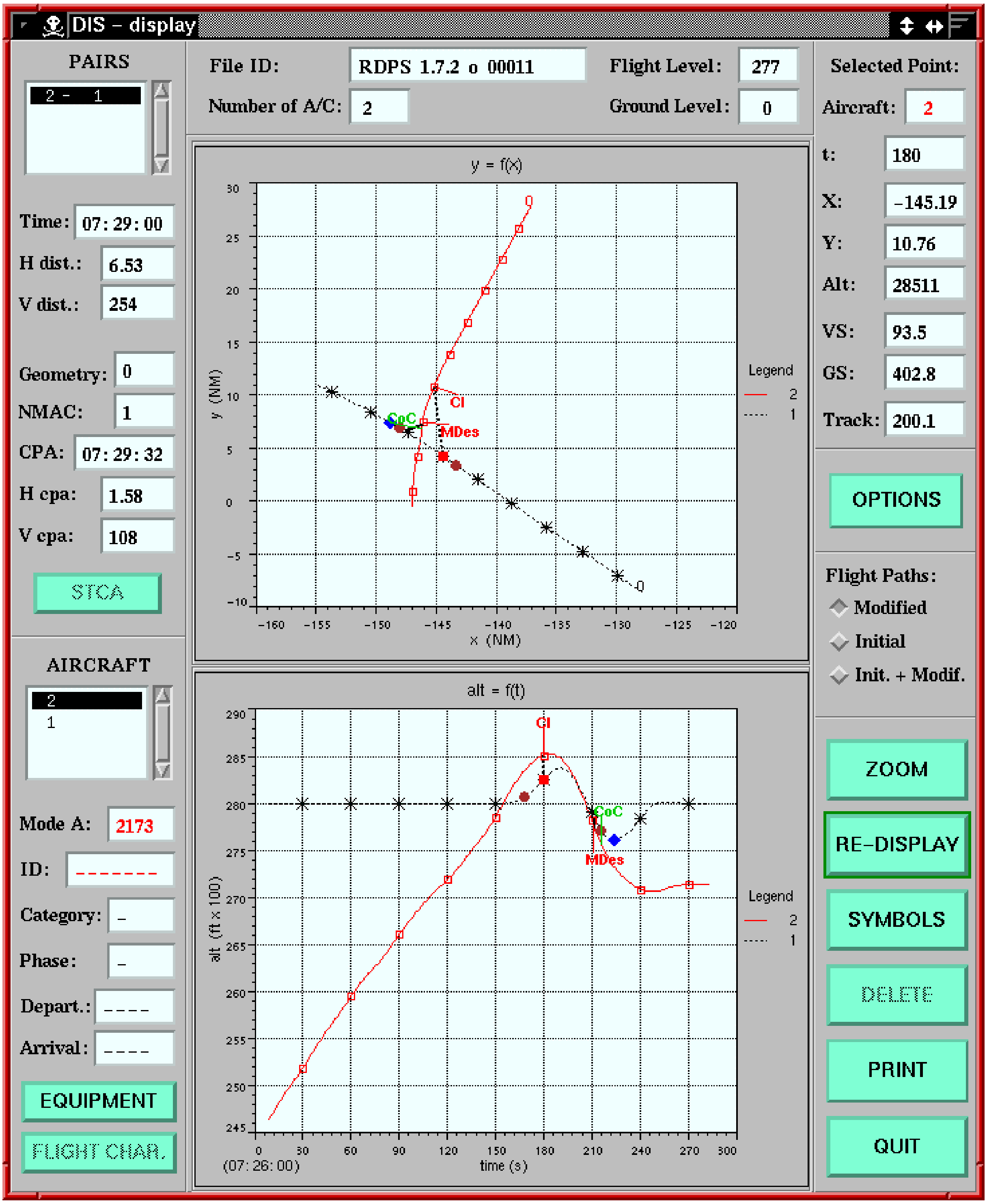

Figure 24: Issue SA01a - Event of July 2001
RAs onboard aircraft 1

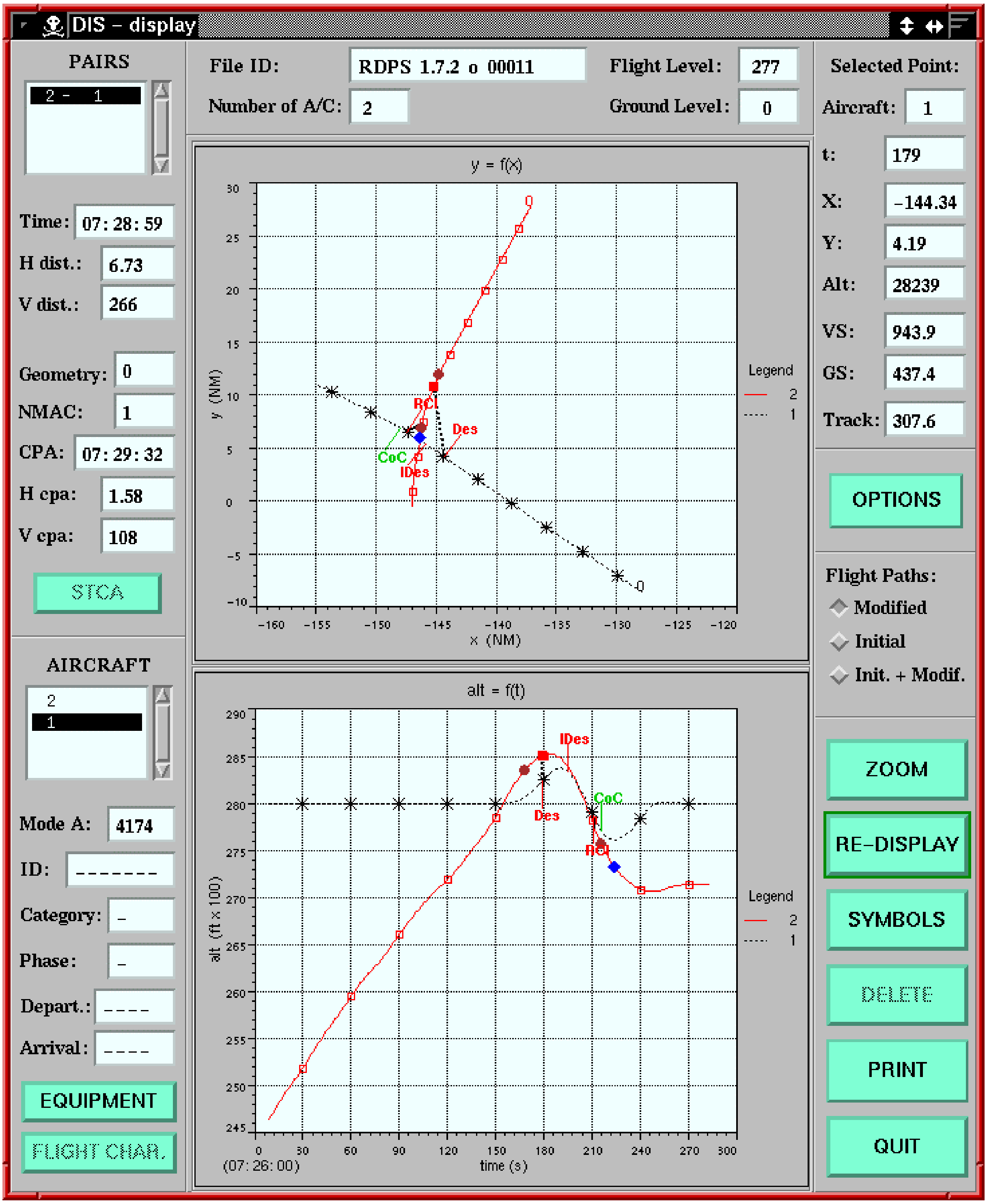

Figure 25: Issue SA01a - Event of July 2001
RAs onboard aircraft 2

4.3.4.2.3. Aircraft 1 reported ATC it was at FL280. Aircraft 2 contacted ATC and was cleared to climb to FL270. ATC then asked aircraft 2 if it could achieve a rate of climb of at least 2000 fpm if re-cleared to FL290. Aircraft 2 answered that it could not and it was told to wait for further climb. At this stage, aircraft 2 continued its climb to FL290 instead of levelling off at FL270. ATC instructed aircraft 2 to descend immediately to FL270 (aircraft 2 was observed passing FL274 climbing). ATC instructed aircraft 1 to climb to FL290 and provided a traffic information (aircraft 2 was observed passing FL278 climbing). But aircraft 2 was still climbing, and ATC instructed it to maintain FL280. Then, ATC requested aircraft 1 and 2 to turn left. Aircraft 1 was also instructed to expedite climb.

4.3.4.2.4. Aircraft 1 reported following a Descend RA. Aircraft 2 had a climb RA. ATC instructed aircraft 2 to maintain its level. Aircraft 2 reported having aircraft 1 in sight. Aircraft 1 reported not having aircraft 2 in sight and the end of the TCAS II advisory.

4.3.4.2.5. This encounter is very close to the one shown in §4.3.2.1, as one pilot follows a descent RA while the other does not follow his climb RA but descends instead. Reversal RAs are triggered, but too late to be efficient (i.e., 1s before CPA). This encounter is therefore a real example of issue SA01a. The 5 other events listed in 4.3.4.1 are very close to this one.

4.3.4.2.6. The encounter was simulated including CP112: the reversal RAs are generated 9 seconds earlier, (i.e. 10 seconds before the CPA). In this case, a standard pilot's reaction to the reversal RA improves significantly the safety, as the pilot has now the time to follow the reversal RA.

4.3.4.2.7. Simulations on this encounter have shown that if both pilots had followed their initial RAs, the vertical distance at CPA would have been over 1,000ft. No increase or reversal RAs would have been necessary to achieve a safe vertical distance at CPA. This shows that **compliance with RAs is by far the best way to assure safety**. **Reversal RAs only provide a limited contribution in comparison with a reaction of both pilots to initial RAs. CP-112 improves this contribution. Nevertheless, no solution can be as efficient as a full compliance with RAs.**

4.4. Issue SA07 : Discrepancy between altitude quantization and altitude reporting capability announcement

4.4.1. Issue identification

4.4.1.1. TCAS II version 7.0 includes a new intruder altitude tracker that is in fact a combined vertical tracker [SIC1]: it is composed of a 25ft tracker (i.e., an altitude tracker capable of tracking altitude reports quantized in 25ft) and of a 100ft tracker.

4.4.1.2. The 25ft tracker and the 100ft tracker are very different, as the 100ft tracker is a bin-occupancy tracker (together with an alpha beta tracker for vertical rates above 6000fpm), whereas the 25ft tracker is an alpha-beta tracker [SIC1].

4.4.1.3. When an altitude report coming from an intruder aircraft is accepted as credible, it is passed to one of the two trackers according to the altitude quantization indication, which is provided in the altitude report quantization bit.

4.4.1.4. During the performance of the European ACASA project WP-7.3 [ACA1], it has been reported that some aircraft may indicate a 25ft reporting capability while actually reporting in 100ft quanta. This issue was referenced as issue SA07 in the EMOTION-7 project.

4.4.2. Issue analysis

4.4.2.1. When an intruder indicates a 25ft reporting capability and reports its altitude in 100ft quanta, TCAS II version 7.0 processes the altitude reports with the alpha-beta tracker, which is designed to process altitudes reported in 25ft quanta. The aim of the analysis was to assess the impact of issue SA07, both on a safety and an operational point of view [WP1/046].

4.4.2.2. Simulations of issue SA07 were made on the 100,000 encounters of the European ACAS safety encounter model in order to provide risk ratios for two TCAS equipage scenarios (i.e., both aircraft of the encounter equipped or only one) and for two pilot response models (i.e., the pilot follow the RAs, or does not).

4.4.2.3. These simulations indicated that **issue SA07 could seriously debase the safety performance of TCAS II version 7.0**. Whatever the configuration considered, the risk ratios are significantly increased, as shown in the table below. In the worst case, the risk ratio is multiplied by two.

Configuration		Without issue SA07	With issue SA07
Double equipage	Both pilots follow their RAs	2.3%	3.4%
	One pilot does not follow his RAs	19.0%	28.8%
Single equipage	The pilot follows his RAs	12.7%	25.4%

Table 4: Risk ratios without and with issue SA07

4.4.2.4. Simulations were performed on the European real encounter data base in order to provide statistics dealing with pilot acceptance and compatibility with ATC. These simulations show that issue SA07 can debase some improvements brought by TCAS II version 7.0. Whether one pilot follows the RAs or not, the number of RAs is increased (around 4%). The number of positive RAs increases significantly (increase between 23% and 55%). This may affect both the ATC and pilot performance.

4.4.2.5. The following figures present one example of what can occur with issue SA07 onboard an aircraft experiencing RAs. Figure 26 shows an encounter extracted from the European real encounter data base without ACAS contribution. Figure 27 shows the encounter simulated with TCAS II version 7.0 on board both aircraft and without issue SA07. Figure 28 shows the same encounter simulated with issue SA07. It results in an important deviation for aircraft 2.

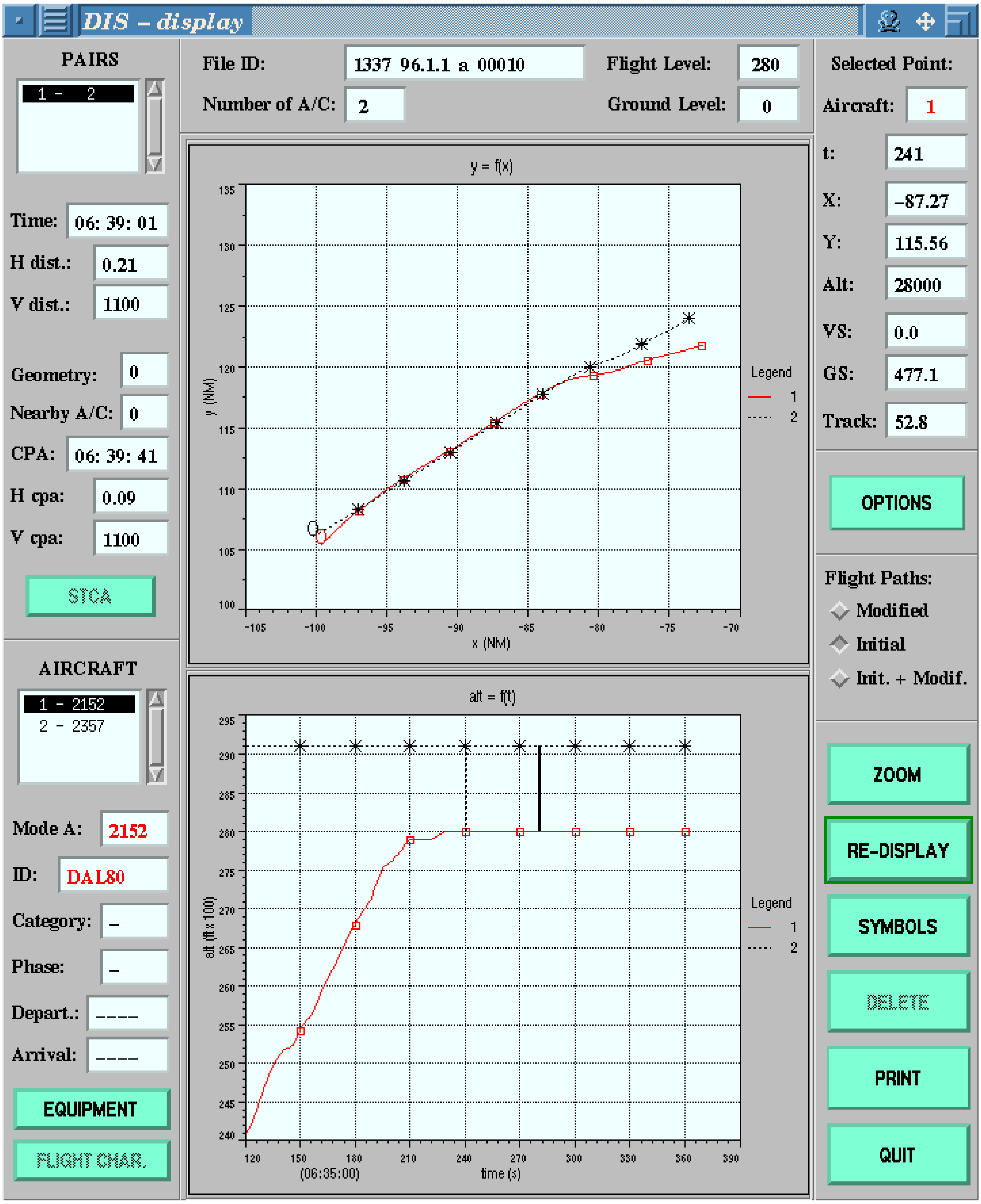

Figure 26: Issue SA07 - Encounter without TCAS contribution

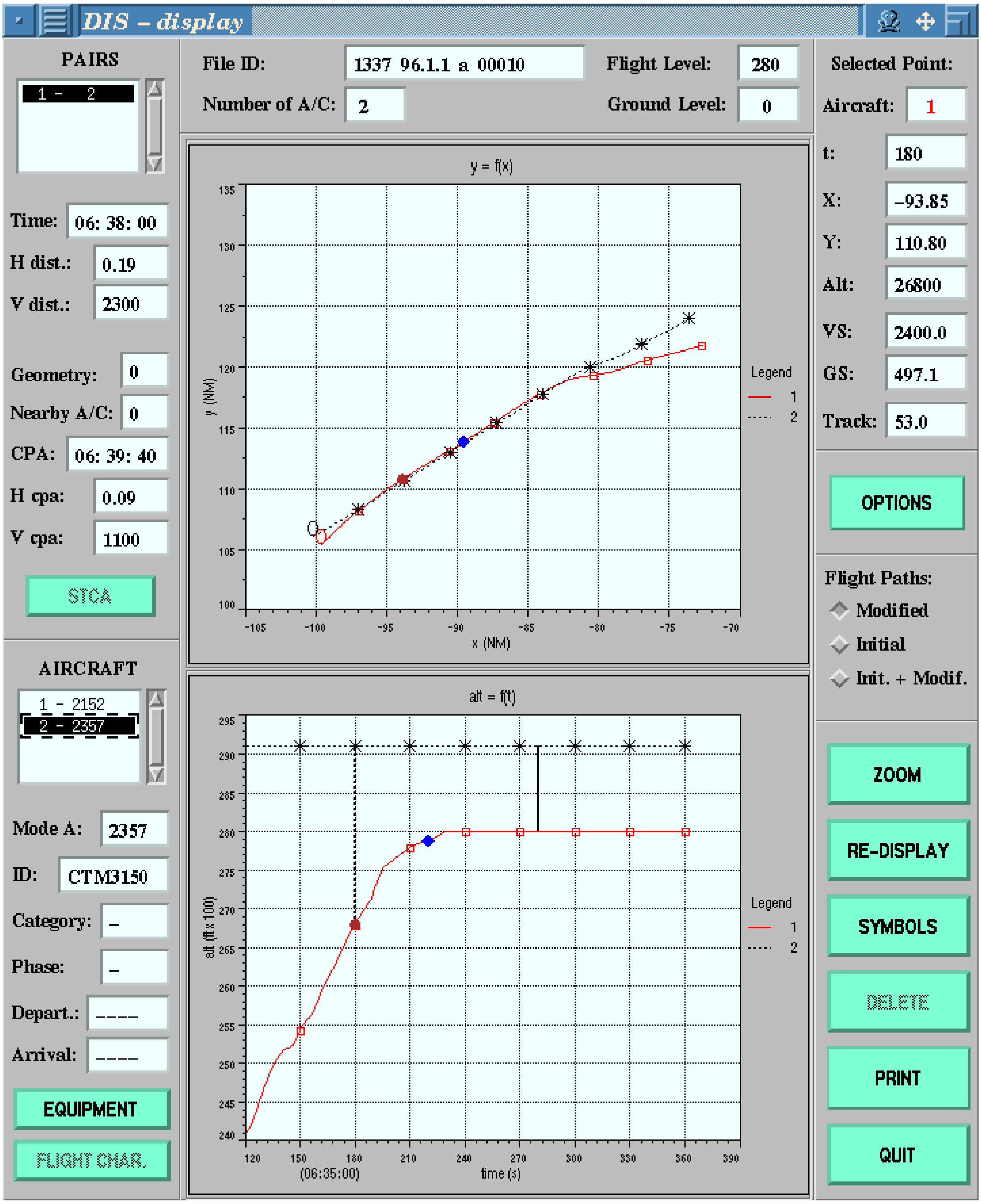

Figure 27: Issue SA07 - Encounter without issue SA07

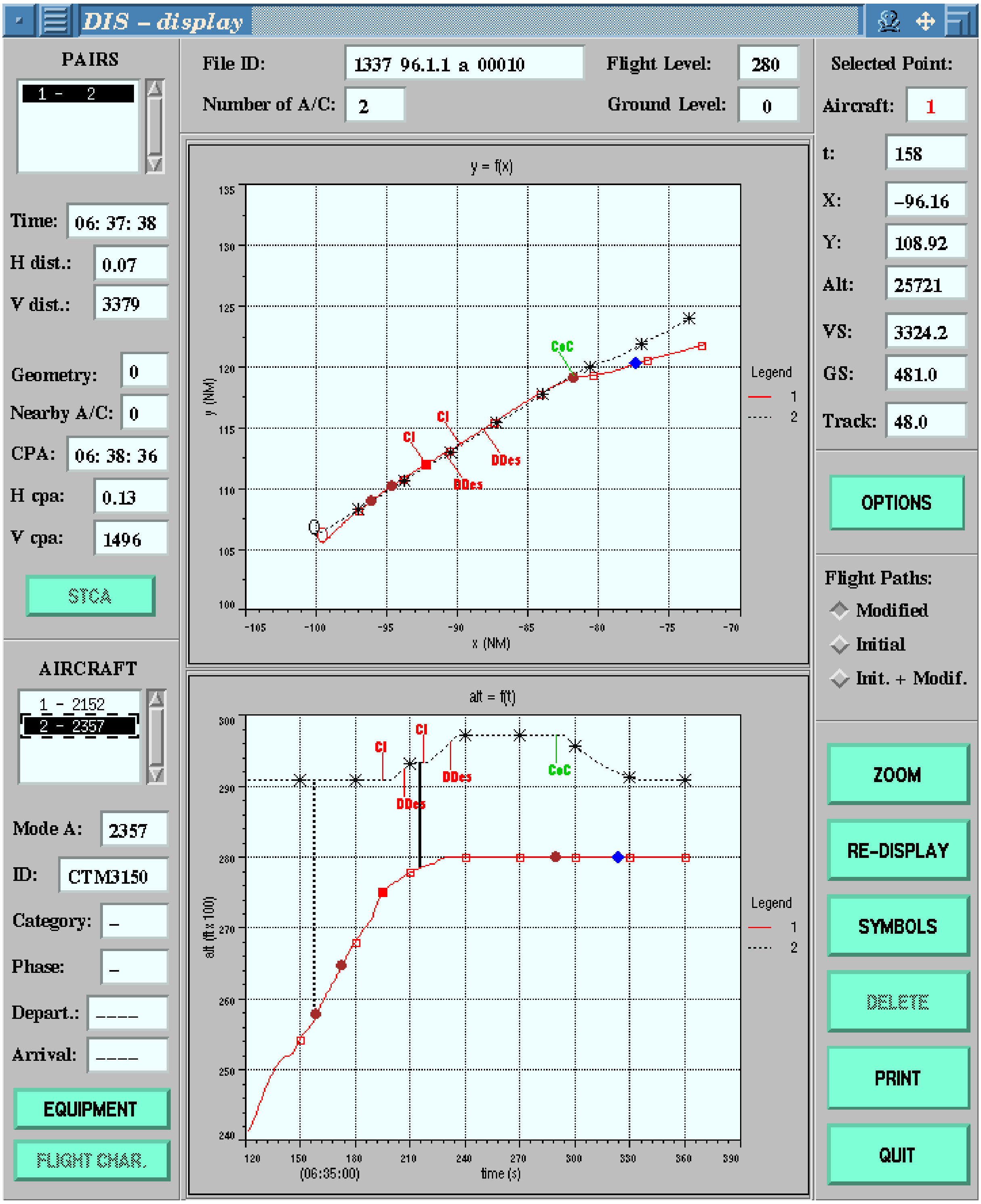

Figure 28: Issue SA07 - Encounter simulated with issue SA07

4.4.2.6. Without issue SA07, TCAS II version 7.0 on board aircraft 2 only triggers a TA. With issue SA07, the logic issues 4 RAs in around 40s, resulting in a deviation over 600ft.

4.4.2.7. It is obvious that such a sequence would be very disturbing for the pilot and the ATC perspectives. **It may also seriously affect the pilot confidence in the system**.

4.4.3. Issue rectification

4.4.3.1. Service Bulletin No.17 from Rockwell Collins had been issued in February 1999 to rectify this issue, but the EMOTION-7 project recommended in March 2001 that issue SA07 be solved through an Airworthiness Directive in order to verify that the altitude reporting quantization is in accordance with the altitude reporting capability indication.

4.4.3.2. Following an FAA investigation of US reports on transponders announcing incorrect altitude quantization, an AD was issued in March 2002, with an effective date of 3 May 2002. **A rectification is therefore now in place.**

4.5. Issue SA10 : Inappropriate RAs due to incorrect altitude reporting

4.5.1. Issue identification

4.5.1.1. RAs triggered by TCAS II are computed using altitude data. This data uses the 1013.25 hPa reference and TCAS receives this data via mode C or mode S replies for the intruder, and via the own mode S transponder for the own aircraft. It is an essential TCAS II input. Therefore this data has to be as accurate as possible.

4.5.1.2. Analysis of recent events [WP1/093] found though EUROCONTROL operational monitoring Programme and from the EMOTION-7 monitoring showed that a significant number of unsafe situations occurred because the altitude data sent to TCAS II were significantly different from the actual one. TCAS II triggered RAs on the basis of the incorrect altitude data provided to it. These RAs proved to be inappropriate or even dangerous, and sometimes led to a reduction of vertical separation.

4.5.2. Issue analysis

4.5.2.1. General

4.5.2.1.1. The purpose of this analysis was to describe events during which incorrect altitudes were transmitted. The purpose of this task was to inform the ACAS Community on the severity of this issue by showing and underlining that only part of it has currently been addressed. The purpose of this analysis was also to identify and list the involved architectures.

4.5.2.1.2. Besides, it also appeared that some aircraft could be undetected or detected late by TCAS, and especially General Aviation aircraft. This issue is different from issue SA10, however as it has also the potential to induce dangerous events, and as it is not uncommon, it was decided to address it in the analysis.

4.5.2.1.3. This part presents the main results from the analysis of 12 events, which occurred between 1996 and 2002. It also presents general observations made from these 12 events. Three events are also presented in details, because they are representative of the other ones.

4.5.2.2. Aircraft detected, but reporting incorrect altitudes

4.5.2.2.1. In TCAS architectures, the barometric altitude is provided by the altitude sources to the TCAS through the Mode S transponders. The mode S transponder is capable of receiving four types of altitude data format from the altitude source: ARINC 429, ARINC 575, Synchro and Gillham[3]. Mode S architectures without TCAS also use these altitude data formats from the altitude source to the Mode S transponder.

4.5.2.2.2. In the specific case of architectures using altitude data with the Gillham format, if two altitude sources are available, the transponder can make a verification of the coherence between the 2 altitudes before transmitting it to TCAS. However, this comparison function is not systematic, and can only detect discrepancies over 500ft between the altitude sources.

4.5.2.2.3. **In some of the analysed events, the involved architecture was using Gilham altitude data** between the altitude sources and the transponder. The error was caused by a bit incorrectly set in the 11 bits Gilham encoding that caused the reported altitudes to be incorrect. Some regulatory texts were modified in order to solve the issue of incorrect altitudes reporting in the case of Gillham architectures (JAA TGL 8 and 13, ARINC 718 characteristic, ICAO Annex 10, publication of ADs in a few countries). However, actions that would provide maximum protection against recurrence of such events where not taken (e.g., no worldwide AD to detect aircraft with potential to report altitudes incorrectly, no direct worldwide rule requiring dual Gilham sources and a comparison function for TCAS or any transponder installation), **therefore there is still the potential for such events to occur again.** One of these events is described hereafter in order to illustrate possible consequences of incorrect altitudes.

[3] Gillham is a code used to provide altitude data, with an 11 bit encoding. It also known as gray code or blind code.

4.5.2.2.4. A B747 was descending from FL370 to FL290. At FL330 it received a TA followed by a maintain descend RA and a descend RA, for an intruder at the same altitude.

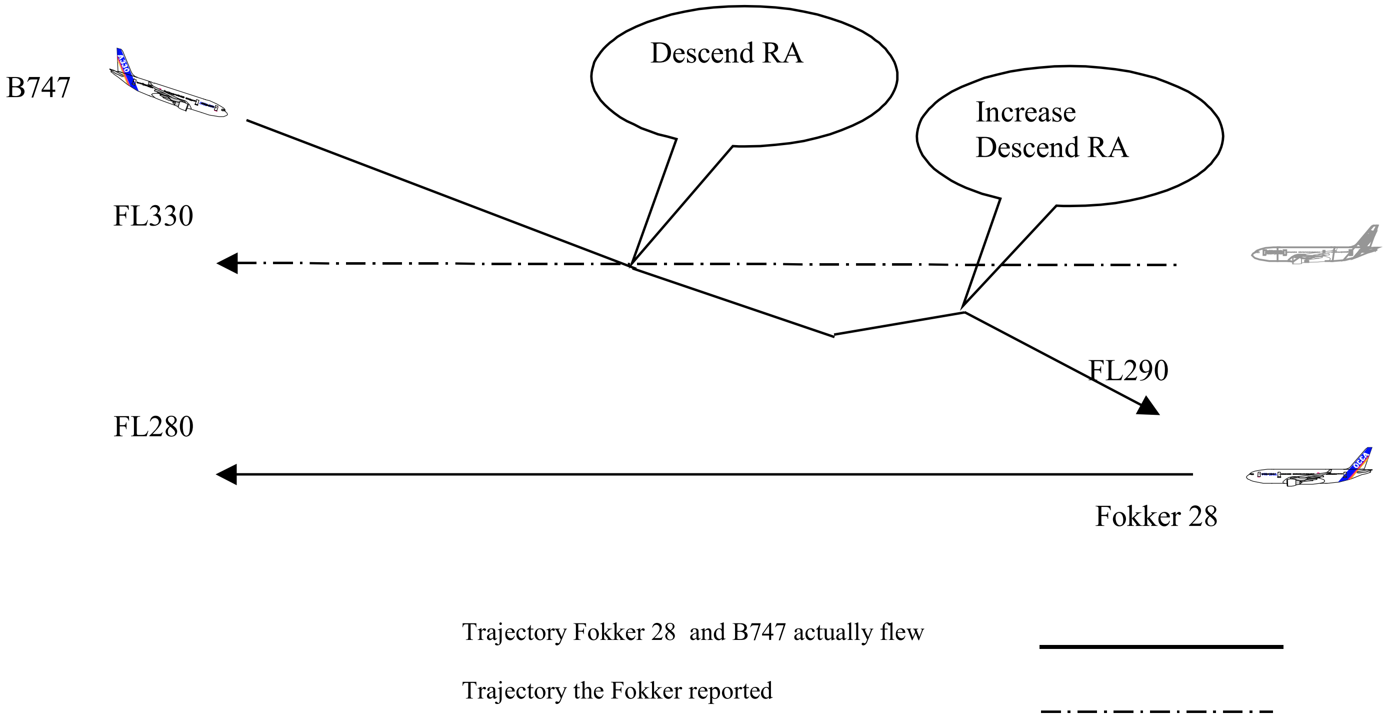

Figure 29: Issue SA10 - Event of the 12 December 1999

4.5.2.2.5. The B747 crew complied with the descend RA. The crew of the B747 saw the intruder, a TCAS equipped Fokker 28, at FL280. In order to prevent further loss of separation, the crew of the B747 performed a lateral manoeuvre and even started to climb again. Then a crossing descend RA and an increase descent RA were triggered. The B747 descended again because the crew was not certain that the alerts were triggered for the aircraft they had in sight. The B747 was cleared to FL290, therefore the crew did not descend below FL290. The crew of the Fokker 28 was then advised by ATC that their reported altitude was incorrect and they were asked to switch their transponder off. The analysis of this event showed that this aircraft was using a single Gilham altitude source to its transponders. A single error on a line of the Gillham has generated the 5000ft, which was observed error by both the ATC and the TCAS of the B747. With dual sources and an altitude comparison function available, the error would have been detected by the F28.

4.5.2.2.6. Other events involved architectures using non-Gillham altitude data [WP1/093] showing that the issue of “Inappropriate RAs due to incorrect altitude reporting” is certainly much wider than the Gillham one. These events occurred in the second part of 2001, and involved Russian aircraft fitted with both Mode S transponders, and old Mode C transponders. In these aircraft, the altitude data is dual and in a format, which is not Gillham. In addition, no comparison between altitudes sources is provided. One of these events is described hereafter.

4.5.2.2.7. A commercial transport aircraft was level at 31500ft. An intruder was seen 8NM away and 200ft below.

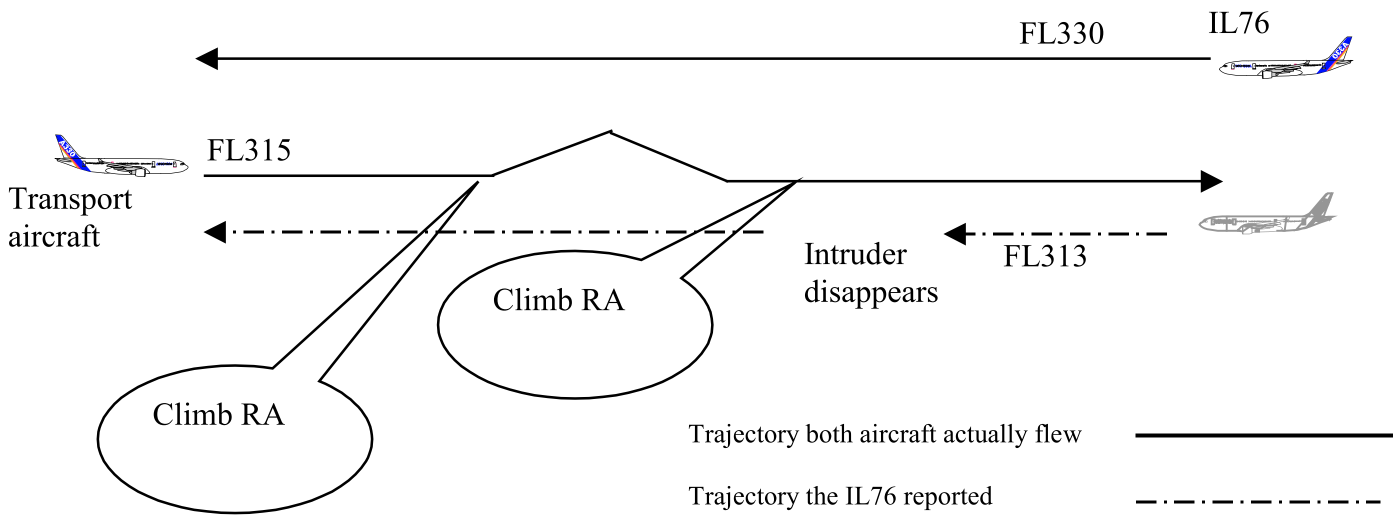

Figure 30: Issue SA10 - Event of the 9 December 2001

4.5.2.2.8. A first climb RA was triggered, which the pilot followed. The track of the intruder then dropped at 6.2NM. The intruder was reacquired 15s later at 2.5NM. A TA was triggered, followed by a second climb RA while the intruder was 0.89NM away. ATC advised the crew that the intruder was an IL76 at 33000ft. The pilots had the IL76 in sight at 33000ft. They performed an horizontal manoeuvre. The pilot reported these RAs were very dangerous.

4.5.2.2.9. The major concern certainly deals with General Aviation, which altitude reporting performance seem to be inadequate, especially when considering the ACAS worldwide mandate. **General aviation aircraft sending incorrect altitudes are not rare**, as shown by a FAA study performed in 1997: 1.5% of GA transponders report altitudes with an error greater than 400ft according to [FAA3].

4.5.2.2.10. The analysis of the 12 events showed that error detection by pilots and ATC is very difficult.

4.5.2.2.11. When an altitude error occurs [WP1/093], **the pilots often do not detect that their aircraft is reporting incorrect altitudes**, because there is no display of the transmitted altitude in the cockpit.

4.5.2.2.12. The analysis of the available events showed that **the controller is often not able to detect the error of altitude because either**:

- He does not have radar; or
- Radar processing detects an error and filters the erroneous data. As a consequence, the controller can be in the situation in which he has an aircraft displayed without altitude, while this altitude is in fact incorrect, transmitted and used by the TCAS of other aircraft; or
- The errors are too short in time to be detected; or
- The use of QNH altitudes makes difficult the detection of an error below the transition altitude. When an aircraft flies over the transition altitude, its altimeters have to operate with the 1013.23 hPa setting (FL). When it flies below the transition altitude, it has to operate using the QNH setting, although mode C/S replies only transmit FL. Some radar displays only display the FL, therefore for approach control, an interpretation of the display has to be made, which makes the detection of errors difficult when aircraft are below the transition altitude.

4.5.2.2.13. The analysis of the available and identified events showed that the consequences of RAs triggered on the basis of incorrect altitudes can include:

- Disruption to the flight crew, without any loss of vertical separation;
- Significant deviations, which could even cause a conflict with a third aircraft;
- RAs, which cause the aircraft to manoeuvre towards the intruder.

4.5.2.2.14. Another risk is the potential loss of confidence in RAs by pilots.

4.5.2.3. Aircraft undetected or detected late

4.5.2.3.1. While bad altitude reporting can cause losses of separation, undetected or intruders detected late affect the ability of TCAS to reduce the risk of collision and to improve safety, and nullify TCAS capabilities to avoid the aircraft. However, this issue is different from issue SA10 as initially detected, but since it may also induce dangerous events, it was included in the analysis.

4.5.2.3.2. 63 events, the majority involving Russian aircraft, were reported [WP1/093] in the second half of 2000 in Finland. In these events, aircraft were reported to be undetected by radars and/or by TCAS II.

4.5.2.3.3. **General Aviation aircraft [FAA3] are also subject to this type of error in a significant proportion**, confirming that the major concern certainly deals with General Aviation, when considering issues linked to altitude data: 3.1% of the GA transponders are invisible to TCAS according to [FAA3]. However a recent AD was published to correct this issue in the case of a specific transponder type.

4.5.2.3.4. It is likely that these events are caused by low quality reply pulses, which are rejected by TCAS and SSRs radars. Therefore the aircraft are invisible to recent SSRs and TCAS, while they would be visible to older radars, which have broader tolerance criterion. Another possible explanation for this issue is antenna shadow.

4.5.2.3.5. One of these events is described hereafter. While climbing through 15200ft (FL157), a commercial transport aircraft (black dotted line) faced a near miss event with a VFR aircraft (red full line).

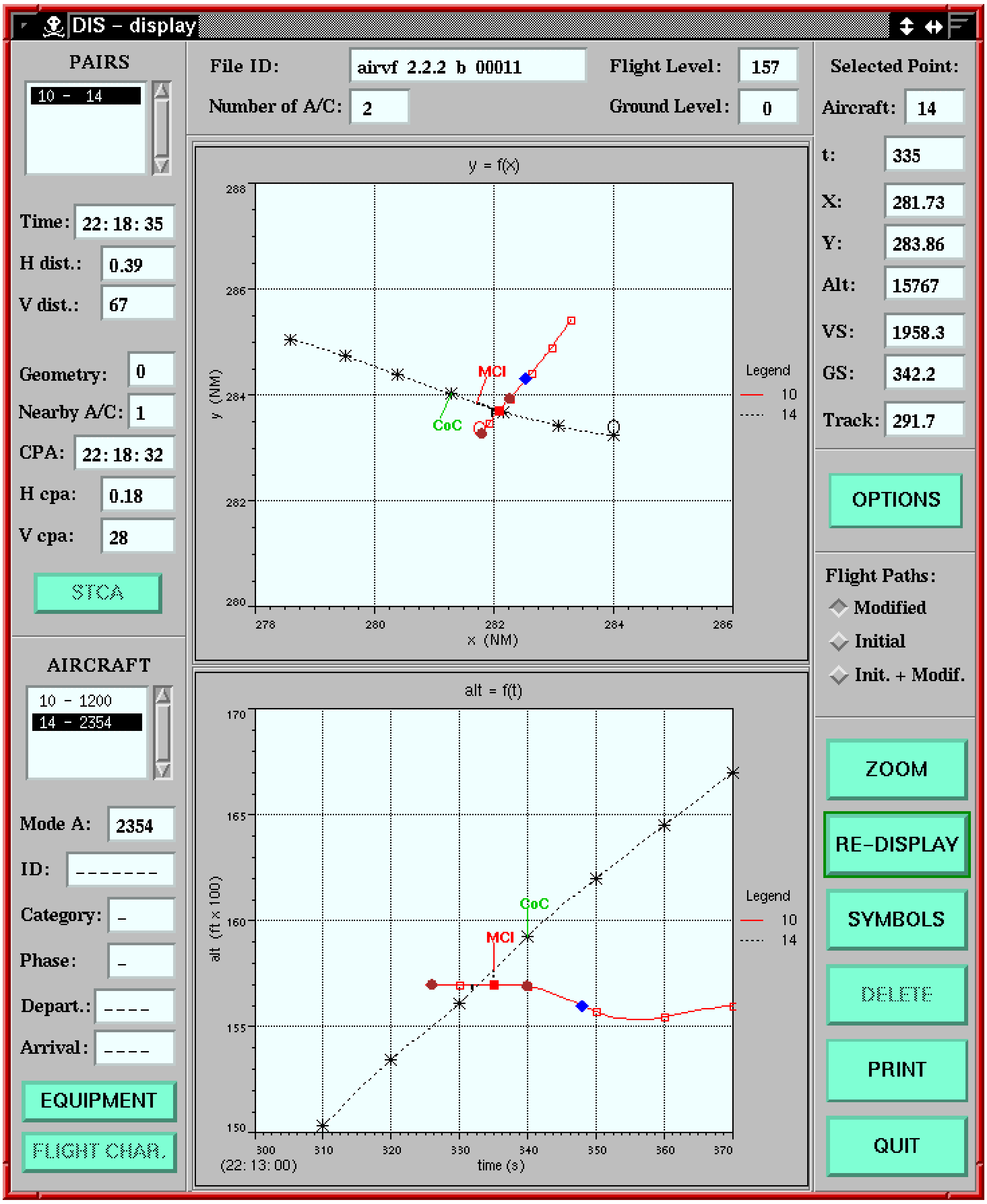

Figure 31: Issue SA10 - Event of 2002

4.5.2.3.6. The crew of the transport aircraft reported that TCAS did not trigger any alert until the VFR aircraft was behind and clear. Airborne data enabled to confirm that a TA was triggered during 4s at 15000ft, followed by a maintain vertical speed RA, which lasted 6s.

4.5.2.3.7. From the analysis of the available data, the most likely explanation for this event is a surveillance issue with the VFR aircraft, which was detected very lately (i.e., just before CPA) by the TCAS of the transport aircraft. According to the radar data the horizontal separation at CPA was 0.18NM, with a vertical separation at CPA of 28ft.

4.5.3. Issue rectification

4.5.3.1. Incorrect altitude reporting

4.5.3.1.1. **The output of this analysis was a set of recommendations**, which should provide maximum protection against recurrence. These recommendations are as follows.

4.5.3.1.2. If the use of Gillham altitude can not be avoided, it is recommended that:

- Two altitude sources with a comparison function should be used, for both aircraft equipped with TCAS and aircraft not equipped with TCAS. Consideration should be brought to the possibility to use an altitude comparison threshold lower than 500ft;
- Modes S transponders should include a feature to automatically compare the two altitude sources;
- A failure should be reported to the crew if the comparison function is not activated;
- Any comparison failure should be reported to the crew, and/or the transponder should cease to provide altitude data, in replies to interrogations from TCAS or ATC;
- The altitude comparison function should be tested on a regular basis;
- No further installations of TCAS and Mode S transponders should be certified using Gillham altitude sources.

4.5.3.1.3. All the installations utilising single Gillham altitude sources should be modified.

4.5.3.1.4. The recommendations made for Gillham architectures should be applied to any architecture for maximum protection against accidents.

4.5.3.1.5. Altitude should now be considered as a critical data, thus inducing strengthened requirements to be applied on this data.

4.5.3.1.6. The following recommendations would bring protection against recurrence of this issue:

- Regular inspections should be undertaken on the altitude reporting link, to detect aircraft with unsatisfactory altitude reporting;

- The altitude reporting links with unsatisfactory altitude reporting capabilities should be repaired as soon as possible;
- A monitoring programme should be established to detect General Aviation aircraft with unsatisfactory altitude reporting.

4.5.3.2. Aircraft undetected or detected late

4.5.3.2.1. The following recommendations would bring protection against recurrence of this issue:

- Regular inspections should be undertaken on the altitude reporting link, to detect aircraft with unsatisfactory altitude reporting;
- The defective altitude reporting links should be repaired as soon as possible;
- A monitoring programme should be established to detect General Aviation aircraft with unsatisfactory altitude reporting.

4.6. Issue OP06 : Unecessary RAs in 1000ft level-off geometries

4.6.1. Issue identification

4.6.1.1. The EMOTION-7 monitoring performed in 2000 confirmed that RAs triggered during 1000ft level-off encounters were a source of disruption for ATC and were perceived as nuisance by pilots in 50% of the encounters [WP3/035].

4.6.1.2. However, these RAs were mainly triggered in encounters involving TCAS II version 6.04a equipped aircraft as this version of the logic was still the most represented in the European airspace in 2000.

4.6.1.3. It was expected that TCAS II version 7.0 would reduce the number of unnecessary RAs during 1000-ft level-off encounters and generate more compatible RAs for the remaining ones by introducing new features:

- A 25-foot α-β vertical tracker;
- Reduction of the VTT threshold values above FL200, from 30s to 25s;
- Modifications to reduce the frequency of rate reversing RAs;
- A Miss Distance Filtering.

4.6.1.4. However, although a significant reduction of the number of RAs has taken place, the issue is still there.

4.6.2. Issue analysis

4.6.2.1. The goal of the analysis [WP1/045], which was performed in 2000, was to assess the improvements to be expected with TCAS II version 7.0.

4.6.2.2. In order to assess the impact of the new features of TCAS II version 7.0, a comparison between TCAS II version 6.04a and TCAS II version 7.0 was made on a database of actual encounters (gathered in the European airspace) in which aircraft were in a 1000ft level-off geometry. The data base included 113 single level-off encounters (i.e., one aircraft is levelling-off and the other one is level) and 111 double level-off encounters (i.e., both aircraft are levelling-off). Simulations with these two scenarios enabled to assess the improvements brought by TCAS II version 7.0.

4.6.2.3. Figures 32 and 33 show, for the data base of single level-off encounters, the number of RAs and of positive RAs (i.e., climb or descend at 1500ft/mn), with TCAS II version 6.04a and with TCAS II version 7.0, for the level aircraft and then for the levelling aircraft.

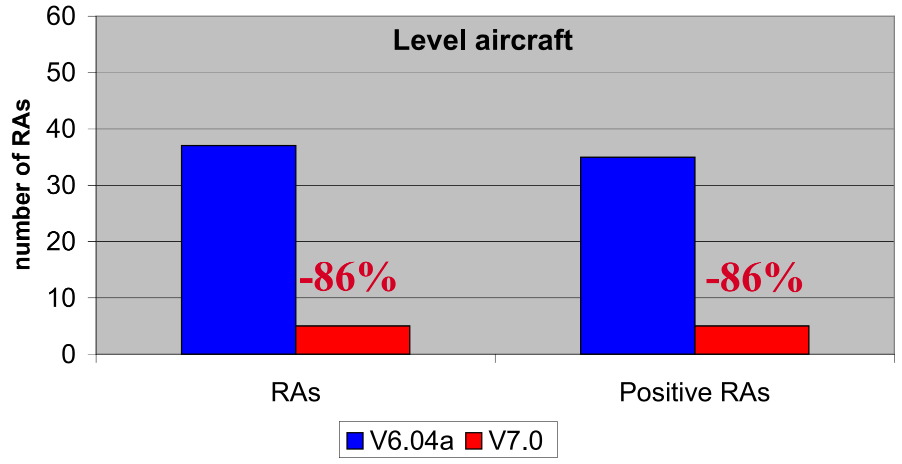

Figure 32: Number of RAs for single level-off encounters – level aircraft

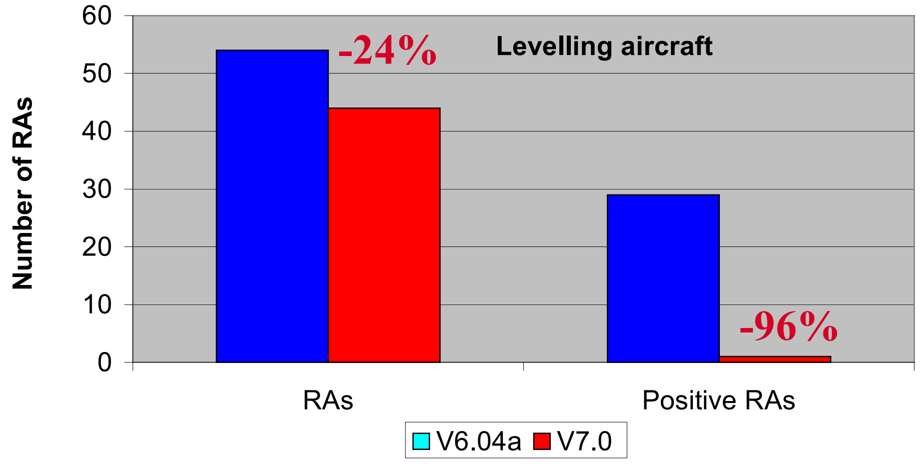

Figure 33: Number of RAs for single level-off encounters – levelling aircraft

4.6.2.4. For single level-off encounters, a high RA reduction rate is observed for the level aircraft (-86%) with TCAS II version 7.0. For the levelling aircraft, TCAS II version 7.0 triggers RAs that are more compatible with ATC clearances, as the number of positive RAs is reduced by 96%. However the RA rate reduction for the levelling aircraft is 24%, which is far from being as significant as for the level aircraft.

4.6.2.5. The following figure shows, for the data base of double level-off encounters, the number of RAs and of positive RAs, with TCAS II version 6.04a and with TCAS II version 7.0.

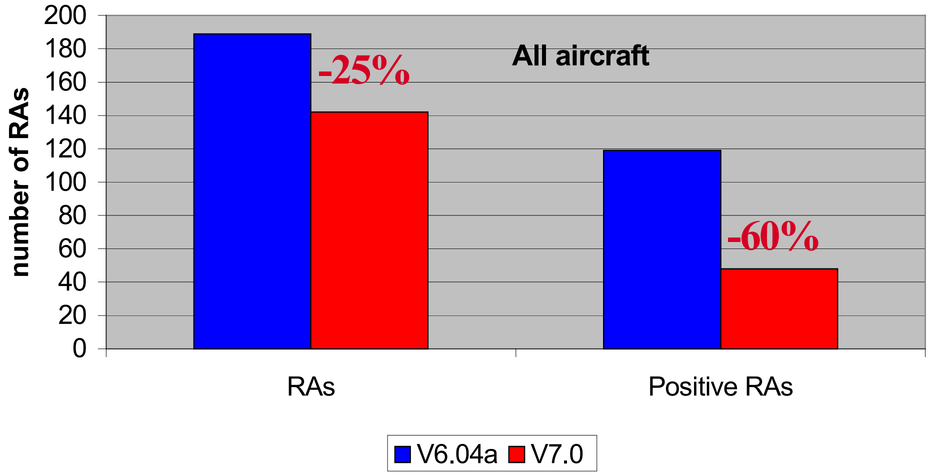

Figure 34: Number of RAs for double level-off encounters

4.6.2.6. Improvements are observed for double level off encounters (decrease of 25% of the number of RAs). These improvements are equivalent to what is observed on the levelling aircraft of the single level-off encounters. In addition, the RAs are also more compatible with ATC clearances with version 7.0 than with version 6.04a (reduction of 60% of the number of positive RAs).

4.6.2.7. On an ATC perspective, it appears that the improvements are noticeable because of the significant decrease in the number of encounters in which at least one RA is triggered (25% decrease) and because of the lower deviations. The following figures show the number of aircraft function of deviations, for the data bases of level-off encounters, with TCAS II version 6.04a and version 7.0.

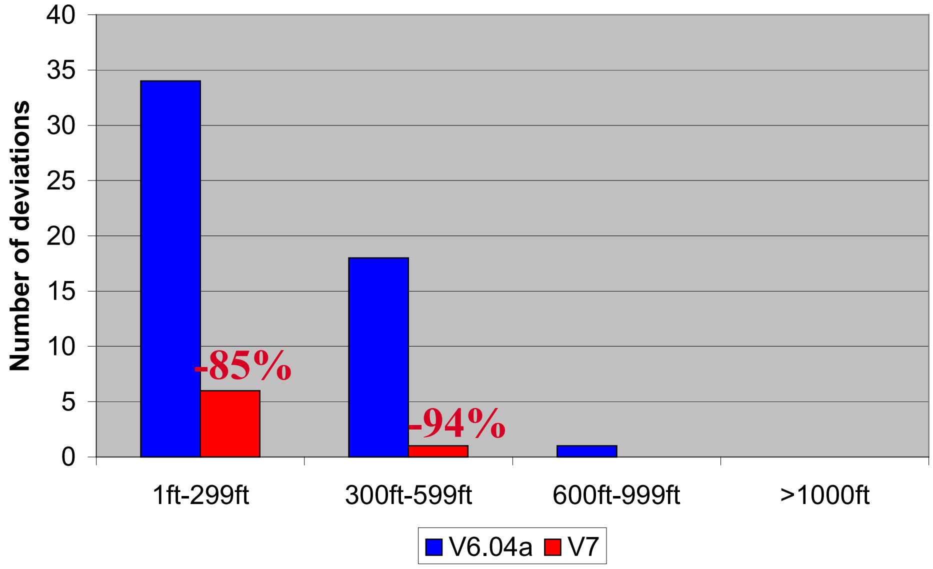

Figure 35: Deviations for single-level off encounters

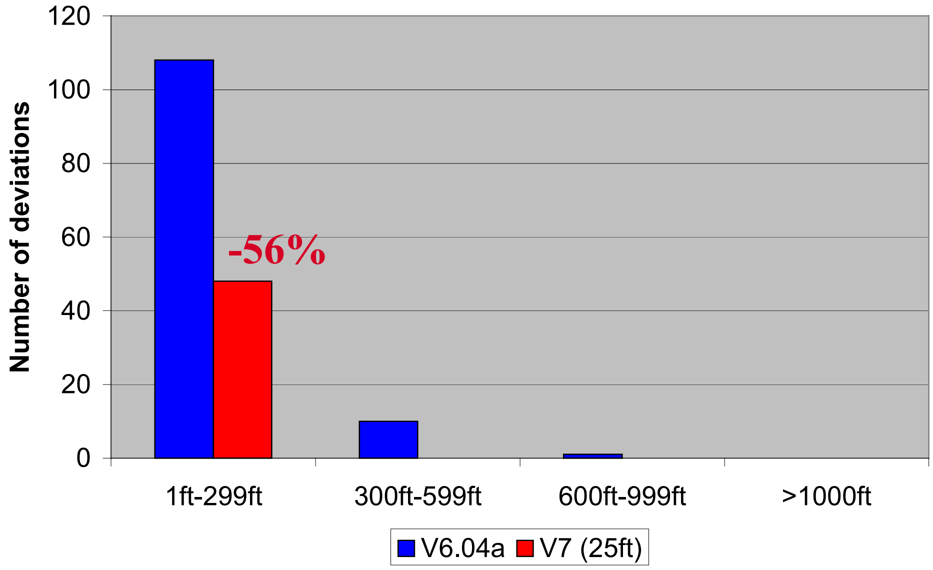

Figure 36: Deviations for double level-off encounters

4.6.2.8. With version 6.04a, many encounters result in important deviations. With TCAS II version 7.0, the number of important deviations is significantly reduced.

4.6.2.9. This analysis concluded that "TCAS II version 7.0 should decrease the proportion of nuisance RAs, but as the total fleet of equipped aircraft will increase, the perception of the number of nuisance RAs (by both ATC controllers and pilots) should probably remain high" [WP1/045].

4.6.3. Issue rectification

4.6.3.1. Technical solution

4.6.3.1.1. Two technical solutions could be envisaged.

4.6.3.1.2. The first one is to use the information of own intent (selected flight level) in order to avoid the triggering of unnecessary RAs while approaching the selected flight level. However such a solution would certainly not be implemented in the short or medium term:

- The idea of filtering RAs in case of 1000-ft level off encounters would be a major change in the CAS logic: such a solution would be long to develop, and to implement due to validation and certification delays;
- The altitude capture mode of the autopilot would have to be 100% reliable for such a solution to be implemented. In case of failure of altitude capture, if this technical solution was implemented, TCAS would not trigger some necessary RAs, or would trigger them too late (i.e., after detection of altitude capture failure). Indeed, recent figures prove that altitude capture is not absolutely reliable, as British Airways reports a failure rate of 18% for altitude captures in year 2000.
- This solution would use as main input the own selected flight level, therefore any error in the selection of this flight level would have consequences on the behaviour of TCAS. Indeed, the use of selected flight level by the crews is not currently 100% reliable.

4.6.3.1.3. The second solution is to change the altitude capture laws of the autopilots in such a way that the probability to have an RA while levelling-off is lower than what is currently experienced. However, such a solution requires each aircraft manufacturer to compute new laws for each aircraft type, and to implement them. This will take a certain time.

4.6.3.1.4. Therefore, whilst retaining the technical solution as a desirable longer-term objective, the EMOTION-7 Project investigated a resolution for the problem, which could be implemented in the short term, through potential modification of operational ATC procedures [WP2/064].

4.6.3.2. Operational solution

4.6.3.2.1. In a first step, it was underlined that **1000ft level-off encounters occur at recurrent places. The places where RAs occur frequently were called "hot spots**". Such hot spots were identified for example in Paris, London and Oslo TMAs [WP1/064]. These hot spots are multiple for each of these TMAs, and are situated around FL100. They involve aircraft descending to FL110 and aircraft climbing to FL100. The following figure shows traffic in the TMA of Paris. The place shown with a dotted circle on this figure is one of the hot spot found in Paris TMA.

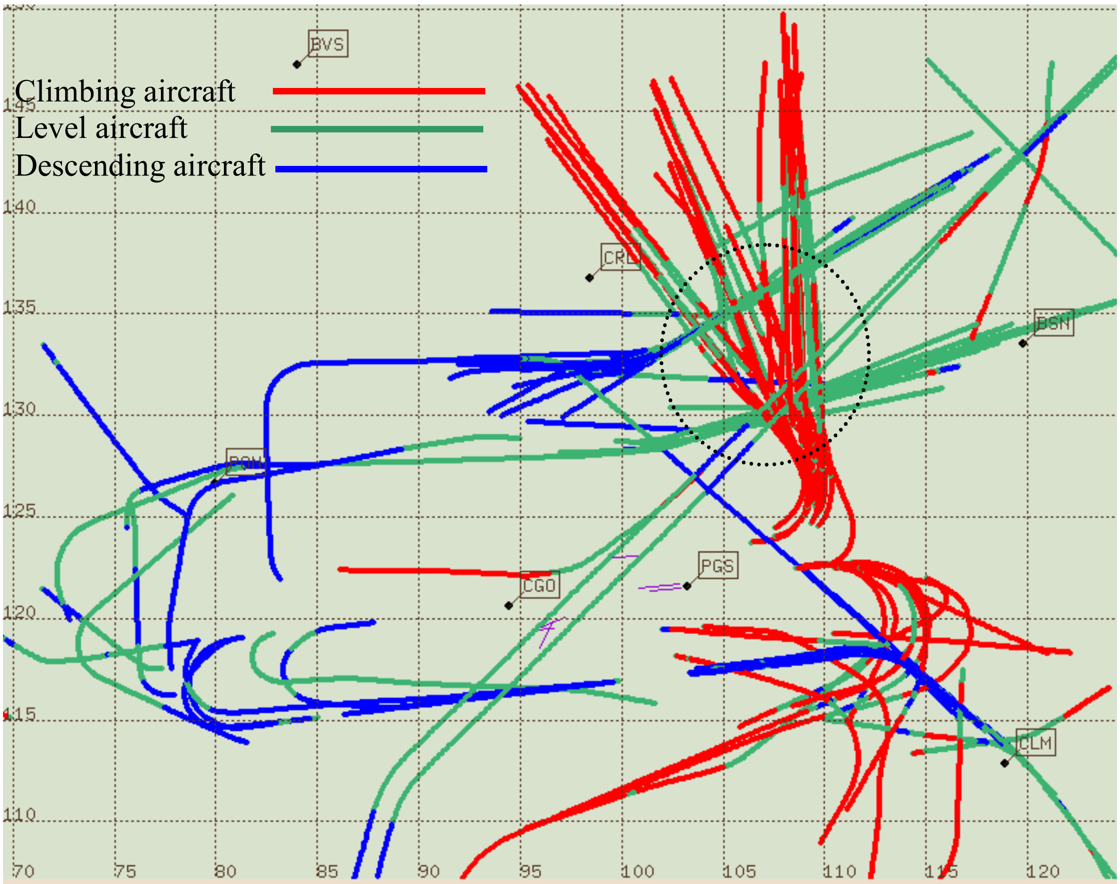

Figure 37: Paris' hot spot – real traffic

4.6.3.2.2. In order to reduce the probability of RA at these hot spots, different procedural solutions can be envisaged:

- **To increase the vertical distance at CPA** so that an RA is less likely. The idea is simply to separate converging aircraft by 2000ft each time at least one of them is climbing or descending to the other aircraft. This solution does not prevent aircraft from being converging simultaneously in both vertical and horizontal plane. It only reduces the probability of RA provided that the relative vertical rate between both aircraft is not too important; or
- **To delay the vertical convergence** beyond the time of the horizontal convergence, so that an RA cannot be triggered. A method could that SID/STARS designers modify the procedures so as to obtain, as far as possible, a delay in the vertical convergence between the aircraft. The principle of this modification is explained hereafter.

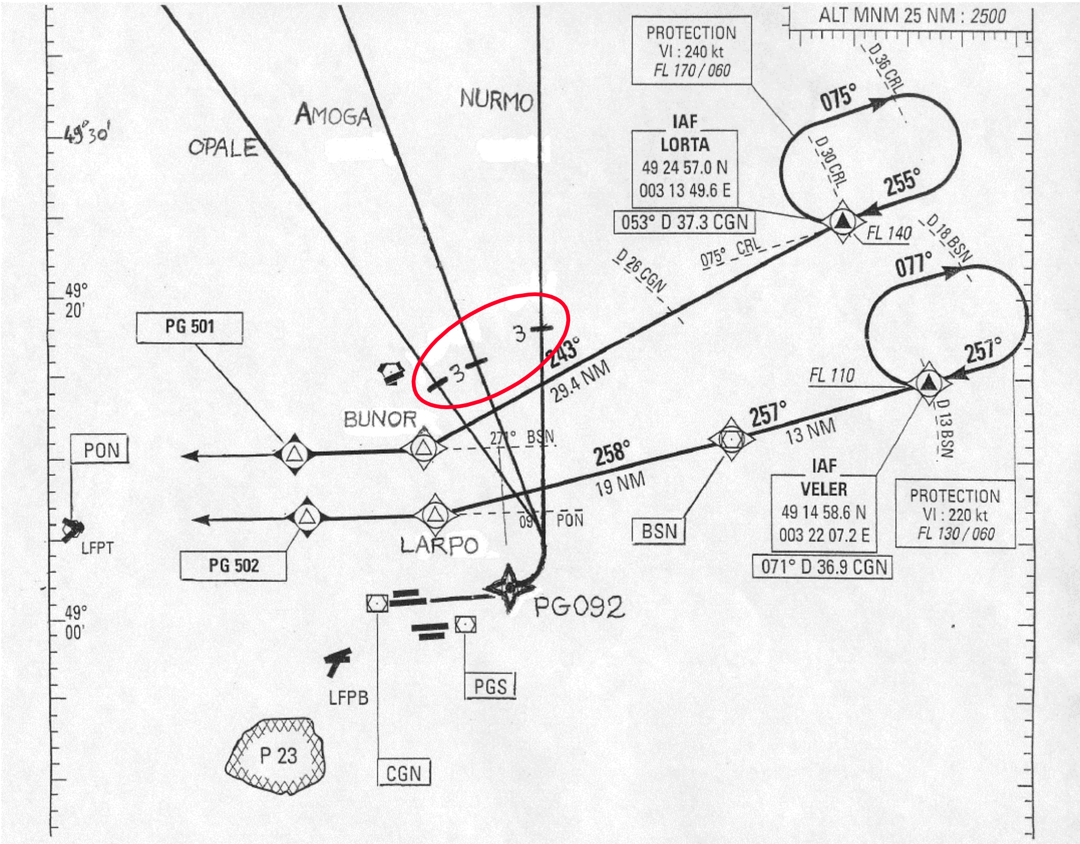

Figure 38: Climbing aircraft reach FL100 at waypoint "3" or after

4.6.3.2.3. Currently, LORTA-BUNOR arrivals descend from FL140 down to FL110. OPALE departures climb to and maintain FL100. Aircraft usually cross each other as the arrival is levelling at FL110 and the departure is levelling at FL100. Sometimes the arrival is already steady at FL110 but this does not prevent TCAS RAs, because the departing aircraft can be still climbing. The modification would be achieved, on this SID, by making the aircraft reaching FL100 for example 3NM after crossing the LORTA-BUNOR track, as shown by the red mark on figure 38. This would result in aircraft climbing with reduced vertical rates, and should therefore be easily achievable, in terms of flight performances.

4.6.3.2.4. These two solutions have the advantage of reducing the occurrence of unnecessary RAs **while improving safety**.

4.6.3.2.5. The two procedural modifications were tested on a data base of 98 real 1000ft level-off encounters, which occur around FL100, in order to assess their influence in term of RA reduction rate [WP2/078]. The following table presents the number of aircraft with RAs, and the number of aircraft with TAs on our data base of 1000-ft level-off encounters. The first column shows the results for the encounters before any modifications applied on them (i.e., the current procedure actually flown). The second column shows the results for the encounters modified so as to have a vertical separation of 2000ft rather than 1000ft. The third column shows the results for the encounters modified so as to delay the vertical convergence.

	Current procedures	New procedure with 2000ft separation	New procedure with convergence delayed
Number of aircraft with TAs	182	99	44
Number of aircraft with RAs	96	0	0

Table 5: Effect of the solutions on real encounters

4.6.3.2.6. This assessment shows the significant operational benefits brought by the modified procedures. **On a data base of 98 1000ft level-off encounters modified so as to apply the modified procedures, all the RAs are removed.** In addition, the number of TAs is significantly decreased (i.e., decrease of 45% and 75% depending of the simulated procedure).

4.6.3.2.7. In addition to assess the consequences of the procedures on capacity, real traffic data for Paris TMA were analysed. A high level analysis showed [078] that the vertical profiles modifications and speed restrictions resulting from the modified procedures would only have benign effects, whatever the location where the procedural modifications are implemented. In addition, this analysis also showed that, for the example of Paris TMA, there is no conflicting traffic in the altitude band where the modified procedures apply (i.e., between FL70 and FL100). **Therefore, there would be no effect on airspace capacity**.

4.6.4. Operational implementation of a rectification

4.6.4.1. A new arrival procedure to CDG via MOSUD (March 2002) in easterly landing configuration was recently applied. This procedure lead to simultaneous horizontal and vertical convergences with departures to the South (BENIP – MOU – PTV – PIROG). Many STCA alerts and RAs were observed.

4.6.4.2. In order to improve the situation, the procedure was modified: the descent point from FL140 to FL120 over CLM VOR was moved forward by 4 NM for MOSUD arrivals, thus delaying the vertical convergence with departures climbing to FL110.

4.6.4.3. As a result, it was observed that there were no more STCA alerts nor RAs in that configuration, thus showing the benefits of the solutions proposed to rectify issue OP06.

4.7. Issue OP08 : Operational implication for ACAS due to proposed movement control techniques utilising Mode S multilateration

4.7.1. Issue identification

4.7.1.1. The goal of this study [WP1/065] was to report on a very preliminary investigation of the interaction between ACAS operations and the Mode S multilateration implementation planned in the major European airports. This issue is very different from the other ones studied, as it was performed by anticipation of a potential future problem by the EMOTION-7 Steering Committee.

4.7.1.2. Surface movements surveillance is mainly based on the use of primary radar. However, the system is not completely satisfactory, because the correlation between mobiles' identification and primary radar tracks is not fully automated, and because primary detection on ground can be limited by buildings' shadow, garbling in dense traffic zones, or bad weather conditions.

4.7.1.3. Providing a better surface guidance and curbing the increasing number of runway incursions is a sufficient incentive for major airports to improve the current surface surveillance system. The idea is to bring the benefit of secondary surveillance to the ground movement controllers. Between 10 to 20 (dependent on airport configuration) receivers are placed in strategic positions throughout an airport. Each of them listens to the spontaneous short squitters sent by Mode S transponders each second. As not all aircraft are fitted with mode S transponders, they also listen to the replies sent by Mode A/C transponders in response to Mode C interrogations.

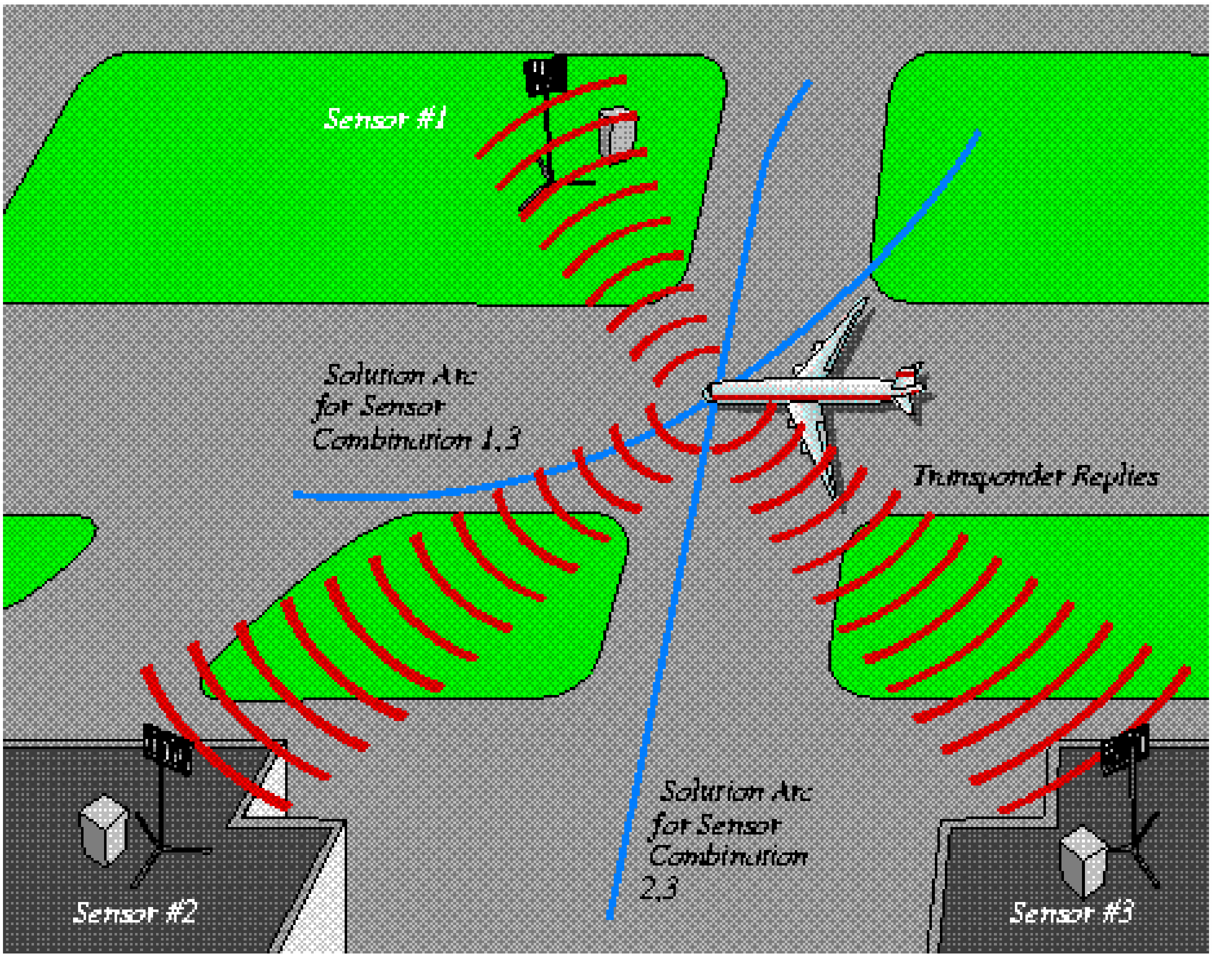

Figure 39: Determination of an aircraft position by multilateration

4.7.1.4. The operation of multilateration implies that transponders be transmitting even when they are not on the runway. As ACAS relies on transponder's signals to initiate and maintain a surveillance track for each surrounding aircraft, concerns have been raised by the EMOTION-7 Steering Committee about a possible adverse influence of multilateration on ACAS operation.

4.7.2. Issue analysis

4.7.2.1. With the introduction of multilateration, the number of active transponders in the area around the airport will increase by the number of on-ground aircraft located between the gates an the runways. On major airports, this number is often around 50 and could rise as high as 100 [WP1/065]. The concern here is that transponders will have to spend more time processing the additional signals coming from the on-ground transponders, thus reducing the overall transponder availability. As ACAS relies on transponders to keep track of the threats and to coordinate avoidance manoeuvre, this may have a detrimental effect on the surveillance and coordination functions of ACAS.

4.7.2.2. During the development of ACAS standards, special attention was paid to avoid that ACAS interrogations, made on the same frequency as SSR interrogations, would not use more than 2% of an airborne transponder total operating time. In order to respect this constraint, ACAS units count the number of surrounding ACAS units and reduce its interrogation power according to interference limiting algorithms. With the introduction of multilateration, if ACAS is switched on at the same time as its Mode S transponder, the on-ground transponder will reply to ACAS interrogations and indicate the aircraft is ACAS-equipped, except if the weight on wheel switch is considered. These on-ground ACAS units will be taken into account by airborne ACAS unit when applying the interference limiting power reduction. The concern here is that the resulting reduced ACAS surveillance range will reduce the capability of airborne aircraft to avoid collisions, by reducing the time during which the pilot will have to react, for example [WP1/065].

4.7.2.3. Additional TAs will result from multilateration. In a terminal area, the introduction of multilateration could have two equally undesirable effects because of additional TAs being triggered:

- More stress for the pilot due to the presence of more numerous plots on the screen and possibly a ”TRAFFIC, TRAFFIC” aural while in final approach; and
- The risk of using the display to monitor surface movements and, based on it, make some important decisions such as interrupt one’s landing or delay one’s taking-off. The scale and accuracy of the TCAS display do not allow such uses.

4.7.2.4. According to the TCAS II MOPS, the RA generation against on-ground aircraft should be inhibited. Operational experience has shown that it is not always the case. The reason could be a mistake in the implementation of the MOPS, or a failure to determine that the target aircraft is on the ground (unconnected/faulty squat switch or wrong altitude transmission). The concern here is that because of multilateration unjustified resolution advisories will arise from this situation, leading the pilot to deviate from its trajectory, possibly disturbing other aircraft.

4.7.3. Issue rectification

4.7.3.1. The Steering Committee recommended and agreed that at this stage, no rectification work was required, because there is currently no evidence that the likelihood of this issue would justify rectifying it.

4.8. Issue OP09 : TAs for intruders on the ground

4.8.1. Issue identification

4.8.1.1. Several papers ([WP3/066], [SCR1]) highlighted that Traffic Advisories against intruders physically on the ground do exist in a sizeable number, although only one pilot complaint was received during the EMOTION-7 monitoring. The latter was registered a “serious nuisance”. The pilot mentioned this kind of TA “had been noticed on previous departures”.

4.8.1.2. An FAA paper presented at the SCRSP meeting in Paris in October 2001 ([SCR1]) says that two of the manufacturers’ TCAS units were sending newly initiated tracks to the CAS logic without testing the Air/Ground status. This could have caused TAs against intruders on the ground although the Minimum Operational Performance Standards (or DO-185A, [MOPS]) requires that the track of an intruder on the ground shall not be forwarded to the CAS logic.

4.8.2. Issue analysis

4.8.2.1. The aim of this analysis [WP1/075] was to describe the issue, its severity and present its possible causes. The input were British Airways operational data as well as information provided by four European airlines, amongst them, three major ones. The DO-185A standard [MOPS] was used as a reference to identify the gaps between the expected and the actual TCAS behaviour.

4.8.2.2. From the WP-3 monitoring, it was possible to determine that 30% of TAs are for intruders on the ground. These TAs are triggered in TCAS aircraft, which are either in a take-off or landing configuration. Most of the aircraft against which these TAs are triggered are Mode S intruders reporting their altitude.

4.8.2.3. From an operational point of view, no specific complaint was received from pilots (apart from one British Airways ASR). One reason for this could be that TAs are generated while the TCAS aircraft is either in a climb or descent phase at an altitude where, at some point, TCAS aural alarms are inhibited. During these phases, the pilot is fully concentrated on the aircraft manoeuvre and

- does not notice the TAs at all or understands it is the aircraft landing before or taking off after him; or
- is aware that TAs are regularly generated by intruders on the ground and considers there is no safety reason that motivates him to complain about those.

4.8.2.4. From a TCAS system point of view, the own aircraft experiences TAs based on data input provided by intruders (i.e. the TCAS calculates the advisories using data transmitted by the intruder’s transponder). Airline operational procedures influence what data is transmitted by the intruder and when, because they decide on how the ATC/TCAS control panel shall be used within the cockpit. Procedures vary from one airline to the other. One airline was required to modify its procedures to match recent surface surveillance operations. Moreover, equipment manufacturers leave it up to airlines to configure part of their equipment.

4.8.2.5. This means that there are a multitude of intruder aircraft behaviour, depending on

- the airlines operational procedures;
- the configuration of its equipment (which is not always the same throughout its fleet);
- on ATC requirements.

4.8.2.6. This is illustrated by the following table. This table summarises the period in time during which the Mode S transponder answers TCAS Mode S interrogations while the intruder is on the ground (■), for 4 European airlines.

Airline	Pre-Start Check	Post-Start Check	Pre Take-Off Check	Post Landing Check	Post Engine Shutdown
A			■		
B	■	■	■	■	
C	■	■	■	■	
D		■	■	■	
t = 0 -- → t					

Figure 40: Use of the transponder while on the ground

4.8.2.7. Unjustified traffic advisories against intruders on the ground may be due either to data treatment performed by the own TCAS computer (including the direct forward of newly initiated tracks to the CAS logic) or to a specific Mode S transponder configuration or behaviour.

4.8.2.8. **The most probable and obvious reason for unjustified TAs against intruders on the ground is the direct forward of newly initiated tracks to the CAS logic without testing the Air/Ground status**, as identified by the FAA [SCR1] [SCR2]. If the issue proved to be related to a specific Mode S transponder configuration or behaviour, ATC operations relying on information provided by Mode S transponders could also be affected.

4.8.2.9. **At the moment, there is no obvious operational issue related to pilot acceptance or compatibility with ATC**.

4.8.3. Issue rectification

4.8.3.1. A SB was issued to address the problem of direct forward of newly initiated tracks to the CAS logic without testing the Air/Ground status. It is recommended that this SB should be implemented as soon as possible.

4.8.3.2. It is also recommended that the operational monitoring Programmes continue to monitor this issue.

5. Conclusion

5.1. General

5.1.1. The EMOTION-7 project provided the tool and the structure, that enabled to maintain the required level of TCAS II expertise in Europe while deploying TCAS II version 7.0 over the fleet operating in the European airspace. This permitted the identification and the rapid rectification of issues between January 2000 and December 2002.

5.1.2. The EMOTION-7 project also permitted to gain a better knowledge of the behaviour of TCAS II version 7.0 in Europe.

5.2. EMOTION-7 monitoring

5.2.1. The EMOTION-7 monitoring was a very useful source of data in the scope of the European maintenance of TCAS II version 7.0. Its relevance in the identification and investigation of potential issues has been highlighted in several occasions.

5.2.2. The EMOTION-7 monitoring also provided statistical and operational inputs concerning the behaviour of TCAS II version 7.0. These inputs confirmed the expected gains provided by version 7.0.

5.2.3. A reduction by two of the number of reported RAs was observed with TCAS II version 7.0, in comparison with version 6.04a.

5.2.4. TCAS II version 7.0 also shows a better handling of 1000ft level-off encounters than version 6.04a. It triggers less RAs, which are also more compatible with ATC clearances.

5.2.5. The British Airways monitoring enabled to find three operational examples of issues SA01 (Inappropriate reversal logic operation). This confirmed the operational realism of the issue.

5.3. *Issues investigated during the project*

5.3.1. The following table provides a summary of the issues investigated during the project. The means that enabled either to identify a potential issue or to confirm its relevance, are also presented.

Issue	Name	Identified/confirmed through					Analysed	Rectified
		E7 monitoring	E7 team expertise	E7 Steering Committee	National operational monitoring programmes	ACASA project		
SA01	SA01a: Late reversal RAs or no reversal RAs in coordinated encounters	✓	✓				✓	✓
	SA01b: Late reversal RAs or no reversal RAs in uncoordinated encounters		✓					
	SA01c: Undesirable reversal RAs in coordinated encounters		✓				✓	✓
SA02	Inappropriate RAs against glider clusters		✓					
SA07	Discrepancy between altitude quantization and altitude reporting capability announcement				✓	✓	✓	✓
SA10	Inappropriate RAs due to incorrect altitude reporting	✓			✓		✓	
SA11	RA display misinterpretation	✓			✓			
SA12	Inappropriate RAs in multiple aircraft encounters		✓					
OP03	Split TAs in converging situations					✓		
OP04	Green arc symbology for weakening RAs	✓						
OP05	Nuisance TA aural annunciations at low altitudes	✓			✓			✓
OP06	Unnecessary RAs in 1000-ft level-off geometries	✓			✓		✓	✓
OP08	Operational implications for ACAS due to proposed ground movement control techniques utilising Mode S multilateration			✓			✓	
OP09	TAs for intruders on the ground	✓			✓		✓	✓

Table 6: EMOTION-7 issues

5.3.2. Six safety issues and six operational issues were identified. A detailed analysis was performed for three safety issues and for three operational issues.

5.3.3. A technical solution was proposed by the EMOTION-7 project to rectify issue SA01 (Inappropriate reversal logic operation), and is now referenced as CP112 in the RTCA arena.

5.3.4. A procedural solution was proposed by the EMOTION-7 project to rectify issue OP06 (Unnecessary RAs in 1000ft level-off geometries), and has already been successfully implemented in Paris TMA.

5.3.5. These two rectifications are major deliverables of the EMOTION-7 project, and bring significant benefits in the areas they address.

5.3.6. Following the work done by the EMOTION-7 project, corrective actions were taken to rectify issues SA07 (Discrepancy between altitude quantization and altitude reporting announcement) and OP09 (TAs for intruders on the ground) through ADs and SBs. A SB is also available to rectify issue OP05 (nuisance TA aural annunciations at low altitudes).

5.3.7. A set of recommendations was also developed by the EMOTION-7 project to provide maximal protection against recurrence of issue SA10 (Inappropriate RAs caused by incorrect altitude reporting).

6. Recommendations

6.1. Work on issue SA01 (Inappropriate reversal logic operation, §4.3) should be extended in scope to fully address all of the anomalies identified to date in the CAS reversal logic. The resulting rectification, which will expand the current CP112 solution should be implemented as soon as possible.

6.2. An AD was issued to address issue SA07. A monitoring should be performed in order to verify that this issue has actually disappeared.

6.3. The recommendations developed in the scope of the analysis of issue SA10 (Inappropriate RAs due to incorrect altitude reporting, §4.5) should be thoroughly considered by the appropriate authorities as they would provide maximum protection against recurrence of events reducing the safety performance of ACAS. The corrective actions should be undertaken as soon as possible.

6.4. The benefits resulting from procedural modifications developed to rectify issue OP06 (Unnecessary RAs in 1000ft level-off geometries, §4.6) should be brought to the attention of the ATM authorities and especially those involved in airspace structure design.

6.5. A SB, which addresses issue OP09 (TAs for intruders on the ground, §4.8) was issued. It is recommended that this SB should be implemented, to rectify issue OP09. In addition, the operational monitoring programme should continue to monitor this issue.

6.6. For the same reasons as creating the EMOTION-7 project and because of future changes in the ATM operations, which may impact the TCAS performance, a monitoring programme should be maintained. This would permit to continue identification and investigation of potential TCAS II version 7.0 issues, and to maintain TCAS expertise in Europe. This would also permit to monitor issues identified late, and in particular issue SA11 (RA display misinterpretation).

7. Appendix A: Summary of the EMOTION-7 list of issues

7.1. The status and a detailed description of the issues identified or investigated during the performance of the EMOTION-7 Project is provided in the following tables.

7.2. Safety issues are referenced as SAxx, while operational issues are referenced as OPxx, where xx is the number of the issue.

Name	**Inappropriate reversal logic operation**
	Late reversal RAs or no reversal RAs in coordinated encounters
Reference	SA01a
Type	Safety
Identification date	January 2000
Status	Active - Promotion phase
	WP2 (issue rectification phase) second extension activation
Description	When compared with the previous TCAS II version 6.04a, one significant change included in the TCAS II version 7.0 is the sense reversals that are now permitted in TCAS-TCAS encounters. This change was introduced to cope with changing situations where the original sense has clearly become the wrong thing to do, in particular when one of the pilots decides not to follow its RA.
	The EMOTION-7 Project has identified in early 2000 an area of improvement for this change. This area deals with the late issuance of reversal RAs. Indeed, in about 50% of the late reversal cases extracted from the ICAO ACAS safety standard encounter model, the TCAS contribution is decreasing the vertical separation at CPA.
Severity assessment	The issue has been identified for an encounter set that is representative of operationally realistic scenarios (i.e., late ATC instruction). The EMOTION-7 Project has provided evidences that issue SA01a was indeed happening in operational use (e.g., the July 2nd 2001 event & the February 19th 2002 event).
	A first estimation (mid 2000) has indicated that one reversal RA is expected every two months in the French airspace. A more recent estimation (mid 2002) has shown that the probability for an aircraft subjected to the Phase I mandate to experience a late reversal RA in the European airspace is $4.7\ 10^{-6}$ per flight hour.
Rectification proposal	Change proposal CP112 Modification 1 was developed to address issue SA01a. The main objective of CP112 Modification 1 is to allow an early modelling of sense reversals in TCAS-TCAS encounters, when a manoeuvre opposite to the RA sense is detected onboard one aircraft. CP112 Modification 1 is, therefore, weakening the conditions to model these sense reversals once a specific set of conditions enabling the detection of opposite reaction to the RA sense is met.
	CP112 is significantly improving the safety benefits brought by ACAS. With a standard configuration, CP112 is, indeed, decreasing the risk ratios from 19.0% to 18.2% when considering the European ACAS safety encounter model and from 11.0% to 9.8% when considering the ICAO ACAS safety standard encounter model.
Main deliverable(s)	Analysis report WP1/012/D
	Rectification reports WP2/024/D, WP2/028D & WP2/047/D
	Operational monitoring reports WP3/062/D & WP3/091/D

Name	**Inappropriate reversal logic operation** **Late reversal RAs or no reversal RAs in uncoordinated encounters**
Reference	SA01b
Type	Safety
Identification date	September 2002
Status	Active WP2 (issue rectification phase) second extension activation
Description	Work underway in the CAS logic area has identified in operationally realistic scenarios the potential for failure to initiate reversal logic either in single equipage encounter or similarly in double equipage encounter but with one TCAS II either in stand-by mode or in TA-only mode. The geometries involved are comparable to those already described during the investigation of issue SA01a. In particular, one geometry is for two aircraft flying at the same FL and converging in range with a very late ATC instruction inducing an intruder manoeuvre that thwarts the initial RA issued onboard the own aircraft. This last scenario was already documented in 1995 at the ICAO SICAS Panel level but with TCAS II version 6.04a.
Severity assessment	None at this stage but comparable with issue SA01a
Rectification proposal	None
Main deliverable(s)	issue identification WP5/026/W

Name	**Inappropriate reversal logic operation** **Undesirable reversal RAs in coordinated encounters**
Reference	SA01c
Type	Safety
Identification date	January 2000
Status	Active WP2 (issue rectification phase) second extension activation
Description	The EMOTION-7 Project has identified in early 2000 an area of improvement for TCAS II version 7.0. This area deals with the undesirable issuance of reversal RAs in coordinated encounters when both pilots follow correctly their RAs. Indeed, in some cases not observed with TCAS II version 6.04a, the TCAS contribution is decreasing the vertical separation at CPA.
Severity assessment	The issue has been identified for an encounter set that is representative of operationally realistic scenarios (i.e., altitude bust). However, if the introduction of the reversal mechanism for coordinated encounters in TCAS II version 7.0 can, in some cases, degrade the TCAS II performance, it should noted be that, as already highlighted in several previous studies, the overall safety performance of TCAS II version 7.0 is actually improved when compared with TCAS II version 6.04a.
Rectification proposal	Change proposal CP112 Modification 2 was developed to address issue SA01c. The main objective of CP112 Modification 2 is to forbid the issuance of reversal RAs when they are likely to induce two altitude crossings. CP112 Modification 2 is, therefore, strengthening the conditions for issuing a reversal RA if the aircraft are converging in altitude following a crossing RA issuance. CP112 is solving the identified scenarios without affecting the overall safety performance of TCAS II version 7.0.
Main deliverable(s)	Analysis report WP1/012/D Rectification reports WP2/024/D, WP2/028D & WP2/047/D

Name	**Inappropriate RAs against glider clusters**
Reference	SA02
Type	Safety
Identification date	January 2000
Status	Pending
Description	The issue was identified when preparing the Spring 2001 French glider trial. This experiment was developed after a collision in France between a glider and an Airbus A320. The results of the experiment demonstrate that ACAS will not help in solving the traffic conflicts when small clusters of aircraft operate in close proximity. Even with perfect surveillance, unreliable RAs can be issued. In particular, during glider operations for which a simultaneous threat detection is possible, the management process of the threat list within the CAS logic may lead to inappropriate RAs.
Severity assessment	None
Rectification proposal	None
Main deliverable(s)	issue identification WP5/026/W

Name	**Discrepancy between altitude quantization and altitude reporting capability announcement**
Reference	SA07
Type	Safety
Identification date	December 2000
Status	Closed WP1 (issue analysis phase) completion
Description	TCAS II version 7.0 has introduced improvements to the vertical tracker, which now has the ability to operate more accurately by use of altitude reports quantized to 25 feet rather than 100 feet. However, it is essential that the Mode S transponder replying altitude does not announce 25 foot quantization, when in fact provide 100 foot. This has the potential to significantly degrade the TCAS II version 7.0 safety performance. The issue is that numerous instances have been identified of transponders incorrectly announcing 25 foot altitude quantization.
Severity assessment	The incorrect announcement of 25 foot altitude quantization is seriously debasing the safety performance of TCAS II version 7.0. Whatever the configuration considered, the risk ratios are significantly increased. In the worst case, the logic risk ratio can be multiplied by two. The simulations performed on a European set of actual encounters have also shown that the issue may debase some improvements brought by TCAS II version 7.0. In some cases, the pilot confidence in the system may be affected.
Rectification proposal	A Service Bulletin from one transponder manufacturer had been issued but the EMOTION-7 Project had recommended the issuance of an Airworthiness Directive. Following an FAA investigation of US reports on transponders announcing incorrect altitude quantization, an AD has eventually been issued. A rectification is therefore now in place.
Main deliverable(s)	Analysis report WP1/046/D

Name	**Inappropriate RAs due to incorrect altitude reporting**
Reference	SA10
Type	Safety
Identification date	January 2002
Status	Active WP1 (issue analysis phase) completion
Description	Incorrect altitude reporting is considered as a safety issue with the potential of significantly reducing the benefits brought by ACAS. Indeed, this issue can cause ACAS to issue RAs which increase the risk of collision. This potential is for both the aircraft exhibiting the "incorrect altitude reporting" problem and the ACAS aircraft flying in the vicinity of these aircraft.
Severity assessment	The issue has already been operationally observed in several occasions (e.g., June 1999, December 1999, February 2000, August 2001, December 2001, etc.). Incorrect altitude reporting has occurred with non-Gilham aircraft as well as with Gilham aircraft and a variety of surprising architectures (e.g., both the Mode S and the Russian transponders operating together onboard one IL76). The original requirement (Airworthiness Directive issuances in 1999 & 2000) for dual altitude inputs with active comparator function for Gilham coded altitude inputs only addresses one of the possible failure modes of the system. In addition, the major concern certainly is for GA type intruders: • either due to the issue of low quality reply pulses which are rejected by TCAS; as a consequence, the intruder aircraft is invisible to TCAS; according to a FAA study, it is the case for 3.1% of the GA Mode A/C transponders; • or due to the issue of alticoder shifts; as a consequence, the intruder aircraft is seen at the wrong altitude by TCAS; according to a FAA study, it is the case for 1.5% of the GA Mode A/C transponders. The altitude reporting performance of a majority of GA aircraft seem not to be adequate enough especially when considering the existence of the ACAS worldwide mandate.
Rectification proposal	A list of possible actions for both the airborne side and the ground side has been defined. This list should help the State authorities to take appropriate actions to reduce the risk of a catastrophic event.
Main deliverable(s)	Analysis report WP1/093/D

Name	**RA display misinterpretation**
Reference	SA11
Type	Safety
Identification date	May 2002
Status	Pending
Description	Some recent events (e.g., DLH/DLH & AFR/AFR in 2002) involving Airbus A320 family aircraft have highlighted the possibility of misinterpretation of the RA display (the vertical speed indicator was a vertical tape in these cases). In four cases, the pilot reacted contrary to the RA and not to follow any ATC instruction. This issue has not been identified with Boeing aircraft.
Severity assessment	None
Rectification proposal	None
Main deliverable(s)	issue identification WP5/026/W

Name	**Inappropriate RAs in multiple aircraft encounters**
Reference	SA12
Type	Safety
Identification date	July 2002
Status	Pending
Description	The issue deals with the multi-aircraft logic and is specific to the TCAS II version 7.0. After a multi-threat RA and when one of the threats is no more in an RA status, positive RAs can be issued against the other threat and qualified as preventive (e.g., a preventive “Climb”). This issue is considered as a safety issue because it has an impact on some displays. For instance, an inappropriate RA strength can be displayed to the pilot (e.g., a red arc below 0 fpm without green arc instead of a red arc below 1500 fpm with a green arc just above).
Severity assessment	None
Rectification proposal	None
Main deliverable(s)	issue identification WP5/026/W

Name	**Split TAs in converging situations**
Reference	OP03
Type	Operational
Identification date	January 2000
Status	Closed
Description	The issue consists in TAs occurring once, disappearing and, then, reoccurring later while the aircraft are still converging in range. The issue is related to the way the TA cancellation is dealt within the version 7.0 logic. Such TAs mostly occur in final approach and in cruise flight. The issue has been initially identified during an ACAS and RVSM interaction study performed within the scope of the ACASA Project. In the RVSM airspace, it was computed that the percentage of split TAs with TCAS II version 7.0 should be around 10%. TCAS II version 7.0 generates a larger percentage of split TAs than TCAS II version 6.04a.
Severity assessment	The operational monitoring of a major European airline has shown that some split TAs in converging situations are triggered but, actually, in a lower proportion (5.1%). No pilot complaints have been reported.
Rectification proposal	None
Main deliverable(s)	issue identification WP5/026/W

Name	**Green arc symbology for weakening RAs**
Reference	OP04
Type	Operational
Identification date	January 2000
Status	Closed
Description	The issue was identified in early 2000 by the analysis of a TCAS II version 6.04a event. An aircraft is cleared to descend to FL140. When passing through FL165 with a 1200 fpm descent rate, its TCAS generates a “Descend” RA. To comply with the RA, the pilot increases its rate of descent. Some seconds later, the RA is changed into a weakening “Don’t Climb” RA. In reaction to this second RA, the pilot stops the descent and levels off. Even if the manoeuvre is compliant with the weakening RA, the pilot’s reaction was inappropriate since it is contrary to the ATC clearance and not required by the RA. This reaction is disturbing because it keeps two aircraft in close vertical proximity whereas they could be diverging vertically by complying with ATC clearance while remaining out of the red arc. As the EMOTION-7 Project is not aware of any operators having requested the option to provide altitude alerter data to the TCAS box, this type of reaction might occur more often with TCAS II version 7.0 because of: • the addition of the green arc for weakening RAs; • the new aural annunciation, which requests to “adjust vertical speed”.
Severity assessment	No actual inappropriate reaction to weakening RAs with TCAS II version 7.0 has been observed.
Rectification proposal	None
Main deliverable(s)	issue identification WP5/026/W

Name	**Nuisance TA aural annunciations at low altitudes**
Reference	OP05
Type	Operational
Identification date	August 2000
Status	Closed
Description	The issue has been identified by a feedback from Airbus during the first installations of TCAS II version 7.0. Crews were reporting numerous TAs immediately following takeoff (between 600 ft and 1100 ft) because of intruder aircraft taxiing on the ground.
Severity assessment	None
Rectification proposal	The problem (i.e., the Mode S intruder tracking lasted too long) has been identified and corrected by one TCAS manufacturer. A Service Bulletin has been produced.
Main deliverable(s)	issue identification WP5/026/W

Name	**Unnecessary RAs in 1000-ft level-off geometries**
Reference	OP06
Type	Operational
Identification date	October 2000
Status	Closed WP2 (issue rectification phase) extension completion
Description	The performance of TCAS II in encounters where the aircraft involved are climbing or descending to level-off at a vertical separation of 1000 feet is a matter of concerns for an operational standpoint. Indeed, this type of encounter can cause the generation of “operationally unnecessary” resolution advisories. TCAS II triggers RAs in this type of situation because there are simultaneous rapid vertical and horizontal convergences.
Severity assessment	Quite frequently this type of TCAS II encounter can take place as a result of the airspace design characteristics which are commonly established in terminal airspace. “Hot spots”, areas where RAs frequently occur, can be identified in several major European TMAs (mainly around FL100). When compared with TCAS II version 6.04a, logic version 7.0 improves the compatibility with 1000-ft level-off geometries from an ATC and a flight crew perspective. It is expected that the proportion of unnecessary RAs will decrease, but since the total fleet of TCAS II equipped aircraft has increased, the perception of the number of unnecessary RAs (by both ATC controllers and pilots) is also expected to remain quite high.
Rectification proposal	It is possible that a TCAS II technical solution could be implemented to resolve issue OP06 by use of the selected altitude, or target altitude, on the aircraft to avoid the generation of these “operationally unnecessary” RAs in instances when a level-off manoeuvre is about to be undertaken. However, such a solution would raise issues of integrity and reliability, and, since it would involve some fundamental redesign of the TCAS II, it would be subject to lengthy validation and certification processes. Therefore, it must be viewed as a long term solution only. Therefore, whilst retaining the technical solution as a desirable longer-term objective, the EMOTION-7 Project investigated a resolution for the problem, which could be implemented in the short term, through potential modification of the design of the airspace. Two potential solutions are proposed: • the first consists in separating, at the location of these “hot spots”, the aircraft by 2000 feet instead of the 1000 feet currently in use; • the second consists in delaying the vertical convergence of the aircraft, thereby avoiding simultaneous convergence in both the horizontal plane and the vertical plane. Both these solutions could also be expected to show some improvement in safety in comparison with the current procedures in use.

	It is recognised that there could be concern that either of these proposed solutions could affect airspace capacity. Therefore some preliminary high level analysis was undertaken. The indications from this analysis are very encouraging, but, clearly, this aspect would require some analysis in depth by the appropriate authorities.
Main deliverable(s)	Analysis report WP1/045/D Rectification reports WP2/064/D & WP2/078/D

Name	**Operational implications for ACAS due to proposed ground movement control techniques utilising Mode S multilateration**
Reference	OP08
Type	Operational
Identification date	May 2001
Status	Closed WP1 (issue analysis phase) completion
Description	This potential issue was identified by anticipation of Mode S multilateration plans for A-SMGCS in the major European airports. The operation of multilateration implies that transponders be transmitting even when they are not on the runway. As ACAS relies on transponder's signals to initiate and maintain a surveillance track for each surrounding aircraft, concerns have been raised about a possible adverse influence of multilateration on ACAS operation.
Severity assessment	Some possible interactions between Mode S multilateration and ACAS have been identified in four areas: • reduced transponder availability; • reduced ACAS surveillance range; • additional TAs; and • additional RAs. None were judged significant enough to require further investigations.
Rectification proposal	None
Main deliverable(s)	Analysis report WP1/065/D

Name	**TAs for intruders on the ground**
Reference	OP09
Type	Operational
Identification date	October 2001
Status	Not closed WP1 (issue analysis phase) completion
Description	Traffic advisories against intruders physically on the ground do exist in a sizeable number. For a major European airline, 40% of the TAs are generated below 400 ft radio altitude.
Severity assessment	From an operational point of view, no specific complaint was received from pilots (apart from one in two years time). It is probably because of: • the aural alarm inhibition threshold that is reduced with TCAS II version 7.0; and • the pilot workload during landing and taking off procedures. From a TCAS system point of view, the TCAS aircraft experiences TAs based on data input provided by the intruders, i.e., the TCAS box calculates the advisories using data transmitted by the intruder's transponder. There are a multitude of intruder aircraft behaviour, depending on the airlines operational procedures, on the configuration of its equipment (which is not always the same throughout its fleet) but also on ATC requirements. Unjustified traffic advisories against intruders on the ground may be due either: • to data treatment performed by the own TCAS computer (including the direct forward of newly initiated tracks to the CAS logic); or • to a specific Mode S transponder configuration or behaviour. However, the most probable and obvious reason for unjustified TAs against intruders on the ground is the direct forward of newly initiated tracks to the CAS logic without testing the Air/Ground status. At the moment, there is no obvious operational issue related to pilot acceptance or compatibility with ATC. Nevertheless, RF communications due to intruders on the ground will influence interference limiting computations. This may potentially have safety implications.
Rectification proposal	The Service Bulletin already issued to address the problem of direct forward of newly initiated tracks to the CAS logic without testing the Air/Ground status should be implemented.
Main deliverable(s)	Analysis report WP1/075/D

8. Appendix B: EMOTION-7 working papers

8.1. General documents

Paper Number	Title	Version	Date	Nature
WP1/036	Notes on the OMG Meeting #15	1.0	20-10-00	Working Document
WP1/049	Notes on the OMG meeting #16	1.0	26-03-01	Working Document
WP2/058	EMOTION-7 status report	1.1	06-06-01	Working Document
WP1/060	Notes on the OMG meeting #17	1.0	12-07-01	Working Document
WP1/077	Notes on the OMG meeting #18	1.0	26-02-02	Working Document
WP1/092	Notes on the OMG meeting #19	1.0	03-07-02	Working Document
WP1/096	Notes on the OMG meeting #20	1.0	23-09-02	Working Document

8.2. Issue SA01

Paper Number	Title	Version	Date	Nature
WP1/008	Issue SA01 (slides for RTCA meeting)	1.0	18-02-00	Informal Note
WP1/011	Notes on the OMG Meeting #14	1.0	11-04-00	Working Document
WP1/012	Issue analysis report – issue SA01 – Inappropriate reversal logic initiation in co-ordinated encounters	1.0	13-04-00	Deliverable
WP2/024	Issue rectification report – issue SA01 – Inappropriate reversal logic initiation in co-ordinated encounters	1.1	13-10-00	Deliverable
WP2/025	Notes on the 12 September Meeting with the FAA on issue SA01	1.0	13-09-00	Working Document
WP2/027	Effort required for WP-2 extension on issue SA01	1.0	16-10-00	Working Document
WP2/028	RTCA CP SA01	1.1	25-10-00	Deliverable
WP2/040	Comments on CP112 FAA assessment (EMOTION-7 issue referenced SA01)	1.0	13-11-00	Informal Note
WP2/042	Progress report – issue SA01 extension – Inappropriate reversal logic initiation in co-ordinated encounters	1.0	21-12-00	Deliverable
WP2/047	Study extension – issue SA01 – Inappropriate reversal logic initiation in co-ordinated encounters	1.0	21-03-01	Deliverable
WP3/062	Analysis of a TCAS II event with late reversal RAs in a co-ordinated encounter	1.0	20-09-01	Deliverable
WP3/074	Complementary simulations on the first operational occurrence of issue SA01	1.0	29-10-01	Working Document

WP3/091	Issue SA01 –Probability of occurrence of late reversal RAs	1.1	14-06-02	Deliverable
WP2/106	Reversal logic of TCAS II version 7.0 – Scope analysis of possible additional rectifications	1.0	27-11-02	Deliverable

8.3. Issue SA07

Paper Number	Title	Version	Date	Nature
WP1/046	Issue analysis report - issue SA07 - Discrepancy between altitude quantization and altitude reporting capability announcement	1.0	05-03-01	Deliverable

8.4. Issue SA10

Paper Number	Title	Version	Date	Nature
WP1/090	Issue SA10 analysis – Work content proposal	1.0	30-04-02	Informal Note
WP1/093	Issue analysis report – issue SA10 – Inappropriate RAs due to incorrect altitude reporting	2.1	10-12-02	Deliverable

8.5. Issue OP06

Paper Number	Title	Version	Date	Nature
WP1/041	Issue analysis report – issue OP06 – Nuisance RAs in 1000 ft level-off geometries - Interim report	1.1	13-12-00	Deliverable
WP1/045	Issue analysis report - issue OP06 - Nuisance RAs in 1000ft level-off geometries	2.0	22-02-01	Deliverable
WP2/064	Issue rectification report - issue OP06 - Nuisance RAs in 1000ft level-off geometries	1.0	19-10-01	Deliverable
WP2/078	Study extension – issue OP06 – the 1000-ft level-off procedure	2.0	24-04-02	Deliverable

8.6. Issue OP08

Paper Number	Title	Version	Date	Nature
WP1/065	Issue analysis report - issue OP08 - Operational implications for ACAS due to proposed ground movement control techniques utilising Mode S multilateration	2.0	20-12-01	Deliverable

8.7. Issue OP09

Paper Number	Title	Version	Date	Nature
WP1/075	Issue analysis report – issue OP09 – TAs for intruders on the ground	2.0	25-04-02	Deliverable

8.8. EMOTION-7 monitoring

Paper Number	Title	Version	Date	Nature
WP3/003	WP-3 progress report	1.0	17-01-00	Working Document
WP3/004	Issue identification report #1	1.0	17-01-00	Deliverable
WP3/010	Collection of airborne data for the early monitoring of TCAS II version 7.0	1.0	23-03-00	Working Document
WP3/013	Notes on the 24 March meeting on BA & Sofréavia co-operation	1.0	28-03-00	Working Document
WP3/014	WP3 Description and Results (slides for BA meeting)	1.0	23-03-00	Informal Note
WP3/015	Operational and technical description of the British Airways and Sofréavia co-operation	1.3	05-07-00	Working Document
WP3/021	WP-3 second progress report	1.0	12-05-00	Working Document
WP3/023	Analysis of QAR and radar data for Airbus Transport International RAs (number 16, 17, 18 and 19)	1.0	05-06-00	Working Document
WP3/034	WP-3 third progress report	1.0	20-10-00	Working Document
WP3/035	Statistical analysis of BA ASRs	1.0	20-10-00	Working Document
WP3/037	Issue identification report #2	1.1	25-10-00	Deliverable
WP3/043	Analysis of RAs generated for 1000-ft level off encounters	1.0	11-01-01	Working Document
WP3/048	WP-3/BA fourth progress report	1.0	02-04-01	Working Document
WP3/056	WP-3/Airbus Transport International fourth progress report	1.0	02-04-01	Working Document
WP3/062	Analysis of a TCAS II event with late reversal RAs in a co-ordinated encounter	1.0	20-09-01	Deliverable
WP3/063	WP-3/Airbus Transport International fifth progress report	1.0	19-10-01	Working Document
WP3/066	WP-3/BA fifth progress report	1.0	19-10-01	Working Document
WP3/074	Complementary simulations on the first operational occurrence of issue SA01	1.0	29-10-01	Working Document
WP3/076	EMOTION-7 ACAS Monitoring for Years 2000 & 2001	1.0	26-02-02	Working Document
WP3/079	WP-3/Airbus Transport International sixth progress report	1.0	09-04-02	Working Document
WP3/080	WP-3/BA sixth progress report	1.0	09-04-02	Working Document
WP3/091	Issue SA01 –Probability of occurrence of late reversal RAs	1.1	14-06-02	Deliverable
WP3/095	EMOTION-7 monitoring seventh progress report	1.0	23-09-02	Working Document

8.9. EMOTION-7 Steering Committees

Paper Number	Title	Version	Date	Nature
WP4/016	Item 3: Introduction to EMOTION-7 Project	1.0	12-04-00	Deliverable
WP4/017	Item 8: Presentation of issue SA01 severity assessment	1.0	09-05-00	Deliverable
WP4/018	Item 7: Presentation of identified issues	2.0	12-05-00	Deliverable
WP4/019	Item 4: EMOTION-7 progress report	1.0	05-05-00	Deliverable
WP4/029	Item 5: EMOTION-7 progress report	1.1	25-10-00	Deliverable
WP4/030	Item 7: Potential EMOTION-7 issues	1.1	25-10-00	Deliverable
WP4/031	Item 8: SA01 progress - Logic rectification	1.1	25-10-00	Deliverable
WP4/032	Item 6: OSCAR presentation	1.1	25-10-00	Deliverable
WP4/050	Item 4: EMOTION-7 progress report	2.0	09-05-01	Deliverable
WP4/051	Item 5: List of potential issues	2.0	09-05-01	Deliverable
WP4/052	Item 6: SA01 - issue rectification	2.0	09-05-01	Deliverable
WP4/053	Item 8: OP06 - issue analysis	2.0	09-05-01	Deliverable
WP4/054	Item 9: SA07 - issue analysis	2.0	09-05-01	Deliverable
WP4/067	Item 4: EMOTION-7 progress report	2.0	23-10-01	Deliverable
WP4/068	Item 5: List of potential issues	2.0	23-10-01	Deliverable
WP4/069	Item 6: SA01 – analysis of a real event	2.0	23-10-01	Deliverable
WP4/070	Item 7: OP06 - issue rectification	2.0	23-10-01	Deliverable
WP4/071	Item 8: OP08 - issue analysis	2.0	23-10-01	Deliverable
WP4/082	Item 4: EMOTION-7 progress report	1.0	10-04-02	Deliverable
WP4/083	Item 5: List of potential issues	1.1	17-04-02	Deliverable
WP4/084	Item 6: EMOTION-7 monitoring	1.1	17-04-02	Deliverable
WP4/085	Item 8: SA01 – status report on FAA tech centre work	1.1	17-04-02	Deliverable
WP4/086	Item 9: OP06 – issue rectification, study extension	1.1	17-04-02	Deliverable
WP4/087	Item 10: OP09 - issue analysis	1.1	17-04-02	Deliverable
WP4/098	Item 4: EMOTION-7 progress report	2.0	08-10-02	Deliverable
WP4/099	Item 5: List of potential issues	2.0	08-10-02	Deliverable
WP4/100	Item 6: EMOTION-7 monitoring	2.0	08-10-02	Deliverable
WP4/101	Item 7: SA01 – status report	2.0	08-10-02	Deliverable
WP4/102	Item 8: SA10 – issue analysis	2.0	08-10-02	Deliverable
WP4/103	Item 9: OP06 – operational feedback	2.0	08-10-02	Deliverable

8.10. WP-5 : Project management

Paper Number	Title	Version	Date	Nature
WP5/001	Project Management Plan	3.0	09-01-02	Working Document
WP5/002	Detailed description of the tasks to be undertaken by the Sub-Contractor	1.0	01-10-99	Working Document
WP5/005	Notes on the Kick Off Meeting	2.0	11-02-00	Working Document
WP5/006	Notes on the 9 & 10 February Meeting	1.0	18-02-00	Working Document
WP5/007	EMOTION-7 Project (slides for RTCA meeting)	1.0	18-02-00	Informal Note
WP5/009	The EMOTION-7 Project (SICASP paper)	1.0	16-03-00	Informal Note
WP5/020	Progress report	1.0	10-05-00	Deliverable
WP5/022	Notes on the Progress Meeting #2	1.0	26-05-00	Working Document
WP5/026	List of potential issues	12.0	15-10-02	Working Document
WP5/033	Progress report	1.0	20-10-00	Deliverable
WP5/038	Notes on the Progress Meeting #3	1.0	27-10-00	Working Document
WP5/039	Progress report to APSG on EMOTION-7 activities for year 2000	1.1	06-11-00	Working Document
WP5/044	Progress report to APSG on EMOTION-7 activities since November 2000	1.0	13-02-01	Working Document
WP5/055	Progress report - Progress meeting #4	1.0	28-03-01	Deliverable
WP5/057	Notes on the Progress Meeting #4	1.0	28-05-01	Working Document
WP5/059	Progress report to APSG on EMOTION-7 activities since June 2001	1.1	18-06-01	Working Document
WP5/061	Progress report to APSG on EMOTION-7 activities since September 2001	1.0	31-08-01	Working Document
WP5/072	Progress report - Progress meeting #5	1.0	19-10-01	Deliverable
WP5/073	Notes on the Progress Meeting #5	1.0	26-10-01	Working Document
WP5/081	Progress report - Progress meeting #6	1.0	09-04-02	Deliverable
WP5/088	Notes on the Progress Meeting #6	1.0	23-04-02	Working Document
WP5/089	Progress report to APSG #09 on EMOTION-7 activities between September 2001 and April 2002	1.0	24-04-02	Working Document
WP5/094	Status of the EMOTION-7 list of issues	2.0	15-10-02	Working Document
WP5/097	Progress report - Progress meeting #7	1.0	23-09-02	Deliverable
WP5/104	Progress report to APSG #10 on EMOTION-7 activities between April 2002 and October 2002	1.0	10-10-02	Working Document
WP5/105	Notes on the Progress Meeting #7	1.0	17-10-02	Working Document
WP5/107	EMOTION-7 Final Report	2.0	24-01-02	Deliverable
WP5/108	Final list of actions and meetings	1.0	12-12-02	Working Document

9. Appendix C: External references

Reference	Title	Author	Date
FAA1	FAA William J. Hughes Technical Center final Analysis of EMOTION-7 issue SA01 Working Group A, Langen, Germany	Kathryn Ciaramella	01/10/2002
FAA2	Memorandum – Information: Guidance Regarding latent failures of altimeters	FAA	22/02/2002
FAA3	A field study of Transponder Performance in General Aviation aircraft – DOT/FAA/CT-97/7	FAA/Technical center	12/2002
FAA4	FAA William J. Hughes Technical Centre Final Analysis of EMOTION-7 issue SA01 – SCRSP/WGA/ACASSG Langen	Kathryn Ciaramella	06/2002
SIC1	Implementation of a new Altitude Tracker for TCAS II – SICASP/WG2/WP447	Roland Lejeune	11/10/1994
ACA1	Mode S Monitoring for ACASA – Final report – Version 1.0 – ACASA/WP-7.3/143	Mike Sharples and Yvonne Etem	21/11/2000
ACA2	European Encounter Model. Specifications and Probability tables – ACASA/WP1/186D	CENA/Sofréavia&Qinetiq	20/07/2001
SCR1	Analysis of TCAS Transition Program (TTP) Airline Recorded Data – TCAS II Version 7 – Calendar Year 2001 (SCRSP/WGA/IP/A/2-51)	Jean Petruzzi	09/2001
SCR2	Analysis of TCAS Transition Program (TTP) Airline Recorded Data – TCAS II Version 7 – Calendar Years 2000/2001 (SCRSP/WGA/IP/A/3-80)	Jean Petruzzi	01/2002
MOPS	Minimum Operational Performance Standards for Traffic Alert and Collision Avoidance System II (TCAS II) Airborne Equipment Volume I RTCA/DO-185A	RTCA	11/1997
QUAT	ATC quarterly Volume 6 Number 4 - Contribution of TCAS II Version 7 in the European airspace	Thierry Arino and Francis Casaux	1998
SARPS	International standards and recommended practices: aeronautical communications, Annex 10 to the Convention on Civil Aviation - volume IV, Surveillance radar and collision avoidance systems, second edition	ICAO	07/1998
ABUL	ACAS II bulletin - Safety flash – Follow the RA !	EUROCONTROL ACAS Programme	07/2002

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