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WORK PACKAGE 8

Final Report on
Acceptability and efficiency of lateral collision avoidance manoeuvres

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Abstract

The aim of this study was to assess the acceptability and efficiency of ACAS Horizontal Resolution Advisories (HRAs) from technical and operational points of view.

Keywords

ACAS TCAS RVSM TA RA

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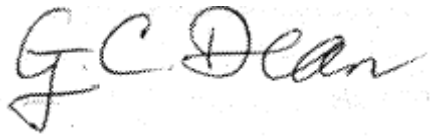
ACASA Project Manager	 Garfield Dean	4 March 2002
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WP8: Final Report on the acceptability and efficiency of lateral collision avoidance manoeuvres

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Executive summary

The aim of this study was to assess the acceptability and efficiency of ACAS Horizontal Resolution Advisories (HRAs) from technical and operational points of view.

Efficiency Assessment

Firstly, real encounters taken from a European data-base were analysed with the expertise of a controller so as to choose the best sense for a horizontal manoeuvre. The OSCAR test bench version 4.3 was run on those encounters in order to simulate the horizontal manoeuvres. Horizontal deviations and gains of separation at CPA were computed to assess the efficiency of the manoeuvres with single and double equipage.

Example encounters were developed where:

a horizontal manoeuvre would be inefficient

a vertical manoeuvre is a poor choice, yet the encounter can be well solved by a horizontal manoeuvre

a horizontal manoeuvre makes the encounter worse.

The results indicate that the contributions of the horizontal manoeuvres in term of supplementary horizontal separation at CPA seems to be low when compared to the probable induced deviations, especially when only one aircraft manoeuvres. However, the separations achieved are sufficient to avoid a collision.

It seems that horizontal manoeuvres would not replace vertical manoeuvres. However, horizontal manoeuvres could make the TCAS more efficient in some specific situations, such as crossing situations that can result in reversal RAs

Operational Assessment

A questionnaire was developed using example encounters described above, and simulations of pilot displays for HRAs.

9 pilots and 12 controllers were interviewed.

The opinions and attitudes of the pilots regarding horizontal resolution advisories is clearly positive. The opinions and attitudes of the controllers are far more diverse; there is not one unique and clear tendency. The format of the study and the structure of the interview have been useful and well accepted in the case of the pilots. Unfortunately, the same comment cannot be made in the case of the controllers. The presentation was not ideal for controllers, and their current views on TCAS could have prevented them from considering horizontal RAs dispassionately.

List of Acronyms

ACAS	Airborne Collision Avoidance System
ACASA	Airborne Collision Avoidance Systems Analysis
ATC	Air Traffic Control
CPA	Closest Point of Approach
FL	Flight Level
FMS	Flight Management System
HMD	Horizontal Miss Distance
HRA	Horizontal Resolution Advisory
MOPS	Minimum Operational Performance Standard
NM	Nautical Miles
NMAC	Near Mid Air Collision
RA	Resolution Advisory
SARPS	Standard and Recommended Practices
SICASP	SSR Improvements and Collision Avoidance Systems Panel
TA	Traffic Advisory
TCAS	Traffic alert and Collision Avoidance System
VMD	Vertical Miss Distance

1 Introduction

1.1 Background and context

1.1.1 Three levels of Airborne Collision Avoidance System (ACAS) have been defined by the International Civil Aviation Organisation (ICAO). ACAS I is an airborne traffic awareness system, that provides Traffic Advisories (TAs) only. ACAS II has ACAS I functions, and also can provide Resolution Advisories (RAs) for collision avoidance. These advisories are vertical manoeuvres only. ACAS III can provide ACAS II functions and Horizontal Resolution Advisories (HRAs) too.

1.1.2 At present only ACAS I and ACAS II have complete performance standards defined for them and have equipment that meets these standards. Although ACAS II provides an effective collision avoidance system, there are nevertheless circumstances where it would be desirable to improve its performance. It is conceivable that HRAs could provide this improvement. On the other hand, nuisance RAs and vertical manoeuvres already cause some disruption to ATC and pilots, and HRAs may exacerbate these problems.

1.1.3 Since the development and subsequent mothballing of the TCAS III system, there has been no serious attempt to develop ACAS III capabilities. Nevertheless, some researchers in Airborne Separation Assurance Systems (ASAS) are considering horizontal manoeuvres for collision avoidance.

1.1.4 For any such development to take place, it should be compatible with the existing ACAS II system performance and be acceptable both technically and operationally. To help inform the debate, CENA conducted a preliminary simulation of horizontal advisories and assessed their effectiveness [Ari97]. This was presented to the SICASP ('SSR Improvements and Collision Avoidance Systems Panel') WG 2 ('Working Group') members at the Honolulu meeting.

1.1.5 The purpose of this study was to build on this previous work and investigate the acceptability of an ACAS III both technically and to pilots and controllers. Ultimately this should help to establish or refute the feasibility of HRAs and if necessary help to define performance standards, before any system development begins.

1.2 ACASA project

1.2.1 The TEN ('Trans European Network') / ACASA ('Airborne Collision Avoidance Systems Analysis') project investigates several areas related to ACAS II operations in Europe [WP001].

1.2.2 The ACASA/WP8 ('Work Package') was dedicated to investigating the operational acceptability and technical effectiveness and efficiency of horizontal RAs.

1.2.3 The ACASA partners involved in this study were:

CENA ('Centre d'Etudes de la Navigation Aérienne') and Sofreavia: responsible for investigating the efficiency of horizontal RAs.

QinetiQ: responsible for investigating the acceptability to pilots and controllers.

1.3 Objectives

1.3.1 The objective of this study were:

To assess the efficiency of Horizontal Resolution Advisories (HRAs) as a means of collision avoidance.

To assess the acceptability of HRAs to pilots and controllers.

To assist the development of SARPs ('Standards And Recommended Practices'), as required.

1.3.2 Implicitly the work was testing the hypothesis "Horizontal RAs are technically and operationally acceptable".

1.4 Work Breakdown

1.4.1 Originally 3 tasks were forseen:

simulation of horizontal advisories and effectiveness assessment,

support to the development of ACAS III Performance SARPS.

design controller and pilot questionnaires, conduct interviews and assess the results.

1.4.2 During the course of the ACASA project, the urgency and necessity to develop ACAS III Performance SARPS diminished. The second task was not carried out, so that resources could be allocated to higher priority work that was not initially foreseen in the project plan.

1.5 Structure of the document

1.5.1 Two horizontal RA studies planned for WP8 of the ACASA project have been completed. This final report is based on the results of both of them

1.5.2 The technical evaluations of horizontal RAs are described in section 2. The third section presents the studies into pilot and controller evaluation of horizontal RAs. This report ends with some concluding remarks about the study and recommendations for future work on horizontal resolution advisories.

2 Technical Assessment of Horizontal RAs.

This section summarises the CENA/Sofreavia report on the efficiency of horizontal RAs [WP107D].

2.1 Organisation of the study

2.1.1 Two types of encounters were used in the study:

Approximately 500 encounters from the European data-base;

Artificial encounters created with the encounter generator of OSCAR.

2.1.2 To perform the study, a controller decided for each encounter whether a left or a right manoeuvre should be selected. It was initially decided that only horizontal advisories would be considered.

2.1.3 However, in some rare encounters (less than 5%), from the controller point of view, an horizontal manoeuvre is not the best choice. Those encounters can not be solved with horizontal manoeuvres because the RAs are generated too late to be efficient.

2.1.4 Simulations were made with both the TCAS II logic Version 7 thresholds and the TCAS II logic Version 6.04a thresholds on those real encounters, using the OSCAR ('Off-line Simulator for Collision Avoidance Resolution') test bench to model horizontal manoeuvres.

2.1.5 Horizontal manoeuvres were simulated with parameters in accordance with the initial studies on ACAS III.

2.2 Results on the European data-base of real encounters

2.2.1 The contribution of the horizontal manoeuvres, in term of supplementary horizontal separation at CPA, seems to be low when compared to the probable induced deviations.

2.2.2 When both aircraft manoeuvre, the results in term of efficiency are nearly twice better than when only one aircraft manoeuvres, with lower deviations and higher gains at CPA.

2.2.3 TCAS II logic Version 7.0 thresholds seem to perform better than TCAS II logic Version 6.04a thresholds in term of efficiency. However, the gains of separations are higher with TCAS II logic Version 6.04a

2.2.4 Nearly 5% of the total amount of encounters in the European encounter data-base are not well solved by horizontal manoeuvres in term of separation. A real encounter of this type is shown in the CENA/ Sofreavia final report [WP107D].

2.3 Results for encounters not well solved by vertical manoeuvres

2.3.1 The efficiency of horizontal manoeuvres was assessed with a subset of encounters that are not well solved by vertical manoeuvres.

2.3.2 On this subset of encounters, the horizontal manoeuvres result in a mean gain of separation at CPA of 0.05NM and a mean deviation of 0.4 NM. So horizontal manoeuvres do not seem to be more efficient than vertical manoeuvres on the worst encounters of the European database.

2.3.3 Also, theoretical encounters were generated using the ICAO standard encounter model. Encounters better solved in the horizontal plane were selected. After analysis, horizontal manoeuvres were considered interesting for geometries where a crossing RA will be chosen. They could avoid some reversal RAs.

2.4 Summary of technical assessment

2.4.1 The results indicate that the contributions of the horizontal manoeuvres in term of supplementary horizontal separation at CPA seems to be low when compared to the probable induced deviations, especially when only one aircraft manoeuvres. However, the separations achieved are sufficient to avoid a collision.

2.4.2 It seems that horizontal manoeuvres would not replace vertical manoeuvres. However, horizontal manoeuvres could make the TCAS more efficient in some specific situations, such as crossing situations that can result in reversal RAs.

2.4.3 TCAS II logic version 6.04a gives the best results in term of separation, but the price in term of deviation is important and results in lower efficiency. TCAS II logic Version 7.0 induces lower deviations and better efficiencies.

3 Operational Evaluation of Horizontal RAs.

This section summarises the QinetiQ report on the efficiency of horizontal RAs [WP166D].

3.1 Methodology

3.1.1 21 interviews were conducted with 9 pilots and 12 controllers. All the interviewees had operational experience of TCAS.

3.1.2 The interviews themselves followed the following structure:

Explore the interviewee's experience of and opinion of TCAS

Discuss operational acceptability of new technology – in particular what is efficiency and what criteria make a system operationally acceptable or not

Show simulations. It was emphasised that the aim of the study was not an HMI investigation. For controllers several encounters simulating horizontal RAs were shown to the interviewee. For pilots two dynamic simulations of a realistic display of horizontal resolution advisories were shown to the interviewee. Other static displays were also shown. Pilots were invited to think aloud on what they saw.

Based on what he had seen during the simulations, the interviewee was asked to assess the acceptability of horizontal RAs. Suggestions for possible improvements of horizontal RAs were also discussed.

Interviewer summarised the main points of the interview. The interviewee was asked to score to what extent horizontal RAs satisfy (or not) the acceptability and efficiency criteria defined by the interviewee during the second part of the interview.

3.2 Results

3.2.1 The opinions and attitudes of the pilots regarding horizontal RAs is clearly positive. Also, the format of the study and the structure of the interview were useful and well accepted by pilots.

3.2.2 The opinions and attitudes of the controllers are far more diverse. There is not one unique and clear tendency. Unfortunately, controllers had a number of problems with the study and interviews:

TCAS is not a tool for the controller (and therefore hard to judge its usefulness)

Although not clearly stated, TCAS is associated with the idea that the controller has made a mistake.

According to them, the realism of the simulations used for this study did not allow the controllers to really assess the acceptability of horizontal resolution advisories.

Some controllers had very strong opinions on TCAS. These opinions may have prevented them from considering horizontal RAs dispassionately.

3.3 Recommendation

3.3.1 Another study should be made to assess controllers' opinions and reactions on horizontal RAs.

This study would have to be specifically designed for them

If simulations are to be used, they must involve surrounding traffic. If this is not possible, simple but detailed descriptions of scenarios would be preferable.

4 Conclusions

4.1 Technical study

4.1.1 With horizontal manoeuvres, the supplementary horizontal separation at CPA seems to be low when compared to the probable induced deviations, especially when only one aircraft manoeuvres. However, the separations achieved are sufficient to avoid a collision.

4.1.2 Horizontal manoeuvres would not replace vertical manoeuvres. However, horizontal manoeuvres could make the TCAS more efficient in some specific situations.

4.1.3 Although TCAS II logic version 6.04a gives the best results in term of separation, TCAS II logic Version 7.0 induces lower deviations and has better efficiencies.

4.2 Operational Evaluation

4.2.1 The opinions and attitudes of the pilots regarding horizontal RAs is clearly positive.

4.2.2 Controllers had a number of problems with the study and interviews. Their opinions and attitudes are far more diverse.

4.3 Hypothesis

4.3.1 The hypothesis that “Horizontal RAs are technically and operationally acceptable” was neither proved nor disproved.

5 Recommendation

5.1.1 If further development of horizontal RAs is planned then another study should be made to assess controllers' opinions and reactions to horizontal RAs.

6 References

6.1 External references

[Ari97] SICASP/WG2/WP2/656 – 'Preliminary Contribution for the ACAS III Performance SARPS' T. Arino & F.Casaux, 1997.

6.2 ACASA references

[WP001] ACASA/WP10/001 – 'European TEN Study – ACAS Analysis – Work Plan' Eurocontrol, Version 1.5.0, 19 June 2000.

[WP107D] ACASA/WP8.1/107D – 'Acceptability of ACAS horizontal advisories' CENA, Version 2.0, 20 June 2000.

[WP166D] ACASA/WP8.3/166D – 'Acceptability of ACAS horizontal resolution advisories: The view of pilots and controllers' QinetiQ, Version 1.0, 29 March 2001.

7 Annexes

Annex A:WP-8.1: Acceptability of ACAS horizontal advisories

Annex B: WP-8.3: The view of pilots and controllers

ACAS PROGRAMME

ACASA PROJECT

Annex A to
Work Package 8

Final Report on

Acceptability and Efficiency of Lateral Collision Avoidance Manoeuvres

Edition 1.0
March 2002

Annex A to Work Package 8

Final Report on Acceptability and Efficiency of lateral collision avoidance manoeuvres

Version 1.1 - March 2002

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WP-8.1

Acceptability of ACAS horizontal advisories

Prepared by Bernard Hasquenoph and Stéphan Chabert

Summary

The aim of this study is to assess the efficiency of horizontal manoeuvres for a collision avoidance purpose.

Firstly, real encounters taken from a European data-base were analysed with the expertise of a controller so as to choose the best sense for an horizontal manoeuvre. The OSCAR test bench version 4.3 was run on those encounters in order to simulate the horizontal manoeuvres. Horizontal deviations and gains of separation at CPA were computed to assess the efficiency of the manoeuvres with single and double equipage.

Secondly we show one example of encounter for which an horizontal manoeuvre would be inefficient.

Thirdly, we show how an encounter can be well solved by an horizontal manoeuvre when the vertical manoeuvre is a poor choice.

In addition, we present one example of horizontal manoeuvre which makes things worse.

Annexe A presents a theoretical data-base of encounters which was built to simulate the most constraining cases seen during the study of real encounters. Deviations and horizontal separations at CPA are provided on these encounters.

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1 Introduction

1.1.1 At the Honolulu SICASP meeting in October 1997, [1] reported that it was possible to assess the deviations induced by horizontal RAs of ACAS III without implementing an ACAS III logic. In fact, it is possible to provide figures concerning horizontal deviations with the use of TCAS II logic.

1.1.2 According to the ACASA work plan, the current study is using the hypothesis proposed in [1].

2 Organization of the study

2.1.1 Two types of encounters were used in the study:

- Encounters from the European data-base;
- Artificial encounters created with the encounter generator of OSCAR.

2.1.2 To perform the study, a controller decided for each encounter whether a left or a right manoeuvre should be selected. It was initially decided that only horizontal advisories would be considered.

2.1.3 However, in some rare encounters (less than 5%), from the controller point of view, an horizontal manoeuvre is not the best choice. Those encounters can not be solved with horizontal manoeuvres because the RAs are generated too late to be efficient.

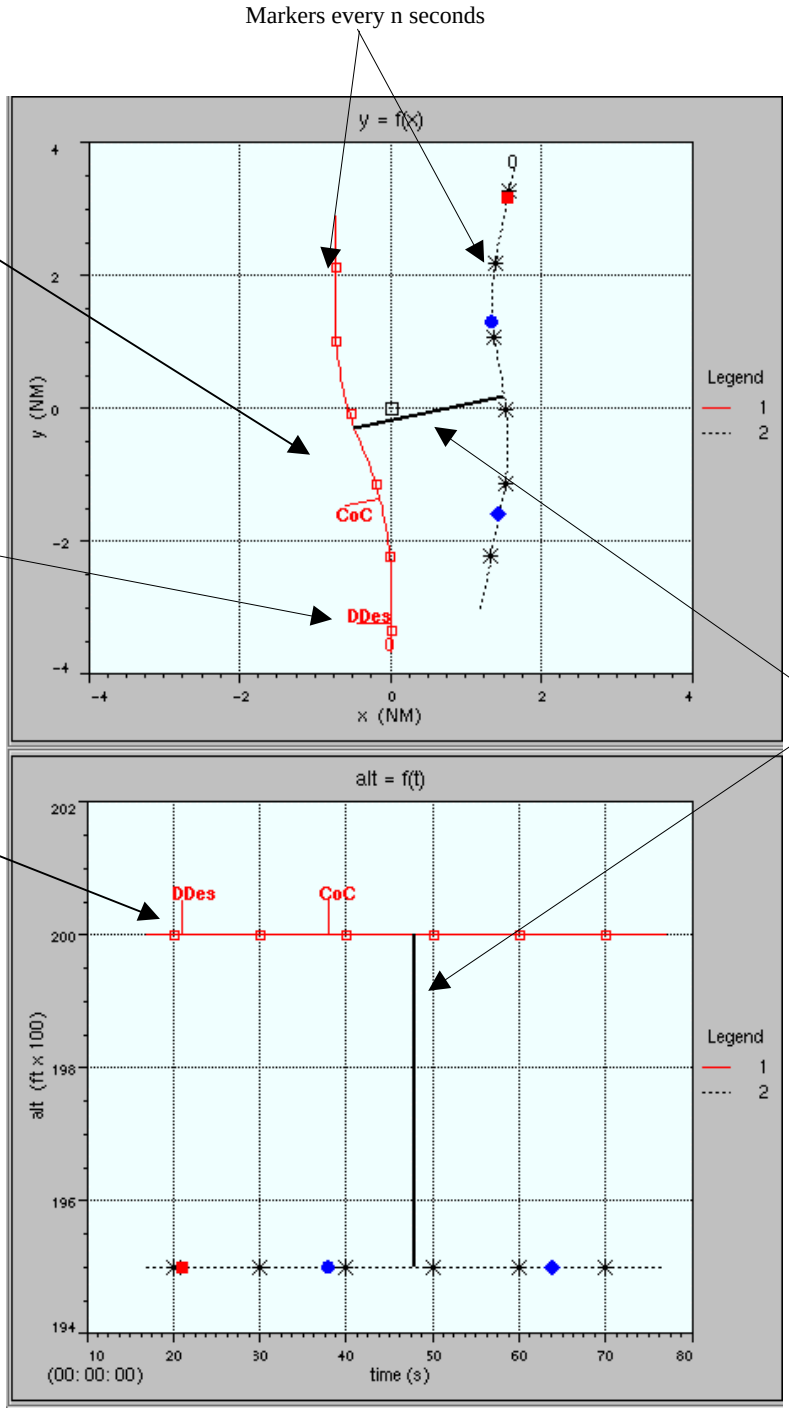
2.1.4 Simulations were made with both the TCAS II logic Version 7 thresholds and the TCAS II logic Version 6.04a thresholds on those real encounters, using the OSCAR test bench version 4.3 to model horizontal manoeuvres.

2.1.5 Horizontal manoeuvres were simulated with the following parameters in accordance with the initial studies on ACAS III:

- The pilot response is initiated 5.0s after the first RA;
- The maximum bank angle is equal to 25 degrees (15 degrees when own altitude above ground level is lower than 2500ft);
- The roll rate (to reach the maximum bank angle) is 5deg/s;
- The turn rate expected can never exceed 3deg/s;
- The pilot initiates a return to the original clearance 2.5s after the clear-of-conflict.

2.1.6 With TCAS II logic Version 7.0, both the 100ft tracker and the 25ft tracker were simulated, but we only present the results obtained with the 100ft tracker as those obtained with the 25ft tracker are very close.

2.1.7 The most relevant results are presented by screen dumps of OSCAR windows. The following information is displayed:


Markers every n seconds
Horizontal trajectories (X,Y) of the aircraft involved in the encounter, beginning at 'O'
RA
Instant of CPA
Altitudes function of the time (alt=f(t)), correlation with the horizontal trajectories through the markers on the trajectory
y = f(x)
y (NM)
x (NM)
O
CoC
DDes
Legend
1
2
alt = f(t)
alt (ft x 100)
time (s)
(00: 00: 00)

3 Presentation of the method

3.1.1 This part presents the principle of the method proposed by CENA.

3.1.2 Figure 1 presents the original flight path of two aircraft in the horizontal plane. The encounter is extracted from the European data-base of real encounters. Figure 2 presents the effect of a left turn manoeuvre chosen by a controller.

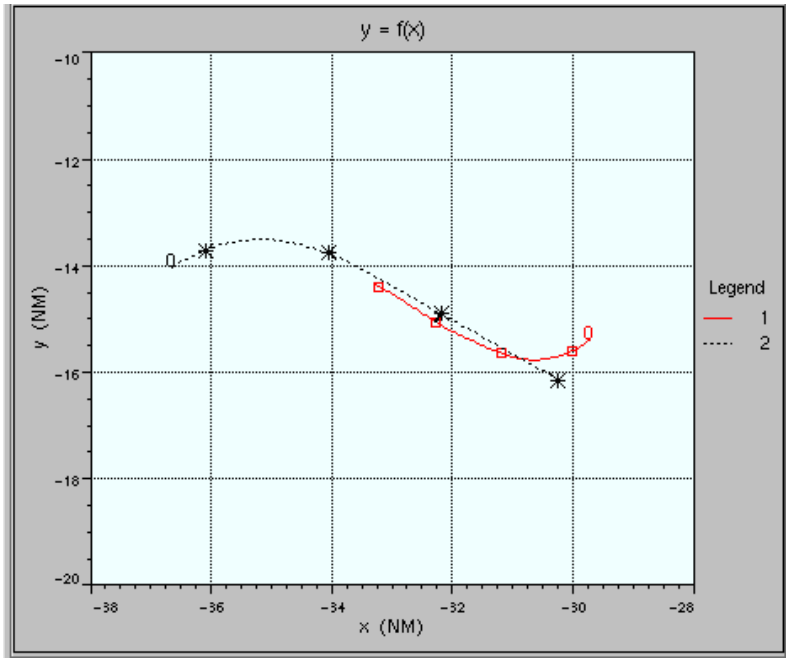


Figure 1: Original flight path

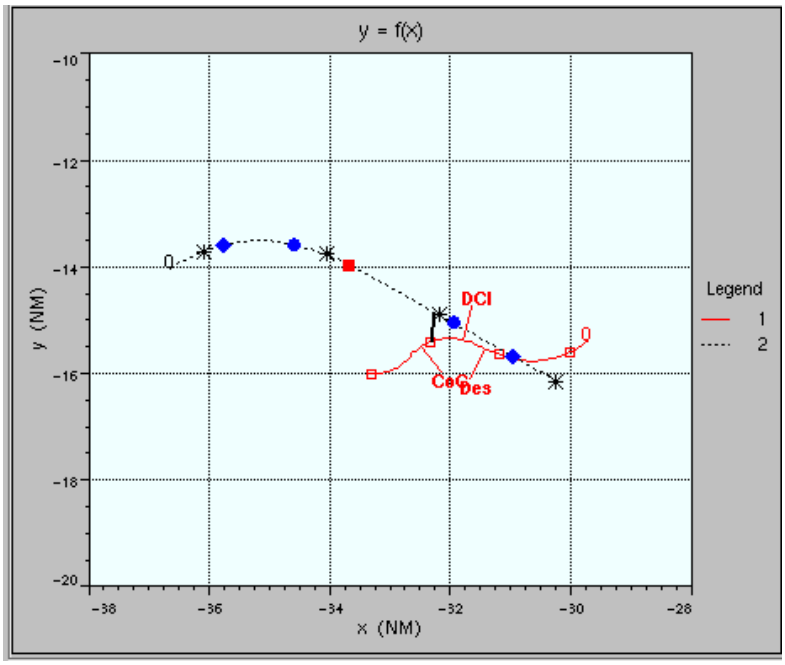


Figure 2: Aircraft one manoeuvres

3.1.3 The separation at CPA is increased from 0.18NM to 0.53NM. The manoeuvre induces an horizontal deviation (measured when it is the greatest) of 1.65NM. As a measure of efficiency of the manoeuvre, we compute the following ratio:

$$efficiency = \frac{gain}{deviation}$$

3.1.4 The left manoeuvre results in an efficiency of 21%. In comparison, the average efficiency of vertical manoeuvres is equal to 55% according to [1].

3.1.5 Figure 3 presents the same encounter, but this time, aircraft two manoeuvres.

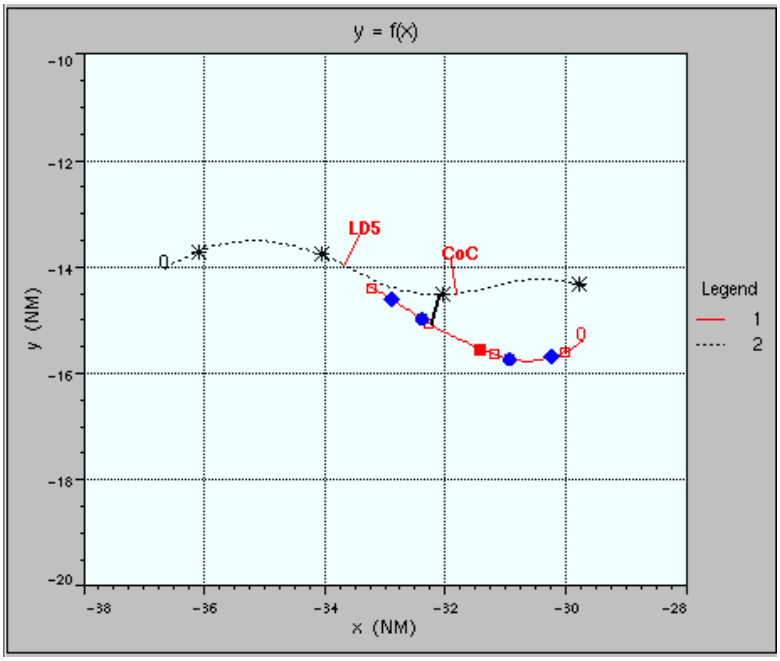


Figure 3: aircraft two manoeuvres

3.1.6 This time the separation at CPA increases from 0.18NM to 0.58NM. The horizontal deviation is 1.9NM. So the left manoeuvre results in an efficiency of 21%, which is similar to the manoeuvre of aircraft one.

3.1.7 Figure 4 presents the same encounter with both aircraft responding to RAs.

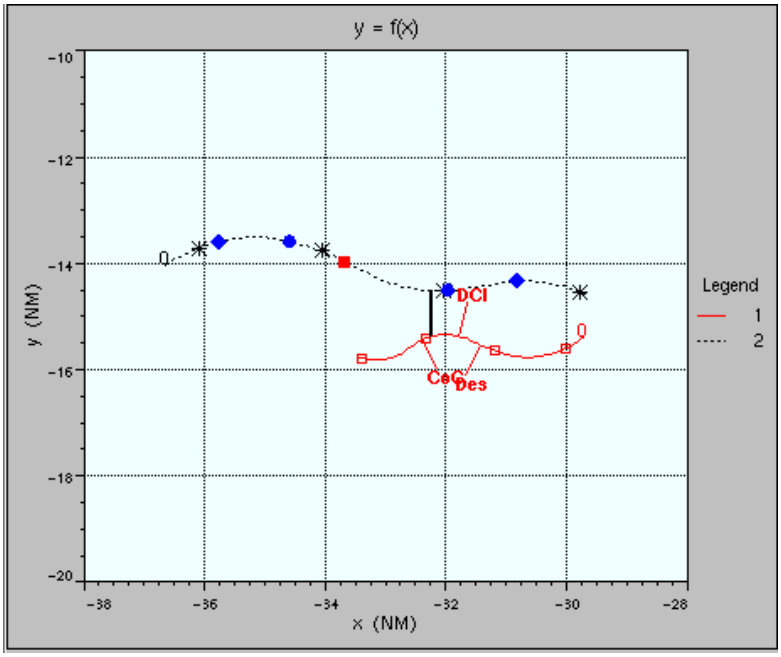


Figure 4: Both aircraft turning left

3.1.8 The horizontal separation at CPA increases from 0.18NM to 0.94NM.

3.1.9 When both aircraft manoeuvre, the deviation is calculated as the mean of the deviations of the two aircraft. The deviation is 1.55NM, which leads to an efficiency of 50%.

3.1.10 In this example, we notice a lower deviation per aircraft with a higher gain of horizontal separation at CPA when both aircraft manoeuvre.

4 Results on the European data-base of real encounters

4.1 Results presented

4.1.1 We show the results for different configurations:

- Single equipage with TCAS II logic Version 7.0;
- Single equipage with TCAS II logic Version 6.04a;
- Double equipage with TCAS II logic Version 7.0, both pilots follow their RAs;
- Double equipage with TCAS II logic Version 6.04a, both pilots follow their RAs.

4.1.2 For each configuration, we show the results for:

- The whole basis of encounters ;
- The encounters which take place above flight level 140. FL140 is considered as a transition between TMA and En Route in the European airspace ;
- The encounters which take place under flight level 140.

4.1.3 The figures were also computed with double equipage and one pilot not following his RAs (no counter manoeuvres). The results are similar to those found with single equipage and are not shown.

4.2 Single equipage with TCAS II logic Version 7.0

4.2.1 Table 1 presents the distribution of the horizontal deviations and the average horizontal deviations.

4.2.2 The results are provided for all the encounters, for the subset of encounters which take place above flight level 140, and for the subset of encounters which take place under flight level 140.

DEVIATION		**<0.5NM**	**0.5NM-1NM**	**1NM-2NM**	**2NM-3NM**	**>3NM**
Distribution	**All encounters**	32%	21%	23%	16%	8%
	FL>140	24%	22%	21%	19%	13%
	FL<140	38%	20%	25%	15%	2%
Average	**All encounters**	1.25NM				
	FL>140	1.53NM				
	FL<140	1.01NM				

Table 1: Horizontal deviations with TCAS II logic Version 7.0 thresholds

4.2.3 The mean horizontal deviation is nearly 50% more important for encounters at flight levels above FL140 than for encounters at flight levels under FL140. This is due to higher thresholds at higher levels.

4.2.4 The results indicate that the horizontal deviation is greater than 3NM in only 8% of the encounters. Deviations greater than 3NM are 13% of the encounters at flight levels above FL140. They are only 2% of the encounters at flight levels under FL140.

4.2.5 The horizontal deviation is lower than 1NM in 53% of the encounters.

4.2.6 The horizontal manoeuvre efficiency can be estimated by measuring the horizontal gain at original CPA, i.e., the supplementary horizontal separation.

4.2.7 Table 2 presents the distribution of the horizontal gains at CPA and the average horizontal gains at CPA.

GAIN		<0.5NM	0.5NM-1NM	1NM-2NM	2NM-3NM	>3NM
Distribution	**All encounters**	73%	23%	4%	0%	0%
	FL>140	61%	32%	7%	0%	0%
	FL<140	83%	16%	1%	0%	0%
Average	**All encounters**	0.33NM				
	FL>140	0.43NM				
	FL<140	0.24NM				
Efficiency	**All encounters**	26%				
	FL>140	28%				
	FL<140	24%				

Table 2: Horizontal gain at CPA with TCAS II logic Version 7.0 thresholds.

4.2.8 The results point out that the horizontal gain is lesser than 0.5NM for the major part of the RAs.

4.2.9 In the European airspace, it leads for horizontal manoeuvres to an average efficiency of 26%. In comparison, the average efficiency of vertical manoeuvres is equal to 55% according to [1].

4.2.10 We computed the figures for several subsets of encounters:

Subset	Mean deviation	Mean gain of separation	Efficiency
Encounters with a deviation less than 1NM	0.42NM	0.15NM	35%
Encounters with a deviation more than 1NM	2.18NM	0.52NM	23%
Encounters with a deviation more than 3NM	3.79NM	0.75NM	20%
Encounters with an efficiency more than 30%	0.92NM	0.44NM	47%

Table 3: figures for specific subsets of encounters

4.2.11 Table 3 shows that important deviation are not very efficient. However, deviations less than 1NM are efficient but lead to low gains of separations at CPA.

4.2.12 In order to assess the impact of the thresholds of the logic, we computed the deviations and separations more precisely in different layers of altitude, using the ACAS II detection thresholds. The following table shows the results:

Altitude	Under FL50	FL50-FL100	FL100-FL200	Above FL200
Mean deviations	0.61NM	1.07NM	1.2NM	1.61NM
Mean gain of separation at CPA	0.07NM	0.25NM	0.33NM	0.46NM
Mean Efficiency	11%	23%	27%	28%

Table 4: Efficiency against the altitude

4.2.13 As expected, the higher the flight level, the better the results. But the increase of efficiency is weak between the three higher layers of altitudes defined in table 4.

4.2.14 The gain at CPA is increased by 40% between flight levels under FL200 and flight levels above FL200.

4.3 Single equipage with TCAS II logic Version 6.04a

4.3.1 Table 5 presents the horizontal deviations computed using the European data-base of real encounters and the TCAS II logic Version 6.04a thresholds.

DEVIATION		<0.5NM	0.5NM-1NM	1NM-2NM	2NM-3NM	>3NM
Distribution	All encounters	17%	19%	37%	20%	7%
	FL>140	10%	15%	41%	24%	10%
	FL<140	28%	22%	32%	14%	3%
Average	All encounters	1.45NM				
	FL>140	1.68NM				
	FL<140	1.12NM				

Table 5: Horizontal deviations with TCAS II logic Version 6.04a thresholds

4.3.2 The horizontal deviations are 16% higher with the thresholds of TCAS II Version 6.04a logic than with the thresholds of TCAS II logic Version 7.0.

4.3.3 The proportion of RAs for which the horizontal deviation is greater than 3NM is nearly the same as with TCAS II logic Version 7.0.

4.3.4 However, only 36% of the encounters have horizontal deviations lower than 1NM.

4.3.5 Table 6 presents gains at CPA computed on the European data-base of real encounters simulated with TCAS II logic Version 6.04a thresholds.

GAIN		<0.5NM	0.5NM-1NM	1NM-2NM	2NM-3NM	>3NM
Distribution	**All encounters**	77%	20%	3%	0%	0%
	FL>140	71%	25%	4%	0%	0%
	FL<140	87%	12%	1%	0%	0%
Average	**All encounters**	0.30NM				
	FL>140	0.37NM				
	FL<140	0.21NM				
Efficiency	**All encounters**	20%				
	FL>140	22%				
	FL<140	19%				

Table 6: Horizontal gain at CPA with TCAS II logic Version 6.04a thresholds

4.3.6 The averages gain of separation at CPA are 10% lesser than those computed with TCAS II logic Version 7.0 thresholds. This result is surprising because the TCAS II logic Version 7.0 thresholds are reduced compared to TCAS II logic Version 6.04a thresholds. This can be explained by the fact that there are more RAs with TCAS II logic Version 6.04a. So, the basis of encounters is not exactly the same.

4.3.7 The thresholds of TCAS II logic Version 6.04a give efficiencies which are 5 to 6 points under those found with the thresholds of TCAS II logic Version 7.0.

Note: The best way to compare both versions of the logic is to run simulations with TCAS II logic Version 6.04a only on the data-base of encounters which generate an RA with TCAS II logic version 7.0. It results in a mean deviation of 1.74NM and in a mean gain of separation of 0.38NM. This gives an efficiency of 22%. So TCAS II logic version 6.04a results in higher gains of separations than version 7.0, but the deviations are also more important. These higher deviations result in lower efficiencies.

4.4 Double equipage with TCAS II logic Version 7.0, both pilots respond

4.4.1 Table 7 presents the distribution of the horizontal deviations and the average horizontal deviations.

4.4.2 The results are provided for all the encounters, for the subset of encounters which take place above flight level 140, and for the subset of encounters which take place under flight level 140.

DEVIATION		**<0.5NM**	**0.5NM-1NM**	**1NM-2NM**	**2NM-3NM**	**>3NM**
Distribution	**All encounters**	30%	26%	27%	13%	3%
	FL>140	20%	31%	26%	17%	6%
	FL<140	42%	20%	29%	9%	0%
Average	**All encounters**	1.11NM				
	FL>140	1.32NM				
	FL<140	0.89NM				

Table 7: Horizontal deviations with TCAS II logic Version 7.0 thresholds

4.4.3 The results indicate that the horizontal deviations are 11% smaller when both pilot manoeuvre than when only one pilot manoeuvres.

4.4.4 Deviations greater than 3NM are only 3% of the RAs, and are all above flight level 140.

4.4.5 The horizontal deviation is lower than 1NM in 56% of the RAs.

4.4.6 As said above, the low flight level encounters result in lower deviations than the high flight levels encounters.

4.4.7 Table 8 presents the distribution of the horizontal gains at CPA and the average horizontal gains at CPA.

GAIN		<0.5NM	0.5NM-1NM	1NM-2NM	2NM-3NM	>3NM
Distribution	**All encounters**	55%	25%	18%	0%	0%
	FL>140	44%	28%	27%	0%	0%
	FL<140	67%	25%	8%	0%	0%
Average	**All encounters**	0.55NM				
	FL>140	0.69NM				
	FL<140	0.4NM				
Efficiency	**All encounters**	50%				
	FL>140	52%				
	FL<140	45%				

Table 8: Horizontal gains at CPA with TCAS II logic Version 7.0 thresholds

4.4.8 The results lead to an efficiency of 50%, which is, as expected, nearly twice the results found when one aircraft manoeuvres.

4.4.9 We computed the figures for several specific subsets of encounters, as shown in table 9. The conclusions are the same as for single equipage.

Subset	Mean deviation	Mean gain of separation	Efficiency
Encounters with a deviation less than 1NM	0.47NM	0.33NM	70%
Encounters with a deviation more than 1NM	1.94NM	0.85NM	43%
Encounters with a deviation more than 2NM	2.74NM	0.53NM	19%
Encounters with an efficiency more than 60%	0.79NM	0.76NM	96%

Table 9: Figures computed for specific subsets of encounters

4.4.10 We computed the deviations and separations more precisely in different layers of altitude, with the ACAS II detection thresholds. The following table shows the results.

Altitude	Under FL50	FL50-FL100	FL100-FL200	Above FL200
Mean deviations	0.64NM	0.9NM	1.03NM	1.41NM
Mean gain of separation at CPA	0.17NM	0.37NM	0.58NM	0.74NM
Mean Efficiency	26%	41%	56%	53%

Table 10: Efficiency against the altitude

4.4.11 The results show an important increase of the efficiency above FL 100.

4.5 Double equipage with TCAS II logic Version 6.04a, both pilots respond

4.5.1 Table 11 presents the same results with Version 6.04a thresholds.

DEVIATION		<0.5NM	0.5NM-1NM	1NM-2NM	2NM-3NM	>3NM
Distribution	**All encounters**	12%	26%	44%	15%	3%
	FL>140	23%	31%	35%	10%	0%
	FL<140	5%	23%	49%	18%	5%
Average	**All encounters**	1.34NM				
	FL>140	1.52NM				
	FL<140	1.04NM				

Table 11: Horizontal deviations with TCAS II logic Version 6.04a

4.5.2 We notice that the results are 20% worse with the thresholds of TCAS II logic Version 6.04a than with those of TCAS II logic Version 7.0.

4.5.3 The horizontal deviations are lower than 1NM in only 38% of the encounters.

4.5.4 Table 12 presents the same results with version 6.04a thresholds.

GAIN		<0.5NM	0.5NM-1NM	1NM-2NM	2NM-3NM	>3NM
Distribution	**All encounters**	51%	29%	20%	1%	0%
	FL>140	40%	32%	26%	1%	0%
	FL<140	68%	22%	10%	0%	0%
Average	**All encounters**	0.61NM				
	FL>140	0.74NM				
	FL<140	0.4NM				
Efficiency	**All encounters**	45%				
	FL>140	48%				
	FL<140	38%				

Table 12: Horizontal gains at CPA with TCAS II logic Version 6.04a thresholds

4.5.5 We notice that efficiencies are around 5 points lower than with TCAS II logic Version 7.0. However, the mean gain of separation is a little more important.

Note: We simulated only the encounters which generate RAs with TCAS II Version 7.0 logic, using Version 6.04a so as to really compare both versions. It resulted in a mean deviation of 1.50NM and in a gain of separation at CPA of 0.68NM. It results in an efficiency of 45%. So TCAS II logic Version 6.04a would give higher deviations and higher separations, with a lower efficiency.

4.6 RA duration

4.6.1 The following table shows the mean duration computed for RAs on the European data-base of encounters:

Configuration		Duration (V7)	Duration (V6.04a)
Single equipage	Vertical manoeuvres	24.0s	25.8s
	Horizontal manoeuvres	20.9s	24.0s
Double equipage	Vertical manoeuvres	24.3s	26.1s
	Horizontal manoeuvres	19.2s	22.5s

Table 13: Duration of RAs

4.6.2 The results show that RAs end earlier with horizontal manoeuvres than with vertical manoeuvres. This is due to horizontal divergence between the aircraft.

4.6.3 We also notice that the RAs last longer with Version 6.04a than version 6.04a of he logic.

➔The results indicate that the contributions of the horizontal manoeuvres in term of supplementary horizontal separation at CPA seems to be low when compared to the probable induced deviations.

➔When both aircraft manoeuvre, the results in term of efficiency are nearly twice better than when only one aircraft manoeuvre, with lower deviations and higher gains at CPA.

➔TCAS II logic Version 7.0 thresholds seem to perform better than TCAS II logic Version 6.04a thresholds in term of efficiency. However, the gains of separations are higher with TCAS II logic Version 6.04a.

5 Comparison between Horizontal and vertical manœuvres

5.1.1 Annexe A presents a geometry which needs important deviations in order to have acceptable separations. This part presents one example in which the separations achieved are not satisfying.

5.2 Encounters better solved in the vertical plan

5.2.1 The goal of this part is to present situations which are not well solved by horizontal manoeuvres in term of separation. We present a real encounter of this type extracted from the European data-base. The amount of encounters which are similar to the one we show is nearly 5% of the total amount of encounters in our data-base.

5.2.2 Figure 5 shows this encounter which has an horizontal CPA of 0.13NM and a vertical CPA of 492ft. Both aircraft are equipped so as to get the best possible results. The initial RA is generated 9 seconds before the CPA.

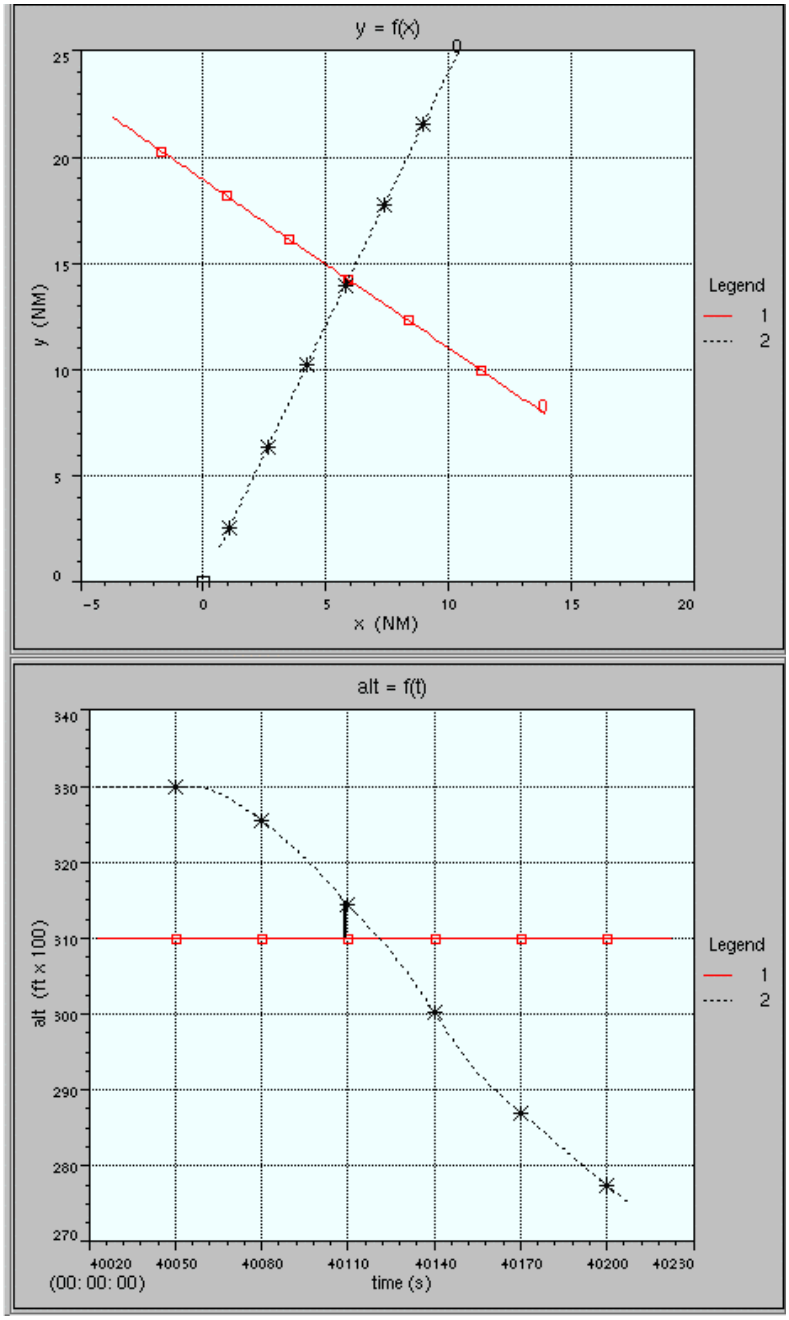


Figure 5: Real encounter, initial trajectory

5.2.3 Figure 6 presents the result of horizontal manoeuvres. Figure 7 presents the result of vertical manoeuvres. We present the encounters zoomed in order to see what happens.

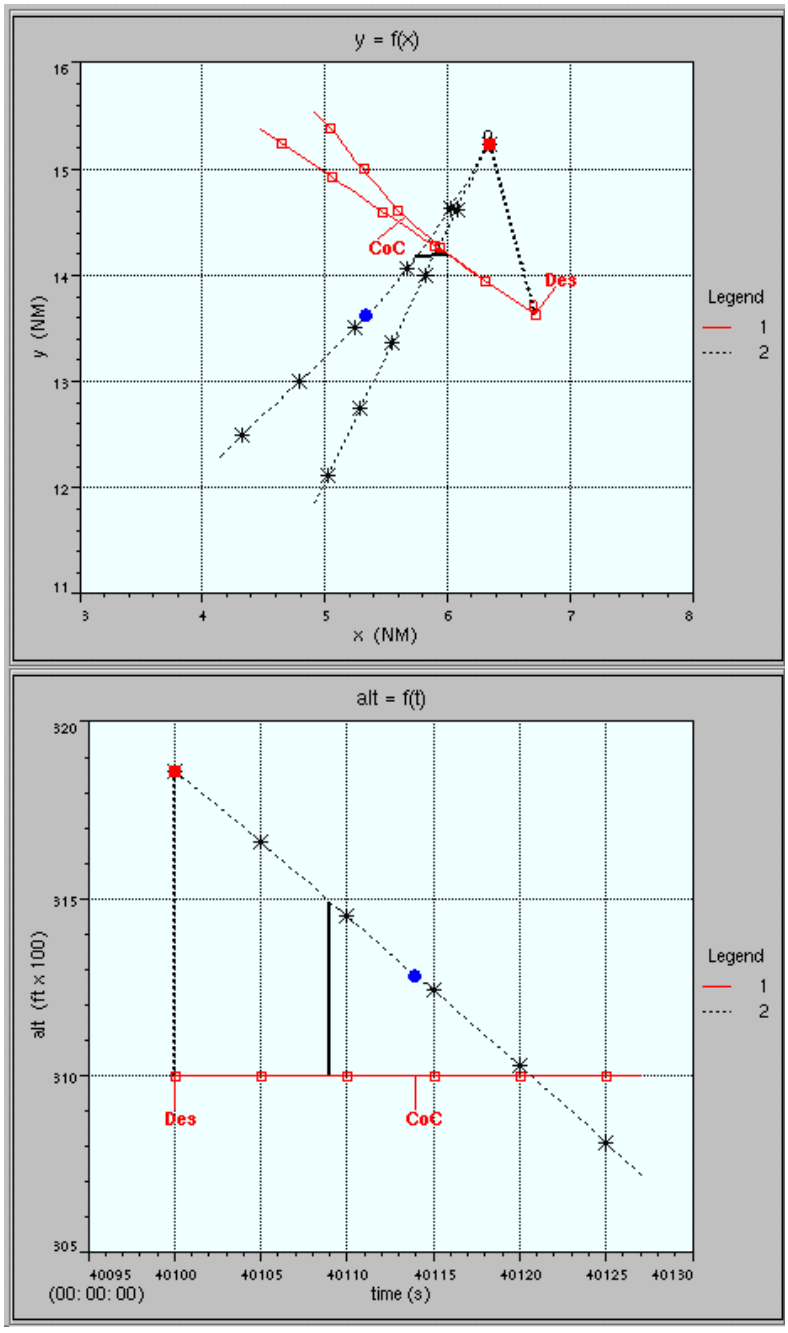


Figure 6: Horizontal manoeuvre

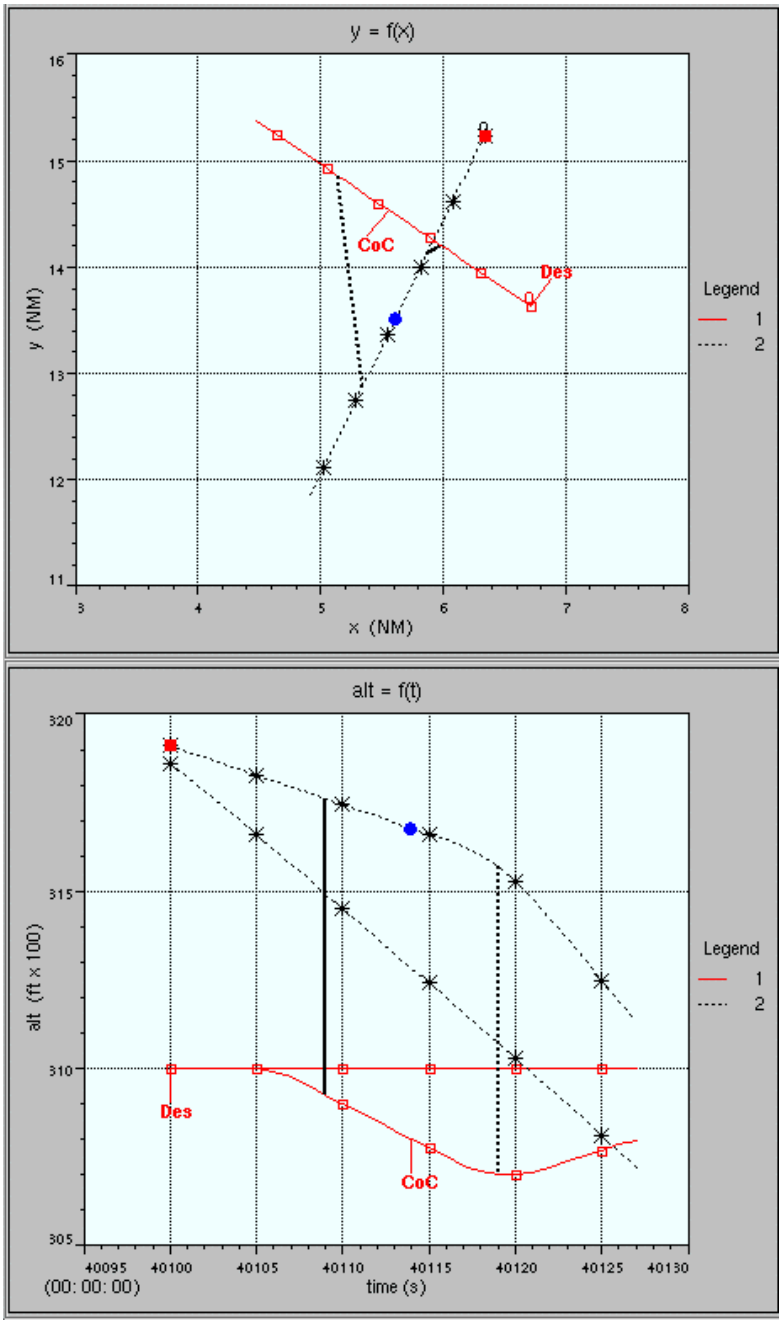


Figure 7: Vertical manoeuvre

5.2.4 The horizontal manoeuvres lead to a deviation of 0.8NM for a gain of separation at CPA which is near zero. So the efficiency of the horizontal manoeuvre is approximately equal to zero.

5.2.5 The vertical manoeuvre leads to a gain of separation at CPA which is 342ft. Aircraft one deviates from an amount of 300ft. Aircraft two has a deviation of nearly 500ft.

5.2.6 In this case a vertical manoeuvre is efficient, whereas an horizontal manoeuvre is not. Horizontal manoeuvres would not be efficient on encounters in which the RAs are generated lately.

5.3 Results for encounters not well solved by vertical manoeuvres

5.3.1 The aim of this part was to assess the efficiency of horizontal manoeuvres on a subset of encounters which are not well solved by vertical manoeuvres.

5.3.2 The encounters of the European data-base were simulated with double equipage and with vertical manoeuvres. Those with the lesser achieved vertical CPA and with null or negative efficiency were simulated with horizontal manoeuvres (13 encounters were chosen).

5.3.3 On this subset of encounters, the horizontal manoeuvres result in a mean gain of separation at CPA of 0.05NM and a mean deviation of 0.4 NM. So horizontal manoeuvres do not seem to be more efficient than vertical manoeuvres on the worst encounters of the European data-base.

5.4 Encounters better solved in the horizontal plane

5.4.1 This part is based on a theoretical encounter generated with the ICAO standard encounter model. The initial encounter is shown in figure 8. The bottom aircraft is equipped, whereas the higher aircraft is not equipped. The initial Vertical separation is 217ft, and the horizontal separation is 0.06NM.

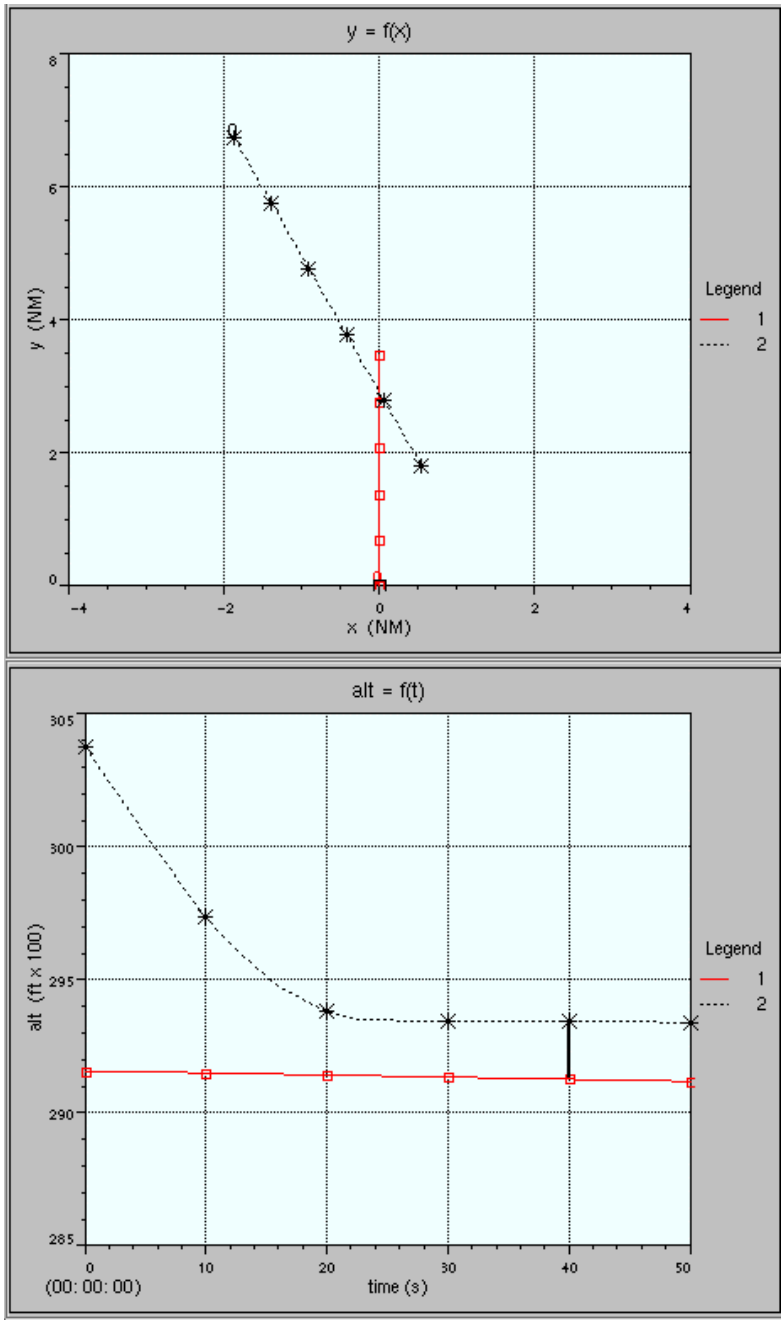


Figure 8: Initial encounter

5.4.2 This encounter has been simulated in the vertical plan, as shown on figure 9.

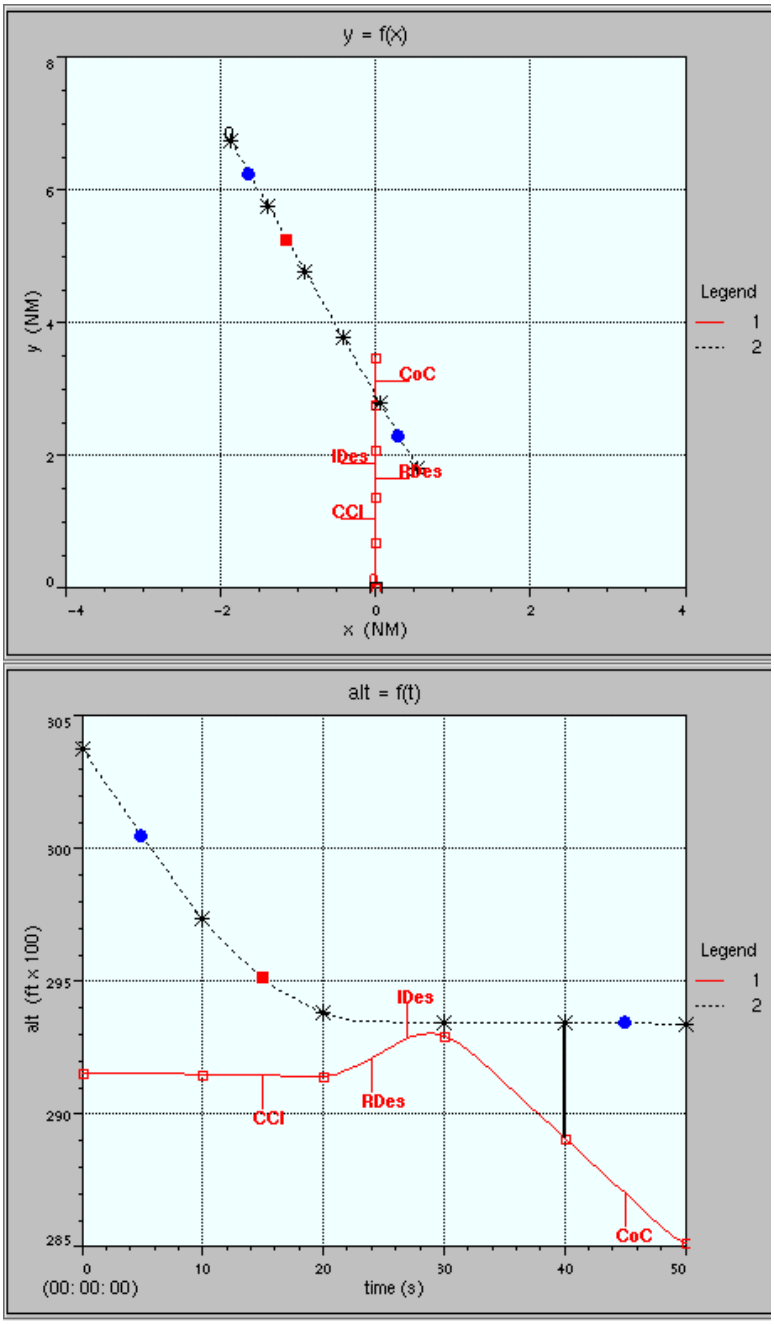


Figure 9: Vertical manoeuvre

5.4.3 TCAS II logic Version 7 chooses a crossing climb manoeuvre which is reversed 9 seconds later. Then, an increase descend RA is generated. The achieved vertical separation is 433ft. So alim is not achieved. The gain of separation is 216ft for a deviation greater than 600ft. It results in an efficiency which is under 36%.

5.4.4 This encounter was simulated with an horizontal manoeuvre. The result is shown on figure 10.

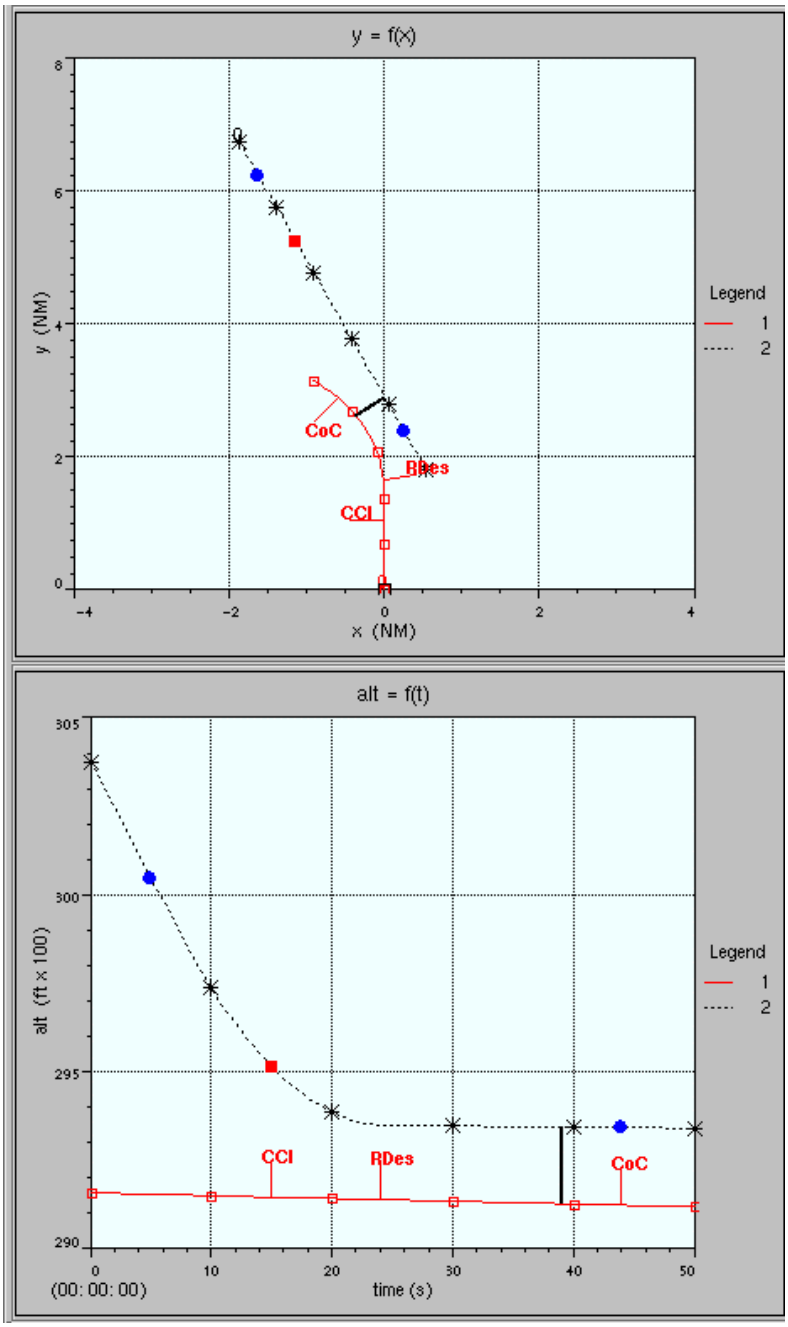


Figure 10: Horizontal manoeuvre

5.4.5 The horizontal separation at CPA is 0.45NM. The vertical separation is not changed. The deviation computed is 0.97NM and the gain of separation at the initial CPA is 0.42NM. This leads in an efficiency of 43%. So the horizontal manoeuvre is more efficient than the vertical

manoeuvre. Moreover, this manoeuvre is certainly more acceptable for a pilot, as it avoids a crossing geometry and a reversal RA.

5.4.6 So horizontal manoeuvres could be interesting in geometries for which a crossing RA will be chosen. It could avoid a part of the reversal RAs.

6 Possible induced collision

6.1.1 The aim of this part is to show the possible results of an error in the choice of horizontal manoeuvres.

6.1.2 We show an example of induced collision, which is the result of a wrong manoeuvre choice in case of an erroneous estimate of the bearing by the logic.

6.2 Initial encounter

6.2.1 Figure 11 shows the initial encounter.

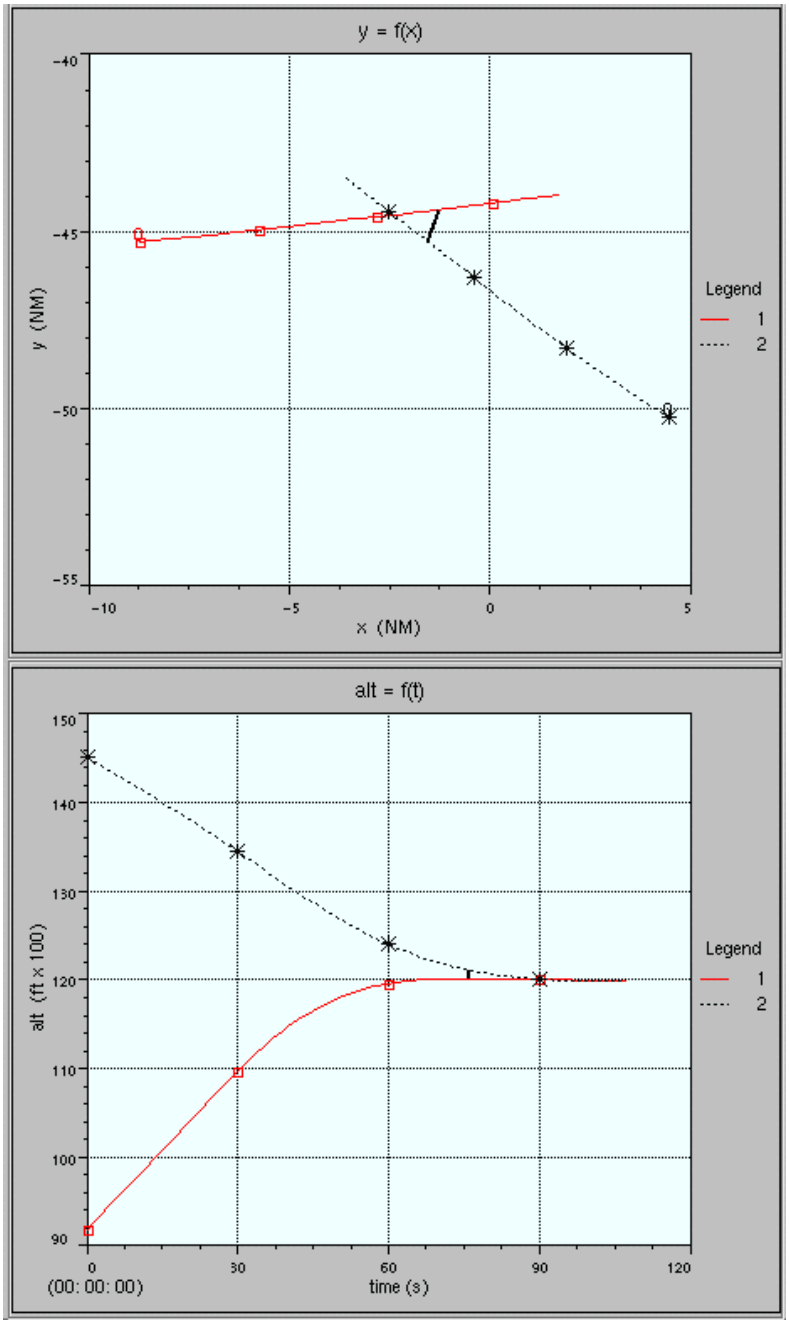


Figure 11: initial encounter

6.3 Manoeuvres on this encounter

6.3.1 For the real encounter(figure 11), the best manoeuvre are:

- Aircraft one going left;
- Aircraft two going left.

6.3.2 This result in an horizontal CPA of 1.55NM.

6.3.3 For the erroneous encounter, we suppose that at the time of generation of the RA, aircraft two makes an error in the estimate of the bearing. This error is 12 degrees. We also suppose that aircraft two imposes its choice of manoeuvre to aircraft one.

6.3.4 For the erroneous encounter, the best manoeuvres are (see figure 12):

- Aircraft one going right;
- Aircraft two going right.

6.3.5 The TCAS will choose a right manoeuvre for both aircraft, on the base of the erroneous image of the situation.

6.3.6 This choice results in a collision for the real encounter, as shown in figure 13.

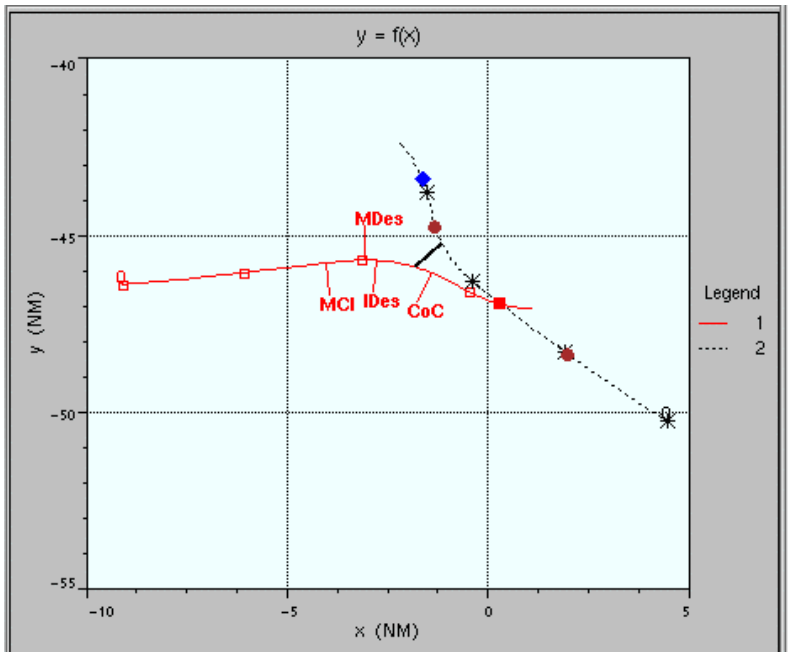


Figure 12: Conflict view as understood by the TCAS

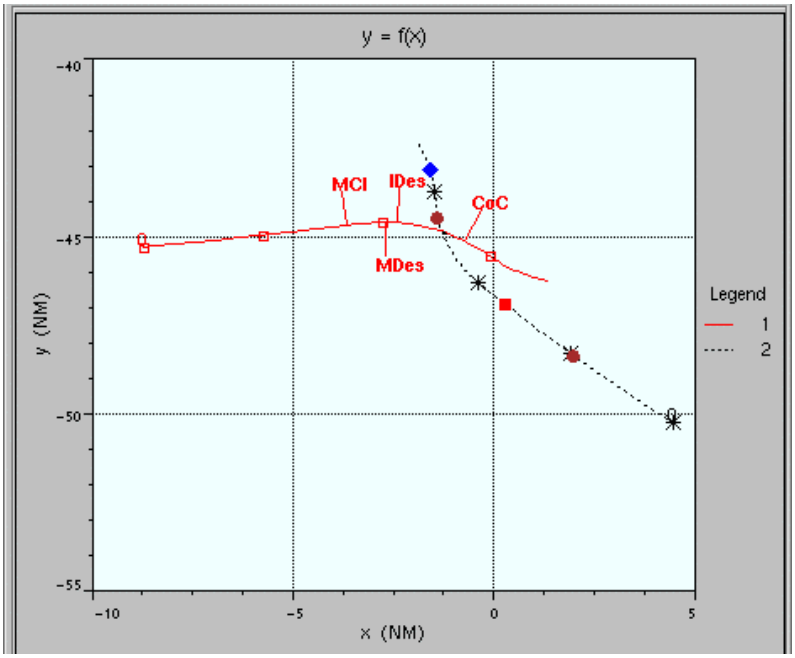


Figure 13: Actual conflict view

7 Conclusion

7.1.1 The results indicate that the contributions of the horizontal manoeuvres in term of supplementary horizontal separation at CPA seems to be low when compared to the probable induced deviations, especially when only one aircraft manoeuvres. However, the separations achieved are sufficient to avoid a collision.

7.1.2 It seems that horizontal manoeuvres would not replace vertical manoeuvres. However, horizontal manoeuvres could make the TCAS more efficient in some specific situations, such as crossing situations which can result in reversal RAs.

7.1.3 TCAS II logic version 6.04a gives the best results in term of separation, but the price in term of deviation is important and results in lower efficiency. TCAS II logic Version 7.0 induces lower deviations and better efficiencies.

8 References

[1] T. Arino & F.Casaux - 1997 – SICASP/WG2/WP2/656 - Preliminary Contribution for the ACAS III Performance SARPS

[2] Eurocontrol - 1999 – Initial work plan for ACAS Analysis (Version 1.4.1) - EUROPEAN TEN STUDY ANALYSIS, Work Plan

[3] T. Arino & F.Casaux - 1998 – Air Traffic Control Quaterly, Vol.6(4) 249-268 – Contribution of TCAS II Logic Version 7.0 in the European Airspace

9 Annexe A: results on a theoretical data-base of highly converging encounters

9.1 Principle

9.1.1 Figure 14 presents an example of theoretical encounter. The aircraft converge in a nearly face to face configuration. This geometry was chosen for theoretical simulations as it appeared that it could be a difficult geometry in term of choice of horizontal manoeuvres. In fact it appeared that the choice could be difficult in these situations, depending of the relative speeds of the aircraft and the presence or not of a sufficient Horizontal Miss Distance. Moreover, those encounters are interesting as they can be well solved by horizontal manoeuvres, but with important deviations (around 2.5 NM). However, the results may vary depending on the vertical profile of the encounter.

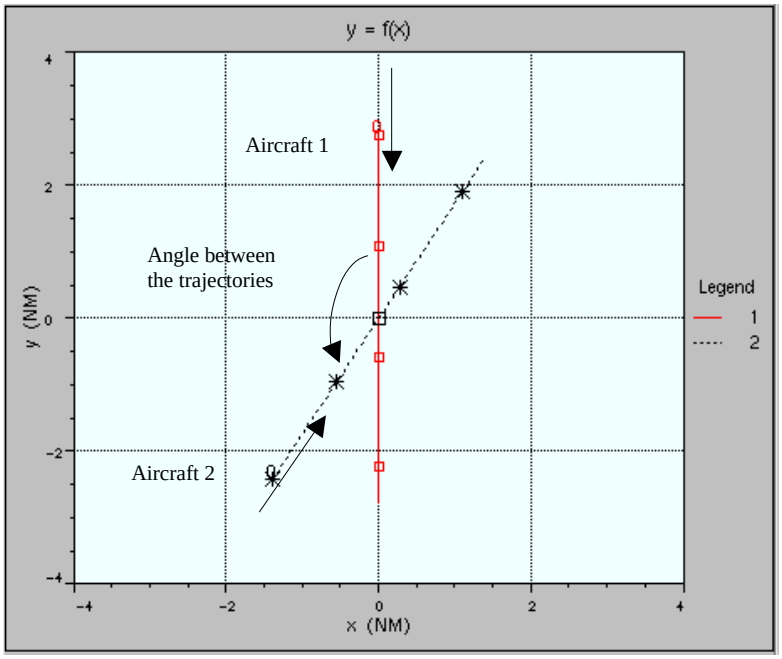


Figure 14: Theoretical encounter

9.1.2 The angle between the trajectories was taken between 90 and 180 degrees, with steps of 10 degrees. Angles between 0 and 90 degrees were not simulated. However, an example is given at page 6. It results in a deviation of 0.73NM for a gain of separation at CPA of 1.07NM.

9.1.3 The simulations were made so as to test the impact of the following parameters:

- The speed:
  - ✓ Same speed for the aircraft;
  - ✓ Different speeds.
- Horizontal Miss distance:
  - ✓ Equal to zero;
  - ✓ Non equal to zero, with aircraft two crossing the trajectory of aircraft one. We simulated this geometry with the same speeds for both aircraft, and with aircraft one faster than aircraft two, as it is the worst case.

9.2 One aircraft manoeuvres, both aircraft have the same speed, no HMD.

9.2.1 Table 14 presents the mean results for different configurations.

	ac1 right	**ac1 left**	**ac2 right**	**ac2 left**
Gain at CPA(NM)	0.69	0.69	0.69	0.66
Deviation (NM)	2.67	3.24	3.24	2.67
Efficiency	26%	21%	21%	26%

Table 14: One aircraft manoeuvres

9.2.2 From the results, we observe the best choice when one aircraft manoeuvres is going in the direction which avoids a crossing of the trajectories.

9.2.3 The deviations computed are all above 2.5NM

9.3 Both aircraft manoeuvre, both aircraft have the same speed, no HMD.

9.3.1 Table 15 presents the mean results for different configurations.

	ac1 right ac2 right	**ac1 right ac2 left**	**ac1 left ac2 left**	**ac1 left ac2 right**
Gain at CPA(NM)	1.24	0.34	1.24	0.8
Deviation (NM)	2.43	2.59	2.43	3.93
Efficiency	51%	13%	51%	20%

Table 15: Both aircraft manoeuvre

9.3.2 We observe both aircraft must choose the same direction, which means aircraft one goes right, and aircraft two goes right (or left/left).

9.3.3 So, for a given aircraft, the best choice is influenced by the intention of the intruder: the best manoeuvre shall not be the same if the intruder manoeuvres or not.

9.3.4 Whatever the choice, we notice the deviations are less important than in the situations in which only one aircraft manoeuvre. However, they are still around 2.5NM. We also notice that the separations achieved are over 1NM.

9.4 One aircraft manoeuvres, aircraft have different speeds, no HMD

9.4.1 Table 16 shows the results for different configurations in which aircraft two is faster than aircraft one:

	ac1 right	**ac1 left**	**ac2 right**	**ac2 left**
Gain at CPA	0.67	0.67	0.68	0.68
Deviation (NM)	2.72	3.3	3.07	2.8
Efficiency(NM)	25%	20%	22%	24%

Table 16: One aircraft manoeuvre, aircraft have different speeds aircraft2 faster than aircraft1

9.4.2 We observe the results are nearly the same as in 9.2.

9.5 Both aircraft manoeuvre, aircraft have different speeds, no HMD.

9.5.1 Table 17 shows the results for different configurations in which aircraft two is faster than aircraft one:

	ac1 right ac2 right	**ac1 right ac2 left**	**ac1 left ac2 left**	**ac1 left ac2 right**
Gain at CPA(NM)	1.23	0.34	1.18	0.72
Deviation (NM)	2.54	2.5	2.71	3.69
Efficiency	48%	14%	43%	20%

Table 17: Both aircraft manoeuvre, aircraft2 faster than aircraft1

9.5.2 The results are nearly the same as in 9.3.

9.5.3 So, when there is no or nearly no HMD, the results are not affected by the differences of speeds.

9.6 One aircraft manoeuvres, same speeds, HMD (ac2 crosses trajectory of ac1)

9.6.1 Aircraft two is simulated to cross the trajectory of aircraft one: when aircraft two is at point A, aircraft one is at point B.

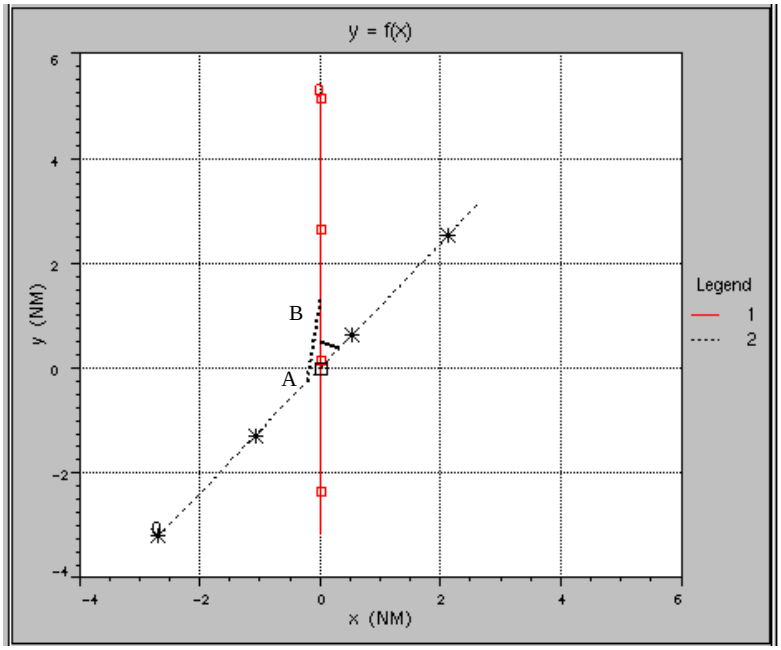


Figure 15: Encounter with HMD

9.6.2 Table 18 shows the results for different configurations in which both aircraft have the same speeds, but aircraft two crosses the trajectory of aircraft one.

	ac1 right	ac1 left	ac2 right	ac2 left
Gain at CPA(NM)	0.66	0.17	0.6	0.02
Deviation (NM)	2.52	3.43	2.24	2.76
Efficiency	26%	5%	27%	1%

Table 18: One aircraft manoeuvres, same speeds aircraft2 crosses trajectory of aircraft1

9.6.3 We observe that aircraft one still has to go right.

9.6.4 With an HMD, aircraft two must not go left.

9.6.5 The deviations are over 2NM.

9.7 Both aircraft manoeuvre, same speeds, HMD

9.7.1 Table 19 shows the results for different configurations in both aircraft have the same speeds, but aircraft two crosses the trajectory of aircraft one:

	ac1 right ac2 right	**ac1 right ac2 left**	**ac1 left ac2 left**	**ac1 left ac2 right**
Gain at CPA(NM)	1.19	0.14	0.48	0.45
Deviation(NM)	1.77	2.73	2.63	3.69
Efficiency	67%	3%	18%	12%

Table 19: Both aircraft manoeuvre, same speeds, HMD

9.7.2 The best choice is the one in which the crossing aircraft goes in front of the other aircraft. The other aircraft goes behind.

9.7.3 We also observe that the good efficiency is mainly due to deviation which is under 1.8NM. Without HMD, the deviations were above 2NM.

9.7.4 This efficiency of 67% is the best we obtained for these theoretical encounters. However, the necessary deviation is important

9.8 One aircraft manoeuvres, different speeds (ac1 faster), HMD (ac2 crosses trajectory of ac1)

9.8.1 Table 20 shows the results for different configurations in both aircraft have the different speeds, but aircraft two crosses the trajectory of aircraft one. This is the most difficult situation to cope with:

	ac1 right	**ac1 left**	**ac2 right**	**ac2 left**
Gain at CPA(NM)	0.64	0.17	0.54	0.18
Deviation (NM)	2.68	3.13	2.81	2.67
Efficiency	24%	5%	19%	7%

Table 20: One aircraft manoeuvres, different speeds, aircraft 1 faster than aircraft2 ac2 crosses trajectory of ac1

9.8.2 These results show that when only one aircraft manoeuvres, the best results are obtained when the fastest one turns right.

9.8.3 The slower aircraft is less efficient than the fastest.

9.9 Both aircraft manoeuvre, different speeds, HMD

9.9.1 Table 21 shows the results for different configurations in both aircraft have the different speeds, but aircraft two crosses the trajectory of aircraft one.

	ac1 right ac2 right	**ac1 right ac2 left**	**ac1 left ac2 left**	**ac1 left ac2 right**
Gain at CPA(NM)	1.12	0.2	0.64	0.34
Deviation (NM)	2.14	2.68	2.65	3.25
Efficiency	52%	7%	24%	10%

Table 21: Both aircraft manoeuvre , different speeds, aircraft 1 faster than aircraft2 ac2 crosses trajectory of ac1

9.9.2 The best choice is the one in which the crossing aircraft goes in front of the other aircraft. The other aircraft goes behind.

9.9.3 Figure 16 presents an example taken from the European data-base. Aircraft one turns left. The gain of separation is 0.94NM, which is good, and the efficiency is 29%. However, the horizontal deviation is 3.22NM.

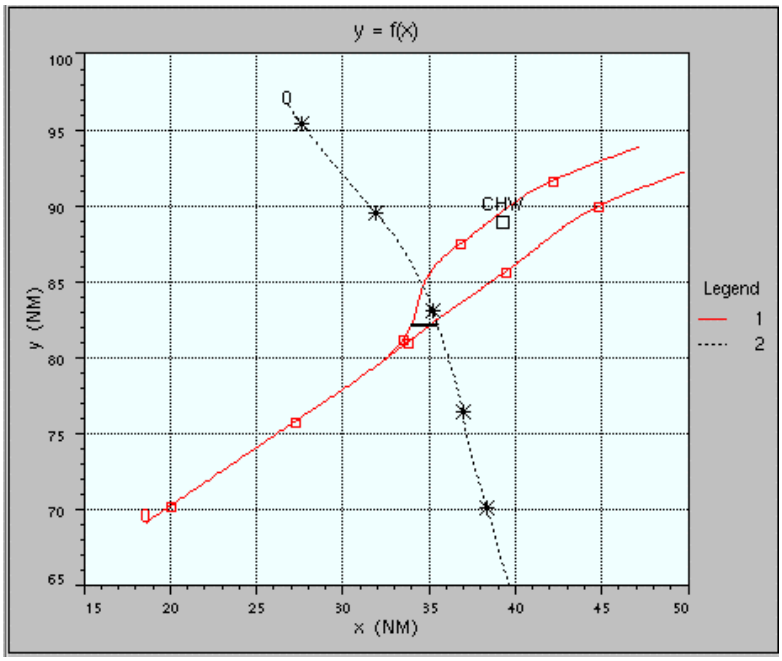


Figure 16: Real encounter, aircraft one turns left

➔The deviations needed to achieve a good separation are important, more than 2NM, in the case of the geometry presented;

10 Acronyms

ACAS	Airborne Collision Avoidance System
ATC	Air Traffic Control
CENA	Centre d'Etudes de la Navigation Aérienne
CPA	Closest Point of Approach
DGAC	Direction Générale de l'Aviation Civile
ICAO	International Civil Aviation Organisation
NMAC	Near Mid Air Collision
RA	Resolution Advisory
TCAS	Traffic alert and Collision Avoidance System
TEN	Trans European Network
WG	Working Group

ACAS PROGRAMME

ACASA PROJECT

Annex B to
Work Package 8

Final Report on

Acceptability and Efficiency of Lateral Collision Avoidance Manoeuvres

Edition 1.0
March 2002

Annex B to Work Package 8

Final Report on Acceptability and Efficiency of lateral collision avoidance manoeuvres

Version 1.1 - March 2002

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WP-8.3

Acceptability of ACAS horizontal resolution advisories

The view of pilots and controllers

Prepared by Emmanuelle Jeannot

Summary

The aim of this study is to assess acceptability of ACAS Horizontal Resolution Advisories (HRAs) from an operational point of view.

Pilots: 9 pilots have been interviewed.

3 at British Airways HQ in Heathrow on the 8th January 2001,

6 at Air France HQ in Roissy on the 5th and 6th February 2001.

Controllers: 12 controllers have been interviewed.

6 in Aix en Provence, at the CRNA Sud Est, on the 12th and 13th October 2000.

6 in Maastricht, at the Upper Airspace Control Centre, on the 7th and 8th February 2001

The organisation of the study and the structure of the interviews are described.

The opinions and attitudes of the pilots regarding horizontal resolution advisories is clearly positive. The opinions and attitudes of the controllers are far more diverse; there is not one unique and clear tendency. The format of the study and the structure of the interview have been useful and well accepted in the case of the pilots. Unfortunately, the same comment cannot be made in the case of the controllers. The presentation was not ideal for controllers, and their current views on TCAS could have prevented them from considering horizontal RAs dispassionately.

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1 Introduction

1.1.1 The aim of this study is to assess both efficiency and acceptability of ACAS Horizontal Resolution Advisories (HRAs) from an operational point of view.

1.1.2 The original ACASA Workplan envisaged that WP8.3 would consist of two parts:

Design of a questionnaire "to assess both efficiency and acceptability of horizontal RAs [… including …] a selected set of simulated examples of horizontal RAs using the outputs of WP8.1"

Selection and interviewing of ~15 controllers and pilots, and finally analysis of results and reporting.

1.1.3 Interviewees: WP8.3 had to address both controllers and pilots. Proposed partition was the following: 2/3 controllers; 1/3 pilots. A minimum of 12 interviews was considered an acceptable sample, although the objective was to carry out 15 to 16 interviews.

1.1.4 The actual population of the study is N = 21. Controllers N = 12 and Pilots N = 9.

2 Organisation of the study.

2.1 Clarifications of the purpose of the study

2.1.1 Efficiency: Efficiency is the balance between efficacy (Does the manoeuvre result in safe separation?) and acceptability (Is the manoeuvre disruptive?) as viewed by the interviewee. The subjective assessment, in particular the relative ordering of the encounters and of vertical and horizontal RAs, might differ from the numerical evaluation in WP8.1 [4].

2.1.2 Acceptability: It is understood that the notion of acceptability will be envisaged within WP8.3 on a qualitative and so highly subjective point of view. Acceptability in terms of technical efficiency is addressed by WP8.1. WP8.3 is more likely to deal with this notion in terms of perceived benefit/loss, personal like/dislike, and expected or feared impact on everyday activity.

2.2 Interviews

2.2.1 Acceptance of new tools is a sensitive issue especially in the case of controllers. This topic is related to the representation of the job and of one's own abilities. Thus, to avoid bias due to self-image consciousness, one-to-one interviews were conducted as often as possible.

2.2.2 The acceptability of horizontal RA might depend on different criteria for pilots and for controllers. Nevertheless, to allow some kind of comparison, the questionnaires should be similar. Rather than totally different interview guides, the controllers' guide was adapted for the pilots.

2.2.3 The six encounters provided by CENA were the basis of the interviews. For the controllers, at least four encounters were presented during the interview, but that it was not always necessary to show more than four. For the pilots, only two dynamic simulations of a realistic display of horizontal RAs were shown.

2.2.4 A total of 21 interviews have been performed either in English or in French according to the preferences of the interviewee.

2.3 Population

2.3.1 WP8.3 is intended to find out how horizontal RAs might be received by the operational community. Because horizontal RAs will be supplementary to existing TCAS, interviewees required operational experience (or at least operational knowledge) of TCAS.

2.3.2 Pilots: 9 pilots have been interviewed.

3 at British Airways HQ in Heathrow on the 8th January 2001,

6 at Air France HQ in Roissy on the 5th and 6th February 2001.

2.3.3 It is to be noted that all of the pilots interviewed are quite experienced (up to 30 years) and have all now, in addition of still being pilots, other administrative responsibilities in their company (see details of population in Annexe A).

2.3.4 Controllers: 12 controllers have been interviewed.

6 in Aix en Provence, at the CRNA Sud Est, on the 12th and 13th October 2000.

6 in Maastricht, at the Upper Airspace Control Centre, on the 7th and 8th February 2001

2.3.5 It is to be noted that, unlike the pilot population, controllers have varied length of professional practice. Only 2 of them have now administrative responsibilities in addition to being a controller (see details of population in Annexe A).

3 Structure of the interviews

3.1 Introduction.

background to ACASA

purpose of interview (part of WP8)

comments treated in confidence

3.2 Part 1: Current TCAS, experience and opinion

3.2.1 The aim of the present study is to assess the acceptability of horizontal advisories. Because horizontal RAs will be supplementary to existing TCAS, it is important to clearly distinguish comments related to TCAS "in general" from comments related specifically to horizontal RAs.

3.2.2 The first part of the interview explored the interviewee's experience of and opinions on TCAS. It allowed the differentiation between opinion on horizontal advisories and comments motivated by previous opinions on TCAS.

3.3 Part 2: Discuss operational acceptability of new technology

3.3.1 The second part then explored the criteria that make a system, or a tool, operationally acceptable or not from the interviewee's point of view.

3.3.2 The notion of (subjective) efficiency was also explored during that early stage in the interview.

3.3.3 It gave indications for the interpretation of the comments during and after the simulations. It also fed the last part of the interview, the "wrap up".

3.4 Part 3: Show simulations

3.4.1 Controllers: Four to six encounters simulating horizontal RAs, were shown to the interviewee. It was emphasised that the aim of the study was not an HMI evaluation. It is a concept exploration. Controllers were invited to "think aloud", to comment on what is presented, as freely as possible.

3.4.2 Pilots: Two dynamic simulations of a realistic display of horizontal resolution advisories were shown to the interviewee. Static pictures of HRA displays for other encounters were also shown on request. Again, it was emphasised that the aim of the study was not an HMI evaluation. It is a concept exploration. Pilots were invited to "think aloud", to comment on what is presented, as freely as possible.

3.5 Part 4: Discuss acceptability of horizontal RAs

3.5.1 This was the crucial part of the interview. In the light of what he had seen during the simulations, the interviewee was asked to assess the acceptability of horizontal RAs. Once again it was emphasised that comments should, as far as possible, be made on the concept of horizontal RAs rather than on the HMI.

3.5.2 The question of how to improve (or create) HRA acceptability was also discussed.

3.6 Wrap up

3.6.1 During the last part of the interview, the interviewer tried to summarise the main points discussed. It enabled both parties to check that there were no misunderstandings and that the most important points, for the controller or pilot, had been recorded.

3.6.2 It also provided a last opportunity for the interviewee to explain his point of view on horizontal RAs.

3.6.3 Seven-step rating scales[1] were used to support this last part of the interview. The interviewee was asked to score to what extent horizontal RAs satisfy (or not) the acceptability and efficiency criteria defined by the interviewee during the second part of the interview.

3.6.4 Finally, the interviewee rated horizontal resolution advisories on a global acceptability scale.

3.7 Justification of the structure

3.7.1 Perceived efficiency and acceptability are difficult notion to assess. They are highly personal and can cover different mixes of different criteria for different people. Furthermore, it was important, for this study, to allow for these, because the purpose was to find out the subjective judgement of operational staff. Whether or not horizontal RAs would be efficient or effective, and whether or not the opinions discovered can be defended objectively, was irrelevant.

3.7.2 In the enforced absence of an agreed definition of what constitutes efficiency and furthermore acceptability of a new tool or technology for controllers and pilots, we decided to explore these elements first. It was the purpose of the second part of the interview.

3.7.3 Only then, with a better understanding of what constituted acceptability for the interviewee, was it possible to ask the interviewee to judge the global operational acceptability of HRAs.

3.7.4 The other advantage of this approach is that this knowledge of what constitutes acceptability for a controller, or for a pilot, can be used a basis for further (and possibly more focused) studies.

[1] Many researchers use seven scale steps as the appropriate balance between scale reliability and discriminative demand on the respondent [7]

4 Pilots

4.1 Population / Interviews

4.1.1 Reminder: 9 pilots have been interviewed.

3 at British Airways HQ in Heathrow on the 8th January 2001,

6 at Air France HQ in Roissy on the 5th and 6th February 2001.

4.1.2 It is to be noted that all of the pilots interviewed are quite experienced (up to 30 years) and have all now, in addition of still being pilots, other administrative responsibilities in their company (see details of population in Annexe A)

4.1.3 Because of the limited availability of pilots, two interviews were conducted with two pilots together:

one at British Airways on the 8th January

one at Air France on the 6th February.

4.1.4 The 2 interviews at British Airways were performed in English. The 5 interviews at Air France were performed in French. All interviews have been recorded on audiotape, with the agreement of the interviewees.

4.2 Main results

4.2.1 Despite some nuisance alerts, the current TCAS is recognised as a very useful tool. One of its most appreciated advantages is that it allows the pilot to have a better picture of the situation around the aircraft. (One of the French pilots reckons that there is a risk of *"using it as, and instead of, a radar and control from the aircraft (*and disregard controller's advisories*)"*)

4.2.2 Pilots mentioned that the first instinctive reaction to most types of encounter is a horizontal manoeuvre.

4.2.3 They all reckon there is a need for horizontal RAs.

4.2.4 As shown by their rating of the Global Acceptability scale (figure 1), pilots were positive about horizontal RAs.

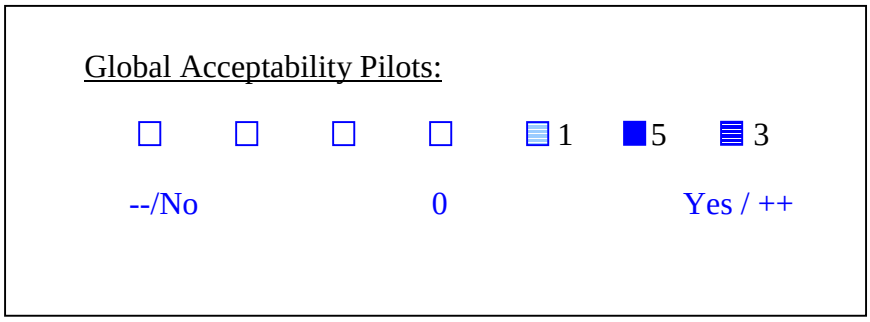

Figure 1: Global Acceptability Scale rated by pilots

4.3 Part 1: opinions on current version of TCAS

4.3.1 Reminder: The first part of the interview explored the interviewee's experience of and opinions on TCAS. It allowed differentiation between opinion on horizontal advisories and comments motivated by previous opinion on TCAS.

4.3.2 As already stated, pilots have a good opinion of TCAS as it is now in use. TCAS is considered as a major improvement regarding safety. A pilot even called it *"the Safety Invention of the (20th) century"*

4.3.3 The two main benefits, or to be precise the two benefits mentioned by all the pilots, are:

huge benefit in some area with poor ATC standards, such as Africa

a better representation of the surrounding traffic, increasing situational awareness (SA)

4.3.4 4 pilots, each in their own words, also mentioned the feeling of confidence regarding controllers:

If the controller "is not very good", or sounds himself not very confident, pilots are happy to have the safety net that is TCAS

Controllers' clearances are better understood as TCAS allows them to have a wider picture of the situation.

4.3.5 They have the feeling that TCAS to a certain extent changed their relationship with controllers for the better. They have the feeling that, as they have a better picture, they are making less information requests. Their manoeuvre requests are also more appropriate.

4.3.6 On the other hand, still concerning the pilot/controller relationship, some of them have the feeling that controllers tend to inform them more "to avoid TCAS surprises" (Traffic Alerts). This is more noticeable in the USA.

4.3.7 On the negative hand side, pilots (7 out of 9) think that their training regarding TCAS is grossly deficient. For most of them, it is reduced to a paper presentation and a single simulation per year. They have the feeling that better training would reduce the number and the range of pilots' over-reactions to TCAS RAs.

4.3.8 They mentioned that the natural tendency of a pilot in case of emergency would be a horizontal manoeuvre rather than a vertical one. Vertical manoeuvres are thought to be efficient but not instinctive. This reinforces the need for better training mentioned above.

4.3.9 Lots of the pilots mentioned nuisance alerts but, if those are Traffic Alerts, they are still acceptable.

4.3.10 More problematic are the false or unjustified Resolution Advisories for they create a high level of stress, lead to unnecessary and sometime even dangerous manoeuvres and cause users to question the reliability of TCAS.

4.3.11 In relation to the last points, 5 pilots complained that current versions of TCAS were poorly adapted to some specific airspace configurations, e.g. RVSM.

4.3.12 Finally, 4 pilots expressed regret that TCAS was not taking into account the "intent" of the aircraft. This would, in their view, avoid many false alarms when one or both aircraft are manoeuvring.

4.4 Part 2: acceptability criteria

4.4.1 Reminder: In the absence of an agreed definition of what constitutes efficiency and acceptability of a new tool or technology for controllers and pilots, we decided to explore these elements during the second part of the interviews.

4.4.2 Pilots were asked to give the main criteria they are taking into account to assess the efficiency and operational acceptability of a new tool. A suggestions list has been prepared in case of lack of inspiration. This list has not been used during the interviews.

4.4.3 First criteria (criteria A)	cited by 'n' pilots
Easy to understand, intuitive coding	3
Simplicity	3
Integrity	2
Correspond to a real need	1

4.4.4 Second criteria (criteria B)	cited by 'n' pilots
Consistent, predictable	2
Ease of interpretation	2
Reliability	2
Efficacy	1
Ease of use	1
No revolution, possible to fly without it (!)	1

4.4.5 Third criteria (criteria C)	cited by 'n' pilots
Response to a real need	2
Integrated in the system and HMI	2
Ease of access to information (ergonomically speaking)	1
Understandable behaviour	1

4.4.6 Fourth criteria (criteria D)	cited by 'n' pilots
Reliability	1

4.4.7 Note: The pilots were free to give as many criteria as they wanted. Most of them gave 3 criteria, focusing on the most important ones.

4.4.8 It is interesting to see that, although there is no consensus on one criteria at a specific rank, the most cited criteria are related to simplicity: simplicity of coding, of use or of understanding (cited 10 times in total)

4.5 Part 3: simulations

4.5.1 Reminder: Two dynamic simulations of a realistic display of horizontal resolution advisories were shown to the interviewee. Static pictures of HRA displays for other encounters were also shown on request. As during the controllers' interview, it was emphasised that the aim of the study was not an HMI evaluation. It is a concept exploration. Pilots were invited to "think aloud", to comment on what is presented, as freely as possible.

4.5.2 In order to solicit the opinions of pilots it was necessary to display to them the HRAs. In the absence of an agreed standard HRA display, DERA have devised a possible display based on the aircraft attitude display [3]. This is shown below: the left-hand diagram shows the primary flight display (PFD) of an aircraft at the instant the HRA is issued; the right-hand diagram shows the PFD some seconds later when the pilot has manoeuvred the aircraft to comply with HRA (more details can be found in reference [3]).

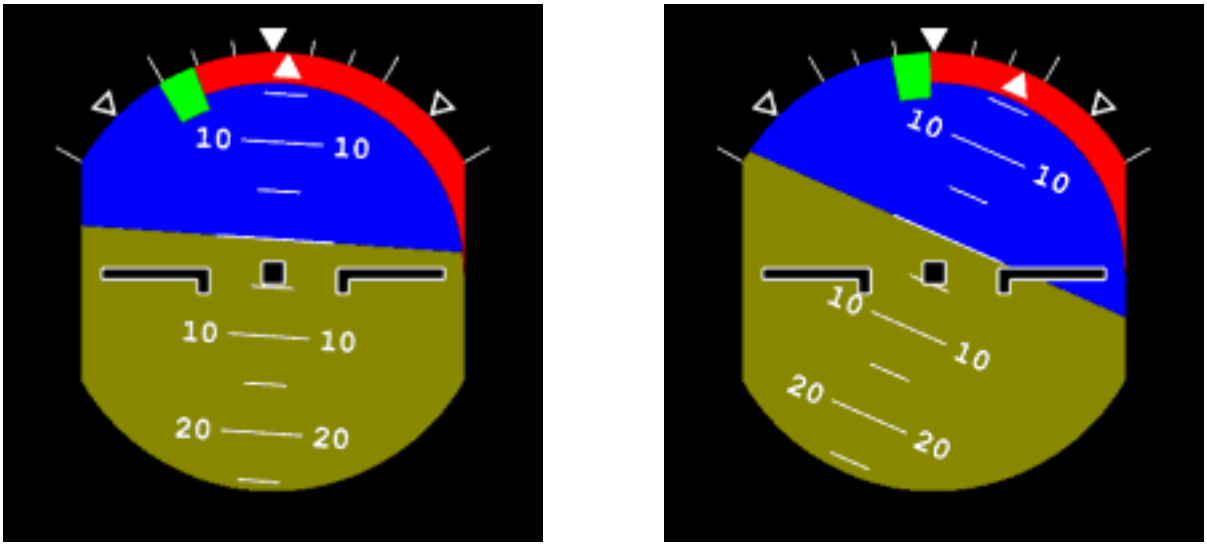

Figure 2: HRA, pilots' display

4.5.3 Note: For the first two interviews, only one dynamic simulation was available. In this simulation, the green segment indicating the required bank angle disappeared as soon as the aircraft achieved the required attitude (the red sector, however, remained). In the light of pilot comments (see 4.5.7) one of the dynamic displays was adapted so that the green segment remained (but reduced in size) when the required bank angle was achieved: displays illustrating both behaviours of the green segment were available in the subsequent interviews.

4.5.4 Finally, the simulation were only visual, the alert message was simulated only as a text message.

4.5.5 Pilots were pleased by the simplicity of the HMI. The display was judged easy to understand, straightforward and in agreement with current coding in use.

"Bien… immédiatement assimilable !" (Good… easily assimilated!)

4.5.6 5 pilots expressed regret at not having the audio messages as part of the simulation. Once again they were reminded that the purpose of the study was not an HMI evaluation. Nevertheless, it underlines the importance of these audio messages.

4.5.7 The 3 pilots interviewed at British Airways (only one dynamic simulation + green segment disappearing: see point 4.5.3) expressed their preference for the green segment to stay on the display

even when the aircraft achieved the required bank angle. The Air France pilot when looking at the first simulation made the same comments.

4.5.8 Examples of comments:

"The pilot wouldn't expect the green to go out. Might ask himself, am I doing the right thing?"

"La zone verte me rassure, je sais que je suis a l' optimal. C' est une situation d'urgence, c'est important d' être rassuré" (The green segment reassures me, I know that I am in the optimal. It is an emergency situation so it is important to be reassured)

"La zone verte doit rester. Si on regarde ailleur quand on atteint le segment vert on peut se demander ce qu' il se passe. Pourquoi plus de vert? Ai je fait une erreur? Y a t il un autre problème?(The green segment should stay. If you are watching somewhere else when it disappears you can wonder: what is happening? Why isn't there any green anymore? Have made a mistake? Is there another problem?)

4.5.9 Some pilots suggested that the green segment could be extended to indicate the maximum acceptable bank angle of the manoeuvre. The HRA displays devised for this study were intended to be analogous to the vertical RA displays on IVSIs, in that the green segment indicated the minimum target manoeuvre in a corrective RA. Indeed, any bank angle beyond that indicated by the green segment would be acceptable from a collision avoidance point of view: the limit of an extended green segment would have to be determined separately with due regard to the aerodynamic envelope of the aircraft.

4.5.10 It is to be noted that the vast majority of the comments, during the simulations, were on the HMI rather than on the concept itself. It is extremely difficult to abstract, or not to focus on the HMI, the first time you are presented with a new tool. Further studies on the operational acceptability of HRA should take this point into account and might require alternative exploration techniques.

4.5.11 Only one pilot made a comment, during the simulation, on the nature of the resolution itself. He declared that in the case of the scenario 5 a vertical resolution would have been more appropriate.

4.6 Part 4: Horizontal Advisories

4.6.1 The general reaction of the pilots is without any doubt positive. They see HRAs as a useful tool that will improve safety. A very enthusiastic French pilot even declared that if TCAS did not already exist it should be invented with Horizontal RA from the outset.*("Si TCAS n' existait pas, il faudrait l'inventer avec des HRAs dès le début"*)

4.6.2 Resolution in the horizontal plane seems to be in agreement with a natural tendency. The pilots even mentioned several cases in which pilots did react to a vertical RA with a horizontal manoeuvre.

4.6.3 When asked if, perhaps, this tendency was seen more in a certain category of pilots e.g. young pilots, they opined that is a general tendency among all pilots.

4.6.4 The other advantage anticipated is in RVSM airspace. HRAs are thought to be particularly adapted to this situation. The number of nuisance alarms caused by the poor adaptation of the current version of TCAS to RVSM is expected to be dramatically reduced.

4.6.5 It is also thought to be a good solution to avoid "chains" of resolution advisories (i.e. situations in which the response to one RA induces another incident with a third aircraft). They are considered more a risk in the case of vertical manoeuvres.

4.6.6 Some pilots asked whether aircraft were going to be equipped with the horizontal system only, or if it would be a combination of horizontal and vertical advisories according to the situation. Two pilots would be happy with the latter option. Two other pilots expressed concerns about the criteria that will lead the system to choose one solution or another. It will have to be very clear for the pilot. A fourth pilot thinks it would be too confusing, especially in emergency situations.

4.6.7 Three pilots went a step further and evoked the possibility of combined resolution advisories. One pilot considered this a bad idea, since it might create a need for the pilot to interpret the advisory. It might then be a source of error. For this pilot, it was essential always to keep in mind that TCAS RAs occur in emergency situations and are accompanied by stress. The two other pilots, on the opposite side, were more focused on the efficiency and accuracy of the manoeuvre. They were in favour of combined RAs.

4.6.8 <u>If they were in charge of the development of HRAs:</u>

All of them would conduct detailed studies both at a technical level and at a Human Factors level

3 pilots mentioned that the technical studies must consider carefully the technical flying possibilities of different types of aircraft in different situations (speed, altitude…)

More Human Factors studies should be made (the current approach was judged very positively). Furthermore, their results should be advertised. Knowing that your peers have been involved in the development of a tool and that their opinion was taken into account is, according to them, an important pre-requisite for that new tool to be accepted.

Finally, 4 pilots emphasised the need for a well designed training programme.

2 pilots mentioned the need to inform controllers of what HRAs were about and what was the policy of the companies.

They would make sure that the green segment stays displayed until the situation is safe again.

4.6.9 If they were in charge of training

Four pilots had already expressed spontaneously the need for proper training. One of them even proposed a single syllabus for both pilots and controllers to allow a better mutual understanding.

But some other pilots, on the other hand, thought that the HMI and logic of HRAs were, or should be, clear enough to be used without any specific training.

Nevertheless all of them said there is a need for more simulations. One a year is definitely not enough.

Finally 3 of them mentioned the importance of training the pilot to react immediately to a HRA without questioning the proposed solution, but also without overreacting

4.7 Part 5: Wrap up, Scales rating

4.7.1 Reminder: During the last part of the interview, the interviewer tried to summarise the main points discussed. It enabled both parties to check that there were no misunderstandings and that the most important points, for the pilot, had been recorded.

4.7.2 Seven-step rating scales were used to support this last part of the interview. The interviewees were asked to score to what extent horizontal RAs satisfy (or not) the acceptability and efficiency criteria defined by themselves during the second part of the interview. Finally, the interviewee rated Horizontal Resolution Advisories on a global acceptability scale

4.7.3 The scales proved to be a useful support for this final part of the interview. Some pilots even commented positively on the fact that they were asked to rate HRAs according to their own criteria.

4.7.4 Ratings:

Criteria A:

Easy to understand + Intuitive coding = quoted by 3 pilots

☐ ☐ ☐ ☐ ☐ ■ 3 ☐

--/No 0 Yes / ++

Simplicity = quoted by 3 pilots

☐ ☐ ☐ ☐ ☐ ■ 2 ▤ 1

--/No 0 Yes / ++

Integrity = quoted by 2 pilots

☐ ☐ ☐ ☐ ☐ ☐ ☐

--/No 0 Yes / ++

Integrity could not be judged on the basis of simulations alone.

Correspond to a real need = quoted by 1 pilot

☐ ☐ ☐ ☐ ☐ ▤ 1 ☐

--/No 0 Yes / ++

Criteria B:

Consistent (know what to expect) = quoted by **2** pilots

☐ ☐ ☐ ▤ 1 ☐ ☐ ▤ 1

--/No 0 Yes / ++

The positive rating is based on the fact that it corresponded to what the pilot was expecting and is consistent with actual TCAS RA coding. He assessed external consistency.

The neutral rating is because, for this other pilot, consistency cannot be judged on two examples. He was thinking of internal consistency and could not assess it.

Ease of interpretation = **2***

☐ ☐ ☐ ☐ ▤ 1 ▤ 1 ☐

--/No 0 Yes / ++

Those two pilots saw only the simulation with the green arc disappearing when the aircraft achieved the required bank angle. We can reasonably infer that the score would have been more positive had the green arc remained throughout.

Reliability = quoted by **2** pilots

☐ ☐ ☐ ☐ ▤ 1 ☐ ☐

--/No 0 Yes / ++

It is difficult to judge reliability on the basis of just two simulations. That is why one pilot could not rate the scale. The other pilot did it on the basis of what he knows and thinks of actual vertical resolution advisories.

Efficacy

☐ ☐ ☐ ☐ ☐ ▤ 1 ☐

--/No 0 Yes / ++

Although the same comments apply, this pilot based his judgement on an *"improved version of what TCAS is doing now"*

Ease of use

☐ ☐ ☐ ☐ ☐ ▤ 1 ☐

--/No 0 Yes / ++

No revolution, possible to fly without

☐ ☐ ☐ ☐ ☐ ▤ 1 ☐

--/No 0 Yes / ++

Criteria C:

Response to a real need = **2**

☐ ☐ ☐ ☐ ▤ 1 ▤ 1 ☐

--/No 0 Yes / ++

Integrated in the system and HMI = **2**

☐ ☐ ☐ ☐ ■ 2 ☐ ☐

--/No 0 Yes / ++

Ease of access to information (ergonomically speaking)

☐ ☐ ☐ ☐ ☐ ☐ ▤ 1

--/No 0 Yes / ++

Understandable behaviour

☐ ☐ ☐ ☐ ☐ ▤ 1 ☐

--/No 0 Yes / ++

Criteria D:

Reliability

☐ ☐ ☐ ☐ ☐ ☐ ☐

--/No 0 Yes / ++

Only one pilot gave a fourth criterion and was unable to rate it for, as many others, he thought reliability could only be judged after many uses of a tool.

4.8 Rating profiles

4.8.1 The rating profiles give us an indication of the consistency of the ratings. They also give, in a single picture, an explanation on what motivated the final global acceptability rating. Finally, they give another indication regarding the importance of each criterion.

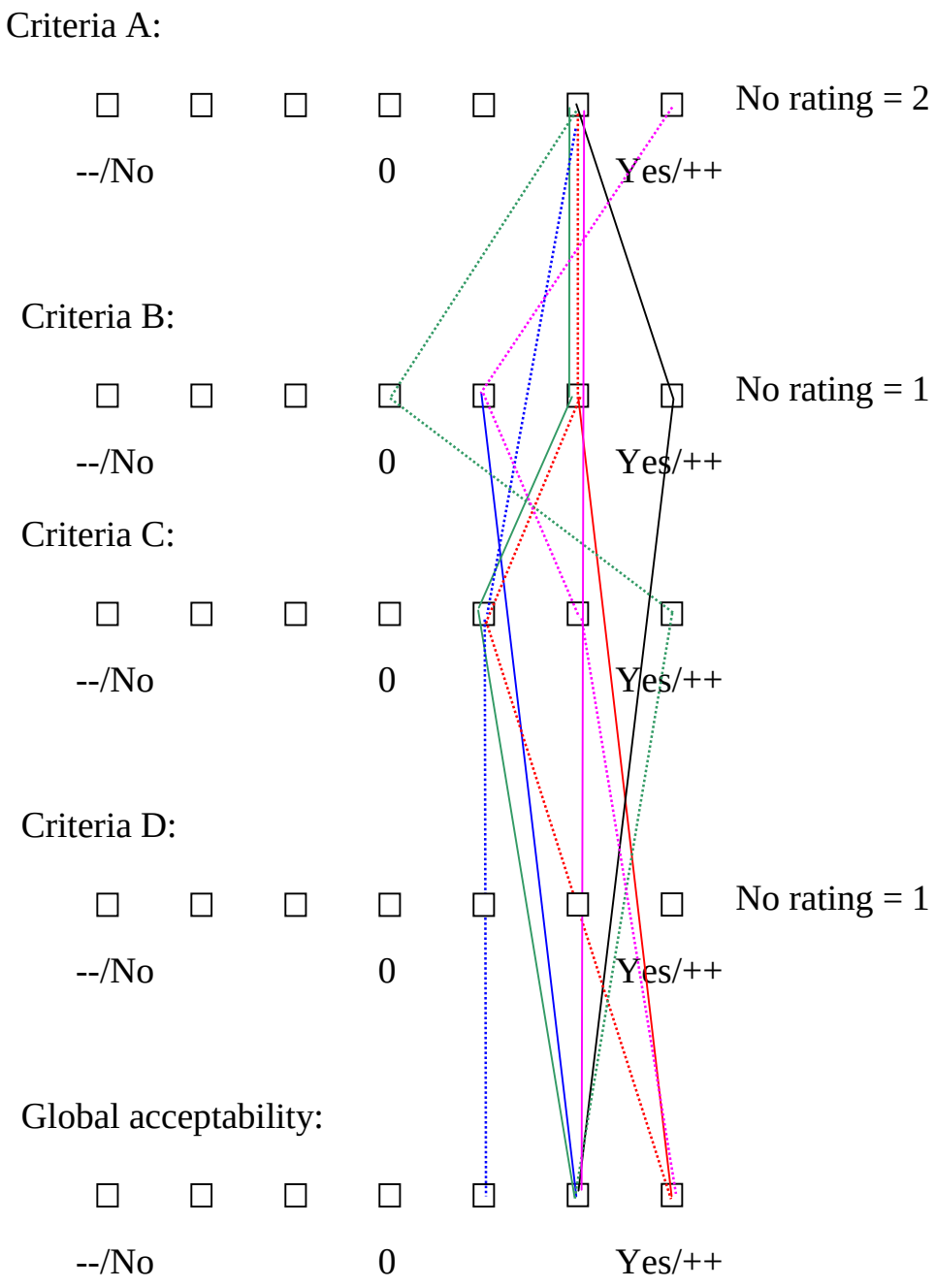

Figure 3: Pilots' rating profiles

4.8.2 It appears clearly that the pilots are very consistent in their ratings. All of them have a profile on the positive side of the scales, which is in total agreement with their final global acceptability ratings.

4.8.3 Nevertheless, it should be noted that for three pilots (four if you include the neutral rating at the second scale), the simulations did not allow them to assess HRAs according to their first criterion (criterion A or B). Those criteria were:

Integrity

Reliability

Internal consistency.

4.8.4 Other ways of exploring those major dimensions of acceptability must be thought of.

5 Controllers

5.1 Population / Interviews

5.1.1 Reminder: 12 controllers have been interviewed.

6 in Aix en Provence, at the CRNA Sud Est, on the 12th and 13th October 2000

6 in Maastricht, at the Upper Airspace Control Centre, on the 7th and 8th February 2001

5.1.2 It is to be noted that, unlike the pilots, controllers have varied lengths of professional practice. Only 2 of them have now administrative responsibilities in addition to being a controller.(see details of population in Annexe A)

5.1.3 The 6 interviews at CRNA Sud Est were performed in French. The 6 interviews at Maastricht Centre were performed in English.

5.2 Main results.

5.2.1 Controllers' results are far less consistent than the pilots' results. Their final rating of the Global Acceptability scale (Figure 4) reflects perfectly this fact. Half of the controllers gave HRAs a negative score; half of them on the opposite side gave a positive score.

5.2.2 Thanks to the use of seven-step rating scales, we can analyse their ratings more precisely. The first observation is that most of the ratings are in fact very close to the middle and neutral step of the scale.

5.2.3 Actually, when looking at each criteria rating (see chapter 5.7) we notice that controllers could not, on many occasions, rate HRA according to their acceptability criteria. Some criteria were simply not rated; some others were given a neutral rating. From their comments we understand that these difficulties are mainly due to the fact that TCAS incorporating HRAs is not a tool to be used directly by the controllers. It is a tool for the pilots.

5.2.4 Some positive ratings (particularly those close to the neutral rating) were a result of the controller distancing himself from the system: *"This tool is not for me, so I can't, or don't want to, say it is not acceptable. It is better to say "rather yes""* The natural tendency to agree with the interviewer and to give the response they thought she was expecting, has probably had an influence here too.

5.2.5 There are also some strong negative ratings. It is interesting to see that those controllers had already negative opinions on current version of TCAS. Before the start of the interview they expressed strong views on HRAs and their final rating was predictable.

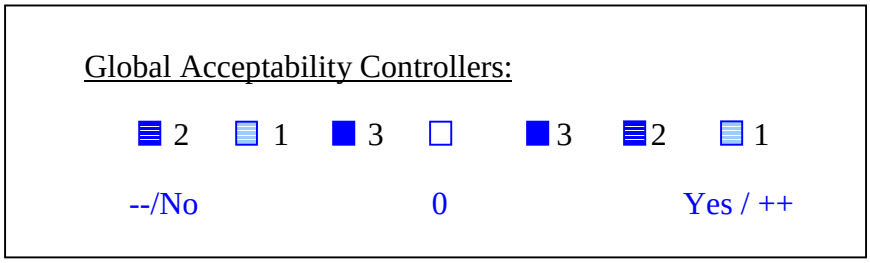

Figure 4: Global Acceptability Scale rated by controllers

5.3 Part 1: Opinions on current version of TCAS

5.3.1 Reminder: The first part of the interview explored the interviewee's experience of and opinions on TCAS. It allowed differentiation between opinion on horizontal advisories and comments motivated by previous opinion on TCAS.

5.3.2 When talking of the current version of TCAS, all the controllers immediately evoked the topic of nuisance alarms. For all of them, there are too many false alarms, creating more workload for no reason. They all mentioned at least one example of a false[2] (or "unjustified", as said the more positive of them) alarm when at least one of the aircraft was climbing or descending.

5.3.3 The second most often evoked aspect is the risk of chain reaction after a TCAS Resolution Advisory in the vertical plane.

5.3.4 This comment is often linked with the regret that TCAS has made it impossible for controllers to operate at the limit of official separation, even though it is judged safe by the controller.

5.3.5 For some controllers, the problem of "TCAS cascade" is attributed more to the overreaction of pilots to RAs than attributed to the system itself. 2 controllers even mentioned cases in which the pilot reacted to a vertical RA in the horizontal plane. This was described as even more disturbing for the controller Horizontal manoeuvres caught their unawareness because they knew TCAS (current version) was not supposed to lead to horizontal deviations.

5.3.6 Information from the pilot has been described as a critical element. 2 controllers insisted on the fact that pilots should inform the controller immediately, i.e. before the start of the resolution manoeuvre.

5.3.7 Controllers reckon that TCAS gives a better picture to the pilots, but they expressed the concern that the pilots can become (or already are) overconfident and do not fully realise that the picture provided by their TCAS is still only a fraction of the wider picture the controllers have. *"sometimes they forget that we have a better view"*

5.3.8 Some controllers regretted that TCAS had not a wider scope, mainly to avoid a manoeuvre that can generate other problems. But, at a certain level, they are quite satisfied to keep the exclusive ownership of this ability.

5.3.9 The fact that pilots have to comply to a TCAS RA, even if the controller has previously given traffic information or another instruction, is neither entirely understood nor entirely accepted. Examples of comments:

"I gave traffic information so it shouldn't have happened (the pilot should not have followed the TCAS RA)".

" La directive doit venir du controleur, c' est ce qui doit primer (the order must be given by the controller. Controller's order must have priority)"

" Quand le pilote l'a, il n' ecoute plus le controleur" (when the pilot has it (TCAS) he doesn't listen to the controller anymore)

[2] "False" was the word used by the interviewees, and it should not be confused with the use of the term in ACAS evaluation programmes to mean an RA caused by some failure of the ACAS to operate as specified. Here it means simply that there was an RA when there was no risk of collision.

5.3.10 TCAS has changed their way of working in the sense that they are giving much more information to the pilots than before. For some of them this is not a big change, but for 2 controllers it is a source of extra workload.

5.3.11 3 controllers also attribute extra workload to the lack of predictability of TCAS and the risk of chain reactions.

5.3.12 Despite all those rather negative comments, controllers declared they have a globally positive opinion on TCAS. TCAS has a safety purpose and safety is (one of) the main concern of every controller.

5.3.13 3 controllers admitted that they were feeling more confident knowing that TCAS was *"in the aircraft as an ultimate safety net"*

5.3.14 Finally, it is interesting to note that controllers from Aix en Provence are more open to the idea of horizontal RAs. Controllers from Maastricht think that it would be better to improve first the current version with its vertical resolutions. Two factors can explain these global tendencies:

The different structure of the airspace controlled by the centres (Aix en Provence "in Layers")

The presence in the team and at management level of controllers with very strong negative opinions (Maastricht)

5.4 Part 2: Acceptability criteria

5.4.1 Reminder: In the absence of an agreed definition of what constitutes efficiency and furthermore acceptability of a new tool or technology for controllers and pilots, we decided to explore these elements during the second part of the interviews.

5.4.2 Controllers were asked to give the main criteria they are taking into account to assess the efficiency and operational acceptability of a new tool. A suggestions-list has been prepared in case of lack of inspiration.

5.4.3 First criteria (criteria A)	cited by 'n' controllers
Ease of use	3
Reliability	3
Respond to real need	2
Predictable	2*
Accurate	1*
Tested, proven efficacy	1
Simplicity	1

* One controller put the combination Accurate + Predictable as his first acceptability criteria.

5.4.4 Second criteria (criteria B)	cited by 'n' controllers
Ease of use	4
Simple	3
Accurate and fast	1
Predictable	1
Fast	1
Benefit corresponding to a real need	1
Reliability	1

5.4.5 Third criteria (criteria C)	cited by 'n' controllers
Easy to understand (including its limitations)	4
Reliable	2
Easy to use	1
No disruption of other task	1
Reduce workload	1
Concision of information	1

5.4.6 Fourth criteria (criteria D)	cited by 'n' controllers
Understanding of functioning and limitations	2
Efficacy	1
Predictable	1
Consistent	1
Responds to a real need	1

5.4.7 Fifth criteria (criteria E)	cited by 'n' controllers
Transparent	1
Understanding of what the tool is doing	1

5.5 Part 3: Simulations

5.5.1 Reminder: CENA have sent DERA encounters featuring examples of possible horizontal resolution advisories (HRAs) and manoeuvres. These comprise 6 original encounters, giving 9 equipage scenarios with a total of 15 HRAs.

5.5.2 DERA converted the encounters into EU1 format (the aircraft's position and altitude are given at 1s intervals) so that the encounters can be viewed with InCAS.

5.5.3 Four to six encounters simulating horizontal RAs, were shown to the interviewee. It was emphasised that the aim of the study was not an HMI evaluation. It is a concept exploration. Controllers were invited to "think aloud", to comment on what is presented, as freely as possible.

5.5.4 The first main comment of the controllers was on the lack of realism of the simulation. Controllers were surprised, some even shocked, by the fact that only two aircraft were simulated. It is not the fact that the encounters themselves involved 2 aircraft that was criticised but the lack of surrounding traffic.

Surrounding traffic is, for a controller, a critical element to take into account when planning a manoeuvre. They said they could not really assess the accuracy and appropriateness of the proposed resolution without the picture of the surrounding traffic.

TCAS is generally seen as a tool that is supposed to compensate a deficiency of the controller. Having a TCAS Resolution Advisory, when only 2 aircraft are part of the situation was felt to be slightly insulting by some of the controllers.

"With 2 aircraft it is not realistic. It's with all the other aircraft in the way that it is difficult to sort out the problem!"

5.5.5 Even though reminded that the purpose of the study was not an HMI evaluation, it was difficult for the controllers to ignore the HMI. Unfortunately, the controllers were shown a display in which the fact of a RA and a vertical arrow (up or down), indicating the sense, were displayed in the radar label at the moment the RA was issued. Even though the controllers had been warned that this feature was not relevant, and even though a static picture of the more probable display was presented, this feature appears to have distracted the controllers from the main issue.

5.5.6 Comments, reactions to specific scenarios: (see scenarios description in Annexe C) It is to be noted that not all the scenarios were shown to all the controllers. Furthermore controllers did not necessarily comment on all the scenarios that were presented to them;

Scenario 1: Most of the controllers, especially in Aix en Provence, would not have chosen a turn of the faster aircraft to the left. *"Turn left only makes the conflict last longer"* One controller thought that the resolution, if in the horizontal plane, should have started earlier. One other controller would have preferred, in this case, a vertical solution.

Scenario 2: Is not seen as a real problem. It is for the controllers an example of an unnecessary RA. *"In theory it should be safe". "This resolution is a complete nuisance! No need"* While observing this scenario, 3 controllers from Maastricht underlined that, according to the type of airspace they are controlling, HRAs could be more disturbing than vertical manoeuvres *"In this case a Vertical RA would have been less disturbing"*

Scenario 3: Here again, the controllers did not see the justification of the RA. *"D' apres moi ce n' est pas un probleme… Je ne comprend pas… Par contre la ca peut etre un probleme pour le controle si il tourne a cote" (According to me there is no problem…I don't understand…but it can be a problem for the controller if it turns horizontally). "Reduce descent is acceptable but Turn Left is far more dangerous .. possibility for a cascade"*

Scenario 4*:* Few comments, not shown every time. For one controller everything was OK. One other regretted that TCAS was only taking into account the horizontal distance[3].

Scenario 5: Few comments, not shown every time. One controller would have preferred a vertical resolution of this encounter.

Scenario 6: Opinions diverge on this scenario. For some controllers, a vertical solution would be better. For some others, this resolution was a good one but there were reservations regarding its timeliness.*"c' est bien… mais c' est tard" (it is good… but late).* One controller stated that the success of this manoeuvre was dependent on an extremely quick reaction from the pilot.

Scenario 8: is once again not seen as a problem and considered as an unnecessary resolution advisory.

5.5.7 At the end of this part of the interview, controllers seemed concerned about the criteria that will be taken into account by the system to choose between a vertical resolution and a horizontal resolution.

5.5.8 Some controllers also mentioned the need to train the pilots. They wanted accurate and timely information.

[3] Of course, TCAS actually does not take account of only the Horizontal distance.

5.6 Horizontal Advisories

5.6.1 It is interesting to note that controllers who expressed a positive opinion on HRAs assumed that the simulations were only a first draft and that the logic of HRAs would be dramatically refined. Their positive comments are on the concept itself.

5.6.2 The importance of the entire situation, of the surrounding traffic was again underlined. Depending on this wider traffic situation, HRAs can either be a good or a bad solution.

5.6.3 This is in agreement with the concern on how the choice between vertical and horizontal advisories will be made by the system.

5.6.4 Controllers from Maastricht had a tendency to think that HRAs were not adapted to the specific characteristics of the airspace they are controlling.

5.6.5 However, all the controllers think that HRAs are less, or not at all, suitable for manoeuvring traffic.

5.6.6 Few controllers (4) think that HRAs would be a better solution than vertical RAs in an RVSM environment. But on the other hand, some others do not see any problem with the current vertical advisories if pilots do not overreact.

5.6.7 Nevertheless, there is a tendency, more marked in Aix en Provence, to think that HRAs are less disturbing than VRAs. If there is a chain reaction, things are happening more slowly and the controller has a chance to regain control of the situation.

5.6.8 3 French controllers pointed out what one of them called the "horizontal paradox". Horizontal resolutions might be more suitable and create fewer knock-on problems, but to be efficient the manoeuvre has to start earlier. And TCAS is an emergency system. *" si TCAS est le dernier filet de securite, l' horizontal seul ne marche pas. Il faut commencer trop en amont.. . on n' est plus dans l' urgence" (if TCAS is the last safety net, resolution only in the Horizontal plan will not work. You have to start in advance…it is not an emergency anymore)*

5.6.9 <u>How to improve HRAs</u>

The first and most frequent answer is to manage to take into account the surrounding traffic.

The second is to try to take the intent, particularly the clearance, into account in order to reduce the number of false alarms in the case of manoeuvring aircraft.

Then there is the training of pilots, who should inform the controller as soon as possible and with no ambiguity on the type of RA: vertical or horizontal (and in which direction!)

Pilots should also be trained in order to limit overreaction due to stress.

Another way of improving HRAs is to work on a combined version vertical + horizontal.

Finally, for a minority of controllers, the only way of improving HRAs is to stop their development and simply forget the idea!

5.6.10 <u>If they were in charge of the training</u>:

They would try to explain the logic and the behaviour of the tool to the controllers. This way they expect to lessen surprise effects. 2 enthusiastic French controllers even thought of a combined controller/pilot training to improve understanding AND communication.

But the majority of them would only focus on pilots' training. *"there is no training to do for the controller, he is not going to use it".*

5.7 Part 5: Wrap up, Scales rating

5.7.1 Reminder: During the last part of the interview, the interviewer tried to summarise the main points discussed. It enabled both parties to check that there were no misunderstandings and that the most important points had been recorded.

5.7.2 Seven-step rating scales were used to support this last part of the interview. The interviewee was asked to score to what extent horizontal RAs are satisfy (or not) the acceptability and efficiency criteria defined by themselves during the second part of the interview. Finally, the interviewee rated horizontal resolution advisories on a global acceptability scale

5.7.3 It was much more difficult for the controllers than for the pilots to rate the different scales. The main reason is that TCAS was not perceived as a tool for controllers but as a tool for pilot having an impact on the controller's task. It explains the higher number of non-rated scales. It is also at the origin of a higher number of neutral ratings. The following comment is a good illustration: *"This tool is not for me, I can't judge it"*.

5.7.4 Ratings:

Criteria A:

Ease of use = **3**

☒ 1	☐	☐	☒ 1	☐	☐	☒ 1
--/No			0			Yes / ++

It is interesting to note that those very different responses are motivated by the same reason. There will be no direct interaction between the controller and the TCAS HRA. Actually they won't use it. So one is thinking "It is not easy to use because I don't use it" the other one thinks "As I have nothing to do it is easy to use" and the third one prefers to remain neutral.

Reliability = **3**

☐	☐	☐	☒ 2	☐	☐	☐
--/No			0			Yes / ++

Controllers felt it was impossible to assess reliability on the sole basis of laptop computer simulations. They remained neutral or did not provide a mark.

Respond to real need = **2**

☐	☐	☐	☒ 1	☒ 1	☐	☐
--/No			0			Yes / ++

Predictable = **2***

▤ 1	☐	▤ 1*	☐	☐	☐	☐
--/No		0			Yes / ++	

Accurate = **1***

☐	☐	■ 1*	☐	☐	☐	☐
--/No		0			Yes / ++	

* One controller put the combination Accurate + Predictable as his first acceptability criteria. He has confirmed that his rating was taken into account both criteria.

Tested/Proven efficacy:

☐	☐	☐	☐	☐	☐	☐
--/No		0			Yes / ++	

By definition this criteria could not be rated

Simplicity

☐	☐	☐	☐	☐	☐	☐
--/No		0			Yes / ++	

Criteria B:

Practical, ease of use: = **4**

☐	☐	▤ 1	■ 3	☐	☐	☐
--/No		0			Yes / ++	

3 of the controllers who put “ease of use” as their second criteria chose a neutral rating because HRAs are not going to be “used” by controllers.

Simple: = **3**

☐	☐	☐	■ 2	☐	▤ 1	☐
--/No		0			Yes / ++	

Accurate and fast:

☐ ☐ ☐ ☐ ■1 ☐ ☐

--/No 0 Yes / ++

"*the information is incomplete, there is a need for a sound signal (for controllers) in addition*"

Predictable

☐ ■ 1 ☐ ☐ ☐ ☐ ☐

--/No 0 Yes / ++

Fast

☐ ☐ ☐ ■ 1 ☐ ☐ ☐

--/No 0 Yes / ++

Benefit corresponding to a real need

☐ ☐ ☐ ■ 1 ☐ ☐ ☐

--/No 0 Yes / ++

"*There is a need for ACAS, however I cannot tell whether it is of any use*"

Reliability

☐ ☐ ☐ ☐ ☐ ■1 ☐

--/No 0 Yes / ++

Rating made according to what the controller knew and thought of current TCAS version.

Criteria C:

Easy to understand, including its limitations = **4**

☐ ▤ 1 ☐ ☐ ▤1 ■2 ☐

--/No 0 Yes / ++

Reliable = **2**

☐ ■ 1 ☐ ■ 1 ☐ ☐ ☐

--/No 0 Yes / ++

Once again this neutral rating is due to the fact that reliability cannot be assessed after only a demonstration.

The negative rating is explained by the fact that an action of the pilot is required and *"this can not be relied on"* This controller expressed very strong opinions on pilots and the fact that they (sometimes) overreact to TCAS RAs.

Easy to use

☐ ☐ ☐ ☐ ☐ ■1 ☐

--/No 0 Yes / ++

"*For the pilot!"*

No disruption of other tasks

☐ ■ 1 ☐ ☐ ☐ ☐ ☐

--/No 0 Yes / ++

"*The horizontal RA would cause more knock on work than vertical RA"*

Reduce workload

■ 1 ☐ ☐ ☐ ☐ ☐ ☐

--/No 0 Yes / ++

Concision of information

☐ ☐ ☐ ☐ ☐ ☐ ■ 1

--/No 0 Yes / ++

Criteria D:

Clear understanding of functioning and limitations = **2**

▤ 1	☐	☐	☐	▤ 1	☐	☐
--/No			0			Yes / ++

Comment accompanying the strongly negative rating "*Its decision which direction to turn does not seem easy to understand or predict*"

Efficacy

☐	☐	☐	■ 1	☐	☐	☐
--/No			0			Yes / ++

"*It depends on the situation, if aircraft are evolving*[4]*, in general, I would say HRA are not good. With RVSM they might be (good)*"

Predictable

☐	☐	☐	☐	☐	■ 1	☐
--/No			0			Yes / ++

Consistent

■ 1	☐	☐	☐	☐	☐	☐
--/No			0			Yes / ++

Responds to a real need

☐	☐	☐	☐	☐	☐	■ 1
--/No			0			Yes / ++

This rating is more a recognition of the need for resolutions in the horizontal plane than a judgement on how well HRAs respond to this need.

[4] This is what he said. English is not this controller's first language. He meant "climbing or descending".

Criteria E:

Transparent

■ 1 ☐ ☐ ☐ ☐ ☐ ☐

--/No 0 Yes / ++

"Because it is going to increase workload and monitoring. Will create problems"

Understanding of what the tool is doing

☐ ☐ ☐ ☐ ☐ ☐ ☐

--/No 0 Yes / ++

Could not rate after few simulations.

5.8 Rating profiles

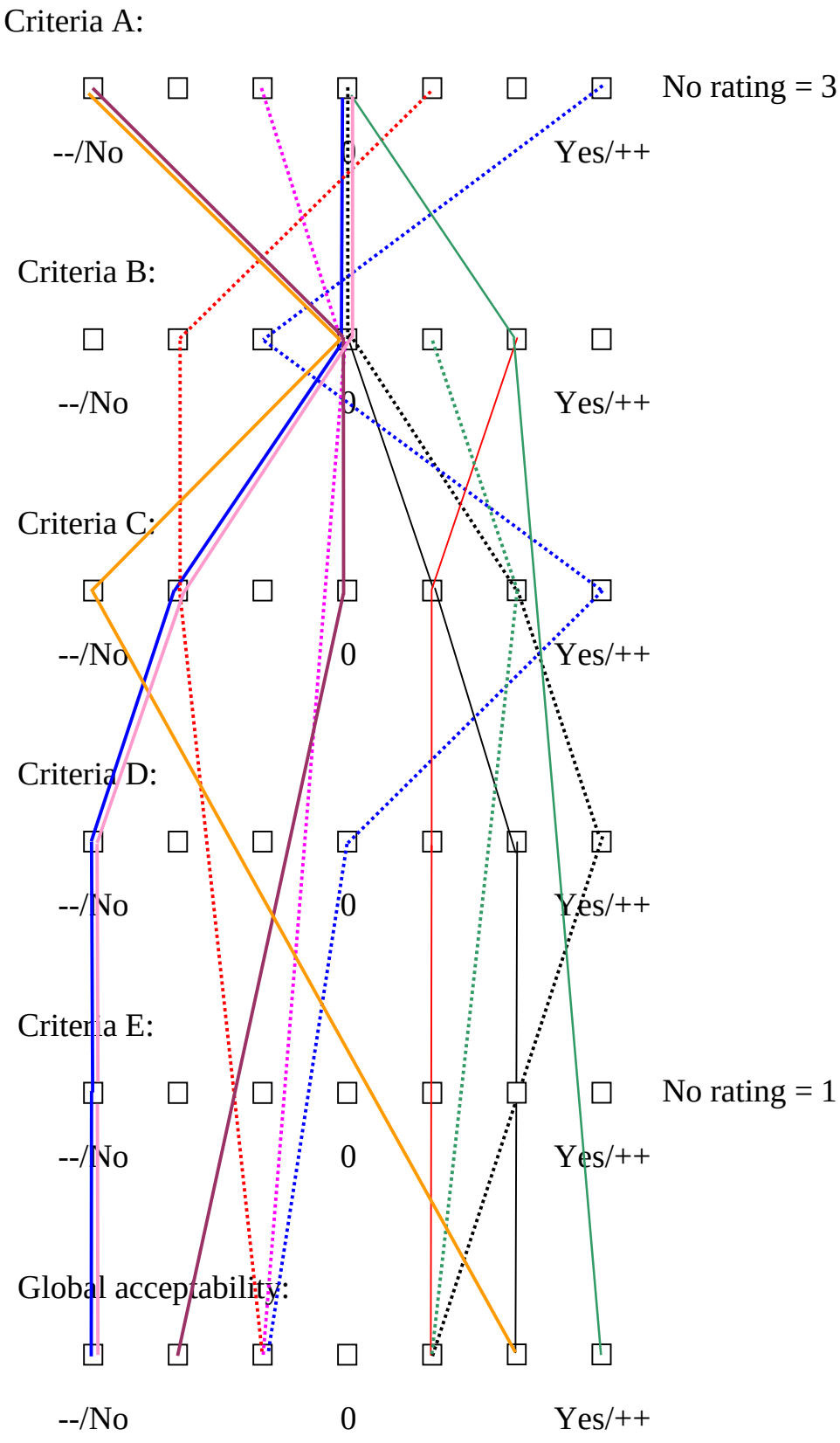

Figure 5: Controllers' rating profiles

5.8.1 It is interesting to see that the picture of controller's rating is far less simple and compact than the pilots' rating profiles.

5.8.2 It was much more difficult, for the controllers, to rate those scales because they do not think of TCAS as a controller's tool. It is clearly a tool for the pilot.

5.8.3 The logic of some final ratings can also be questioned. A controller gave either negative ratings or no ratings for all of the acceptability criteria but her final, global acceptability rating is quite high. On the other hand, another controller twice gave the most positive ratings but ended with a negative rating for the global scales.

5.8.4 Finally, as already mentioned, some positive ratings (particularly those close to the neutral rating) were a result of the controller distancing himself from the system: *"This tool is not for me, so I can't, or don't want to say it is not acceptable. It is better to say "rather yes""*

6 Conclusion, recommendations

6.1.1 The opinions and attitudes of the pilots regarding horizontal resolution advisories is clearly positive.

6.1.2 The opinions and attitudes of the controllers are far more diverse. There is not one unique and clear tendency.

6.1.3 The format of the study and the structure of the interview have been useful and well accepted in the case of the pilots. None of them had difficulties in rating the scales, for example.

6.1.4 Unfortunately, the same comment cannot be made in the case of the controllers. This may be due to several elements:

TCAS is not a tool for the controller, it does not present information to him, it does not require an immediate action from him.

Even if not clearly stated, TCAS is associated with the idea that the controller has made a mistake.

In a way, having TCAS allows the pilot to perform control tasks. The “power” of the pilot is increased. But there is no enrichment of the controllers’ tasks.

According to them, the realism of the simulations used for this study did not allow the controllers to really assess the acceptability of horizontal resolution advisories

Finally some controllers of our population had very strong opinions on TCAS. Those strong opinions may have prevented them from considering horizontal RAs dispassionately. They might also have had an influence on other controllers.

6.1.5 Another study should be made to assess controllers’ opinions and reactions on horizontal advisories.

It is now clear that this study would have to be specifically designed for them.

If simulations are to be used, they must involve surrounding traffic.

If this is not possible, simple but detailed descriptions of scenarios would be preferable.

The acceptability criteria given by the controller during the second part of the interviews can be used as direction of investigation.

7 References

7.1 ACASA

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[2] E. Jeannot- DERA *WP8.3 Workplan*, 11-7-2000, version D 1.1

[3] H. Hutchinson- *DERA WP8.3, Technical notes on encounters received from CENA*, 6-7-2000, version 0.2

[4] B. Hasquenoph & S. Chabert- CENA *WP8.1 Acceptability of ACAS horizontal advisories*, 20-6-2000, version 2.0

7.2 Methodology

[5] J.M.C. Bastien, Laboratoire d' Ergonomie Informatique Paris V, 1999, *Approches, méthodes et techniques d' évaluation des systèmes interactifs*

[6] Information Systems and Commercial Vehicle Operations, 1996, Development of Human Factors Guidelines for Advanced Traveler, *Exploring Driver Acceptance of In-vehicle Information Systems*, publication No FHWA-RD-96-143

[7] J. R. Lewis, 1995 IBM Computer Usability Satisfaction Questionnaires: Psychometric Evaluation and Instructions for Use, International Journal of Human- Computer Interaction 7(1) 57-78

Annexe A: Population

1 Profile Controllers

Population (N) = 12

1.1 Aix en Provence CRNA Sud Est , 12-13 October 2000

Interview C1:

C1: Controller for 2 years

Fully qualified in this Centre: since January 2000

Other Responsibilities: no

Interview C2:

C2: Controller for 23 years (Tower + Other ATC Centre)

Fully qualified in this Centre: for 14 years

Other Responsibilities: no

Interview C3:

C3: Controller for 5 years

Fully qualified in this Centre: for 4 years

Other Responsibilities: no

Interview C4:

C4: Controller for 29 years

Fully qualified in this Centre: for 23 years

Other Responsibilities: yes

Interview C5:

C5: Controller for 20 years

Fully qualified in this Centre: for 17 years

Other Responsibilities: yes

Interview C6:

C6: Controller for 6 years

Fully qualified in this Centre: for 2 years

Other Responsibilities: no

1.2 Maastricht, Upper Airspace Control Centre, 07-08 February 2001

Interview C7:

C7: Controller for 6 years

Fully qualified in this Centre: for 5 years

Other Responsibilities: no

Interview C8:

C8: Controller for 11 years

Fully qualified in this Centre: for 9 years

Other Responsibilities: yes

Interview C9:

C9: Controller for 5 years

Fully qualified in this Centre: for 2 years

Other Responsibilities: no

Interview C10:

C10: Controller for 28 years

Fully qualified in this Centre: for 22 years

Other Responsibilities: no

Interview C11:

C11: Controller for 5 years

Fully qualified in this Centre: for 2 years

Other Responsibilities: no

Interview C12

C12: Controller for 16 years

Fully qualified in this Centre: for 13 years

Other Responsibilities: yes

2 Profile Pilots

Population (N) = 9

2.1 British Airways, Heathrow Airport, 08 January 2001

Interview P1 + 2:

P1: Flying for 30 years

Captain: Boeing 757; Boeing 767

Other Responsibilities: yes

P2: Flying for 30 years

Captain: Boeing 757; Boeing 744

Other Responsibilities: yes

Interview P3:

P3: Flying for 13 years,

Captain on Boeing 757; 777 and 747 classic.

Other Responsibilities: yes (recently).

2.2 Air France, Roissy en France, 05-06 February 2001

Interview P4:

P4: Flying for 20 years

Co-pilot: Boeing 737; Boeing 747

Captain: Airbus 320; Airbus 340

Other Responsibilities: yes

Interview P5:

P5: Flying for 26 years

Co-pilot: Caravelle, Boeing 737and Boeing 747

Captain: Airbus 320; Airbus 340

Other Responsibilities: yes

Interview P6:

P6: Flying for 24 years

Co-pilot: Caravelle, Boeing 727, Boeing 747

Captain: Airbus 320; Airbus 310

Other Responsibilities: yes

Interview P7

P7: Captain for 20 years

Captain: Boeing 747-400, Boeing 737, Airbus 320

Other Responsibilities: yes

Interview P8 + 9

P8: Flying for 26 years

Co-pilot: Boeing 727, Boeing 747 Airbus 300

Captain: Airbus 320, Airbus 340

P9: Flying for 18 years

Co-pilot: Boeing 727, Airbus 300, Airbus 310

Captain: Boeing 737, Boeing 747

Other responsibilities: yes for both of them

Annexe B: Interview guide

Introduction of the study, anonymity guarantee and basic interviewee profile

Part 1 previous experience and opinion on TCAS

Before talking of Horizontal Resolution Advisories, I would like us to talk about the TCAS system as it is operational today.

What is your personal experience of TCAS?

Can you tell me about a positive experience with TCAS? Circumstances in which you think TCAS was useful?

In your opinion, what would be the three main positive aspects of TCAS as it is in operation now?

On the other hand, can you tell me about circumstances in which you think TCAS wasn't useful, had a negative impact on *the evolution of the situation* or even had a dangerous or adverse impact *on the encounter*?

What would be the three negative aspects (as it is in operation now)?

How do you think these aspects could be improved?

All in all what is your overall opinion of TCAS?

Part 2 Operational acceptability of new technology

Generally speaking, what characteristics do you expect from a new system or tool for it to be (operationally)?

- Ease of use?
- Help provided?
- Efficacy?
- No disruption to other tasks?
- Clear understanding of what it is doing? When and Why?
- ….?

What characteristic makes it an efficient tool?

- Reliability?
- Consistency in behaviour? Predictability?
- Speed of response…?

Part 3 Simulations

I am now going to show you simulations of Horizontal Resolution Advisories. Once again, can I emphasise that we are evaluating a concept. It is not an HMI evaluation.

Please feel free to comment on what is presented during the simulations.

Part 4 Exploration of Acceptability of Horizontal Resolution Advisories

From what we have just seen, what is your first impression of Horizontal Advisories?

What are/ could be its advantages?

What are/ could be its disadvantages?

Do HRAs appear more suitable for some situations?

- Which ones?

Do HRAs appear more suitable for some specific airspace configuration?

- Low sectors?
- …?

Do HRAs appear more suitable for certain population of controllers?

- Experienced controller or novice?
- Controllers with less experience of the sector?
- …?

Do HRAs appear more suitable for some population of pilots?

Do you see Horizontal Resolution Advisories as useful?

Explain

Can you see benefits in the introduction of Horizontal Resolution Advisories?

If it were operational tomorrow:

- Do you think it will change your way of working
- In which ways? Positive? Negative?

You are in charge of the development and implementation of HRAs:

- What would you do to improve their operational value for controllers?

If you were in charge of presenting, training controllers who might be faced with HRAs in their daily practice:

- How would you do it?
- What would you say?

Part 5 Wrap up

At the beginning of this interview, you mentioned several criteria, several characteristics that a tool or system should have to be operationally acceptable.

I would like you to rate, on the following scales to what extent you think HRAs matches each criterion, has or does not have each characteristic

Criteria A:

☐ ☐ ☐ ☐ ☐ ☐ ☐

No 0 Yes

Criteria B:

☐ ☐ ☐ ☐ ☐ ☐ ☐

No 0 Yes

Etc…

To recap, I will now ask you to rate the overall acceptability of HRA on the following scale

Global acceptability:

☐ ☐ ☐ ☐ ☐ ☐ ☐

No 0 Yes

Finally, Do you think HRAs will work?

Any comment you would like to add?

Annexe C : Scenario description

Encounter 1

Scenario 1								pilot display screenshots	
aircraft	**equipage**	**altitude**	**phase**	**clearance**	**speed**	**heading**	**time of RA**	**HRA**	**VRA**
ABC 001	**TCAS V7**	**FL330**	**level**	**FL330**	**487 kt**	**136 deg**	**03:49:21**	**TURN LEFT**	**DESCEND**
DEF 002	**TCAS V7**	**FL330**	**level**	**FL330**	**422 kt**	**222 deg**	**03:49:21**	**TURN LEFT**	**CLIMB, CLIMB NOW**

Encounter 2

Scenario 2								pilot display screenshots	
aircraft	**equipage**	**altitude**	**phase**	**clearance**	**speed**	**heading**	**time of RA**	**HRA**	**VRA**
ABC 001	**TCAS V7**	**FL165**	**descent**	**FL160**	**340 kt**	**346 deg**	**20:15:01**	**TURN LEFT**	**ADJUST VERTICAL SPEED**
DEF 002	**TCAS V7**	**FL147**	**climb**	**FL150**	**373 kt**	**164 deg**	**20:15:00**	**TURN LEFT**	**ADJUST VERTICAL SPEED**

Aircraft ABC001 receives a TA at 20:14:55. Six seconds later - as he begins to execute a right turn - a "TURN LEFT" RA is issued. The aircraft continues to bank right until, after five seconds, the pilot responds to the RA. The aircraft then quickly complies with the "TURN LEFT" RA achieving a bank angle of 25 degrees at which point the RA weakens with "MONITOR HEADING" enunciated. At 20:15:29 the "CLEAR OF CONFLICT" indication is given and shortly afterwards the pilot begins to return to his original course.

N.B. weakening RA indicated by reducing prominence of green arc

Encounter 3

Scenario 3								pilot display screenshots	
aircraft	**equipage**	**altitude**	**phase**	**clearance**	**speed**	**heading**	**time of RA**	**HRA**	**VRA**
ABC 001	**TCAS V7**	**FL218**	**descent**	**FL210**	**377 kt**	**086 deg**	**09:50:37**	**TURN LEFT**	**ADJUST VERTICAL SPEED**
DEF 002	**unequipped**	**FL193**	**climb**	**FL200**	**404 kt**	**209 deg**			

Scenario 4								pilot display screenshots	
aircraft	**equipage**	**altitude**	**phase**	**clearance**	**speed**	**heading**	**time of RA**	**HRA**	**VRA**
ABC 001	**TCAS V7**	**FL330**	**descent**	**FL210**	**377 kt**	**086 deg**	**09:50:37**	**TURN LEFT**	**ADJUST VERTICAL SPEED**
DEF 002	**TCAS V7**	**FL193**	**climb**	**FL200**	**404 kt**	**209 deg**	**09:50:38**	**TURN LEFT**	**ADJUST VERTICAL SPEED**

Encounter 4

Scenario 5								pilot display screenshots	
aircraft	**equipage**	**altitude**	**phase**	**clearance**	**speed**	**heading**	**time of RA**	**HRA**	**VRA**
ABC 001	**TCAS V7**	**FL280**	**level**	**FL280**	**306 kt**	**045 deg**	**00:00:58**	**TURN RIGHT**	**DESCEND**
DEF 002	**unequipped**	**FL287**	**level**	**FL290**	**488 kt**	**154 deg**			

Aircraft ABC001 is flying straight and level when he receives a TA at 00:00:46. Twelve seconds later a "TURN RIGHT" RA is issued. After five seconds, the pilot responds to the RA, quickly achieving a bank angle of 25 degrees. At 00:01:07 the RA weakens with "MONITOR HEADING" enunciated. At 00:01:15 the "CLEAR OF CONFLICT" indication is given and shortly afterwards the pilot executes a left turn to return to his original course.

N.B. weakening RA indicated by removing green arc.

Encounter 4

Scenario 6								pilot display screenshots	
aircraft	**equipage**	**altitude**	**phase**	**clearance**	**speed**	**heading**	**time of RA**	**HRA**	**VRA**
ABC 001	**TCAS V7**	**FL280**	**level**	**FL280**	**306 kt**	**045 deg**	**00:00:58**	**TURN RIGHT**	**DESCEND**
DEF 002	**TCAS V7**	**FL287**	**level**	**FL290**	**488 kt**	**154 deg**	**00:00:58**	**TURN RIGHT**	**ADJUST VERTICAL SPEED**

Encounter 5

Scenario 7								pilot display screenshots	
aircraft	**equipage**	**altitude**	**phase**	**clearance**	**speed**	**heading**	**time of RA**	**HRA**	**VRA**
ABC 001	**TCAS V7**	**FL258**	**climb**	**FL260**	**379 kt**	**255 deg**	**00:00:51**	**TURN LEFT**	**DESCEND**
DEF 002	**TCAS V7**	**FL275**	**descent**	**FL270**	**423 kt**	**284 deg**	**00:00:48**	**TURN LEFT**	**ADJUST VERTICAL SPEED**

Encounter 6

Scenario 8								pilot display screenshots	
aircraft	**equipage**	**altitude**	**phase**	**clearance**	**speed**	**heading**	**time of RA**	**HRA**	**VRA**
ABC 001	**TCAS V7**	**FL78**	**climb**	**FL80**	**305 kt**	**263 deg**	**00:01:01**	**TURN LEFT**	**ADJUST VERTICAL SPEED**
DEF 002	**unequipped**	**FL90**	**level**	**FL90**	**257 kt**	**028 deg**			

Encounter 6

Scenario 9								pilot display screenshots	
aircraft	**equipage**	**altitude**	**phase**	**clearance**	**speed**	**heading**	**time of RA**	**HRA**	**VRA**
ABC 001	**TCAS V7**	**FL78**	**climb**	**FL80**	**305 kt**	**263 deg**	**00:01:01**	**TURN LEFT**	**ADJUST VERTICAL SPEED**
DEF 002	**TCAS V7**	**FL90**	**level**	**FL90**	**257 kt**	**028 deg**	**00:01:01**	**TURN LEFT**	**CLIMB**