



Operational performance of CP115 in New York airspace

Safety Issue Rectification Extension plus (+) Project SIRE+ Project

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

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1. Introduction

1.1. Background and objective

- 1.1.1. The operational monitoring performed in the former EMOTION-7 project ([EMO1]) has identified a safety issue consisting of unintentional opposite reactions to initial "Adjust Vertical Speed, Adjust" (AVSA) Resolution Advisories (RA) issued by the Traffic alert and Collision Avoidance System (TCAS). In order to address this issue, the EUROCONTROL SIRE+ project has submitted to RTCA a Change Proposal (CP) to the TCAS Minimum Operational Performance Standards ([RTCA1]), under the name CP115 ([SIRE+1]). A significant body of work has been carried out to validate the safety aspects, the Human Factors aspects and the operational aspects of the proposed change.
- 1.1.2. The objective of the study reported in this document is to complement the operational validation of CP115 that has already been performed on the European airspace model ([SIRE+2]) and on radar data collected in the Boston TMA ([SIRE+3]). It aims at confirming that the introduction of CP115 will not disrupt the current operations in a very dense US TMA mixing various types of traffic.
- 1.1.3. Three main topics are addressed by the present study:
 - An assessment of the overall operational performance of TCAS II Version 7 in the New York area, through the identification of all RA events in 3 months of radar data provided by the FAA;
 - A comparison of the operational performance of both Version 7 and CP115 in pair-wise encounters, through the computation of metrics related to the compatibility of TCAS with Air Traffic Control (ATC) and to the airborne perspective;
 - An assessment of the risk of CP115 inducing conflicts with nearby third party aircraft in a very dense US TMA.

1.2. Document overview

- 1.2.1. Section 2 provides background information on the safety issue of unintentional opposite responses to initial AVSA RAs and on the CP115 solution proposed by the EUROCONTROL SIRE+ project, as well as the validation effort accomplished so far on this change proposal.
- 1.2.2. Section 3 presents an overview of the methodology that has been set up to conduct the analysis of CP115 operational performance in New York TMA and of the data used to support this study.
- 1.2.3. Section 4 gives the results of the assessment of current overall TCAS operational performance in the New York TMA, resulting from the analysis based on the radar data.
- 1.2.4. Section 5 assesses the operational performance of CP115 on the events of interest identified by the methodology and compares this performance to the performance of

Version 7. This section also investigates the likelihood of CP115 inducing a conflict with a nearby third party aircraft.

- 1.2.5. Lastly, section 6 draws some conclusions from the analysis of the operational performance of Version 7 and CP115 in the New York airspace.

2. Background

2.1. *The SA-AVSA issue*

- 2.1.1. Monitoring of TCAS performance carried out within the framework of the former EUROCONTROL EMOTION-7 project [EMO1] has permitted to identify several instances where flight crews responded in the opposite direction to that specified by TCAS when an RA was displayed and announced.
- 2.1.2. Many of these unintentional opposite responses were observed for initial “Adjust Vertical Speed, Adjust” RAs. An AVSA RA is typically issued when a TCAS-equipped aircraft is climbing or descending towards another aircraft, and the Collision Avoidance System (CAS) logic determines that the TCAS-desired vertical miss distance between the two aircraft can best be achieved by the TCAS aircraft reducing its vertical speed, while maintaining its current vertical direction. Depending on the geometry of the encounter, the CAS logic can trigger 4 types of AVSA RAs, which differ from the strength of the vertical rate reduction requested (i.e., reduction to 0 fpm, 500 fpm, 1,000 fpm or 2,000 fpm).
- 2.1.3. The proper response to an AVSA RA is always a reduction in vertical speed (i.e., a manoeuvre towards level flight). When a flight crew manoeuvres in the opposite direction to an AVSA RA, it is almost always manoeuvring towards the threat and thus reducing, rather than increasing, the vertical miss distance with the other aircraft. Such an unintentional opposite response increases the risk of collision and therefore represents a safety issue.
- 2.1.4. Observations performed by a major European airline, based on on-board data collected on their A320 fleet, indicate that although AVSA RAs requesting a vertical rate of 0 fpm account for 32% of all AVSA RAs, less than 1% of them induce opposite reactions. On the other hand, AVSA RAs requesting a reduction to 500, 1,000 and 2,000 fpm account for 19 to 24% of all AVSA RAs and opposite reactions are observed in 4 to 7% of them. It can thus be concluded that the vast majority of unintentional opposite reactions occur with AVSA 500, 1,000 and 2,000 RAs.
- 2.1.5. Additionally, opposite reactions to initial AVSA RAs have only been identified on aircraft fitted with vertical speed TCAS displays. However, the SA-AVSA issue is not specific to a given implementation, as it has been observed on Embraer RJ, Airbus A320, Canadian RJ, MD11, etc ...
- 2.1.6. Through different investigations (e.g., SIRE+ team, airlines), the TCAS design has been identified as the main factor leading to opposite reactions to initial AVSA RAs. Indeed, the position of the green arc or the green area on vertical speed displays can be misleading. This is illustrated by the following figure, which shows a number of RAs as they are displayed on a vertical speed tape and what the requested reaction to these RAs is.

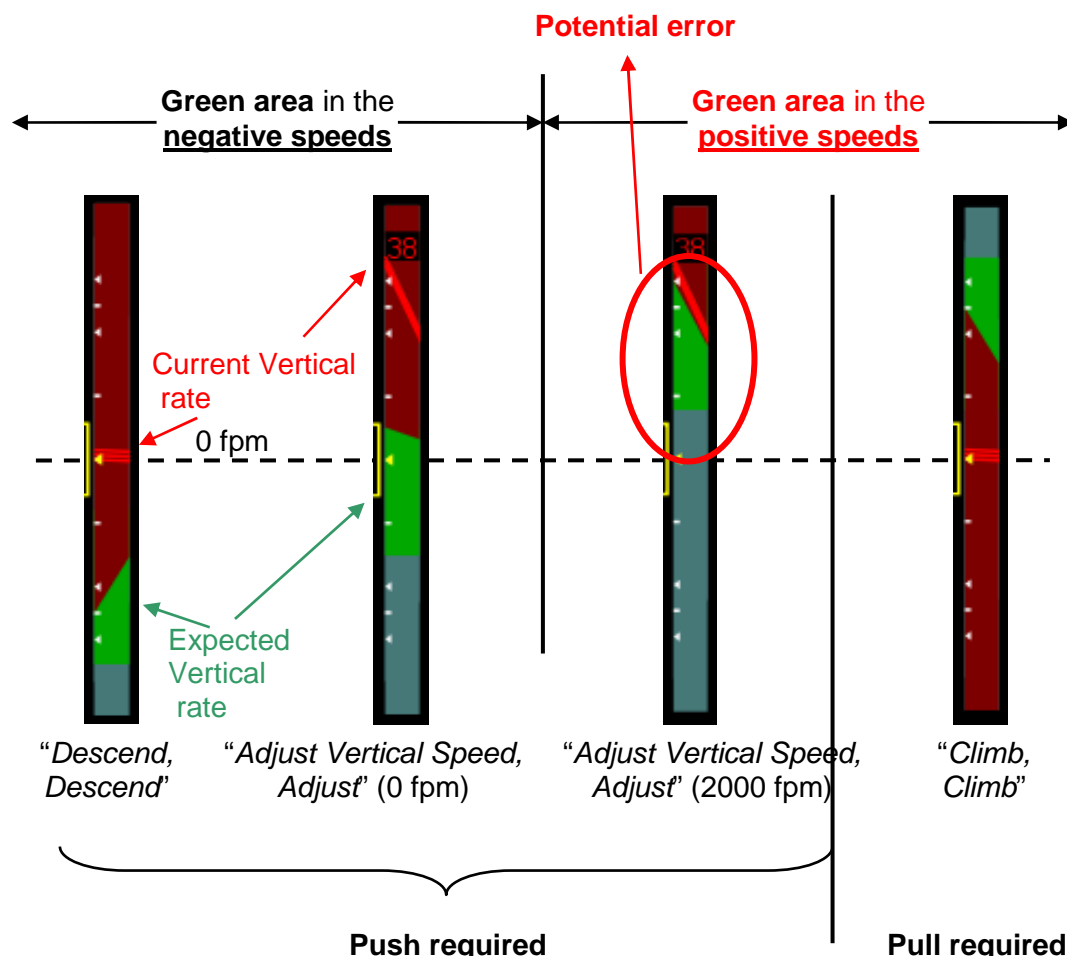


Figure 1: Required pilot action for different RAs

- 2.1.7. It has been observed that some pilots react to TCAS RAs according to the position of the green area relatively to the 0 fpm indicator on their vertical speed display. Consequently, a correct behaviour when faced with positive RAs leads to opposite reactions to AVSA 500, 1,000 or 2,000 RAs. Indeed, as shown on the above figure, a pilot would see the green area in the positive area for a climb RA, and would therefore pull, as expected. A pilot would also see the green area in the positive area for an AVSA 2,000 RA, and would therefore also pull, while an action to push is actually required, as for descend RAs and AVSA 0 RAs.
- 2.1.8. Additionally, the “Adjust Vertical Speed, Adjust” aural annunciation does not provide any information about the sense of the manoeuvre required by the TCAS alert and can not mitigate the risk of opposite reactions.

2.2. The CP115 solution

- 2.2.1. Past experience from some major European airlines has shown that improving training on appropriate reactions to AVSA RAs actually contributes to reduce the rate of opposite responses. However, this improvement alone is not sufficient to solve the SA-AVSA issue, as these airlines continued to experience opposite reactions to initial

AVSA RAs after having specifically addressed this issue in their TCAS training. This failure to solve the issue by improving training indicates that the root cause of these opposite reactions is the design of the AVSA RAs. Therefore a change to the TCAS RA logic is required to successfully address the SA-AVSA issue.

- 2.2.2. The solution to the SA-AVSA issue consists in replacing the 4 different AVSA RAs by a single Level-Off RA. The aural annunciation associated to these 4 RAs is accordingly replaced by the message “Level-Off, Level-off”, which clearly indicates the action required to comply with the RA. The end result of these changes is a single RA associated with an aural annunciation explicitly conveying the required action to comply with this RA.

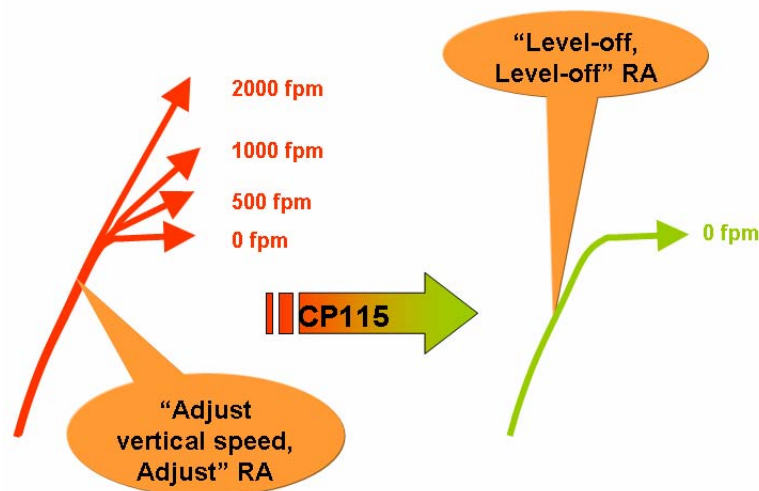


Figure 2: Effect of CP115 – Basic Principle

- 2.2.3. Opposite reactions to AVSA RAs requesting a vertical rate of 0 fpm are far less frequent than with the other types of AVSA RAs, because the interpretation of TCAS displays is much more intuitive (cf. Figure 1). By changing the aural annunciation associated to this RA, and replacing it with a message explicitly indicating the sense of the manoeuvre required to comply with it, it is expected that the reactions to the new Level-Off RA will be as good as those to current Climb or Descend RAs.

2.3. Assessment of CP115 performance in the Boston airspace

- 2.3.1. An assessment of the operational performance of CP115 in the Boston TMA has been performed by EUROCONTROL [SIRE+3]. It was done using radar and RA downlink data provided by the FAA.
- 2.3.2. The analysis of these radar and RA downlink data collected over 6 months in the Boston area has shown that 92 RA events, out of the 992 that have been recorded, featured an initial AVSA RA. Out of these 92 events, CP115 would modify the behaviour of TCAS II Version 7 in only 15 events with some traffic in the vicinity of the aircraft involved in the RA.

- 2.3.3. Given the number of days of data recording used in the Boston study, it could be extrapolated that the rate of potential CP115 involvement in events with some traffic in the vicinity was once every 3 days, assuming that all TCAS aircraft would be fitted with Version 7 including CP115.
- 2.3.4. Furthermore, TCAS simulations performed on these events featuring an initial AVSA RA showed that introducing CP115 would not induce a conflict with any third party aircraft, or would even be close to doing so. No additional RAs, or Traffic Advisories (TA), would be issued against these third party aircraft because of the manoeuvre induced by the Level-Off RA. This result is of particular significance as it is based on 6 months of observation in a US TMA mixing various types of traffic.
- 2.3.5. Analysis of the Level-Off RAs issued by CP115 in those 92 events confirmed the operational benefits that had been demonstrated with CP115 in the European airspace [SIRE+2]. Indeed, it has been shown that introducing CP115 into Version 7 would have no effect on vertical deviations, particularly because of the short duration of the level-off manoeuvre.

2.4. *The need for an assessment in the New York airspace*

- 2.4.1. The Operations Working Group (OWG) of RTCA SC147 expressed the necessity to assess the effect of introducing CP115 in a denser area, and the New York TMA was proposed for that purpose.
- 2.4.2. A set of 92 days of radar recording were provided to the SIRE+ team, so as to perform a similar analysis than for the Boston TMA.
- 2.4.3. The main difference lies in the lack of available RA downlink data, which makes the study more challenging. Indeed, for such an amount of data, only RA downlink permits to absolutely ensure that the RAs obtained in simulation have actually been triggered. However, the OSCAR TCAS test bench used to simulate TCAS behaviour has proven for more than 10 years a very high reliability in TAs and RAs reproducibility in ACAS studies performed for EUROCONTROL, French DSNA, and in the scope of RTCA SC147. Consequently, the general trends to be derived within the present study are considered to be statistically valid.

3. Data and methodology description

3.1. Overview of data and operational environment

- 3.1.1. As an input to the present study, the FAA has provided the EUROCONTROL SIRE+ team with 3 months of radar data, spanning from Sunday 13 May to Sunday 12 August 2007. This amounts to 92 days of data, which have been recorded over a 60 NM radius circle around JFK airport.
- 3.1.2. It has to be noted that, contrarily to the previous analysis performed for the Boston TMA ([SIRE+3]), no RA downlink data was available. This means that TCAS performances were assessed through the results of simulations based on assumptions that aircraft are fitted with TCAS according to the US TCAS mandate and that TCAS is operated in RA mode. Although an individual simulated RA can differ from the one actually experienced onboard, the general trend is considered to be statistically valid.
- 3.1.3. The following figure provides an overview of the NY area in which data have been recorded. It shows the area covered by the radar over a map of NY region. The figure also indicates the 13 airports within this covered area which total more than 100,000 annual movements each and contribute to make it one of the densest areas in the world in terms of traffic.

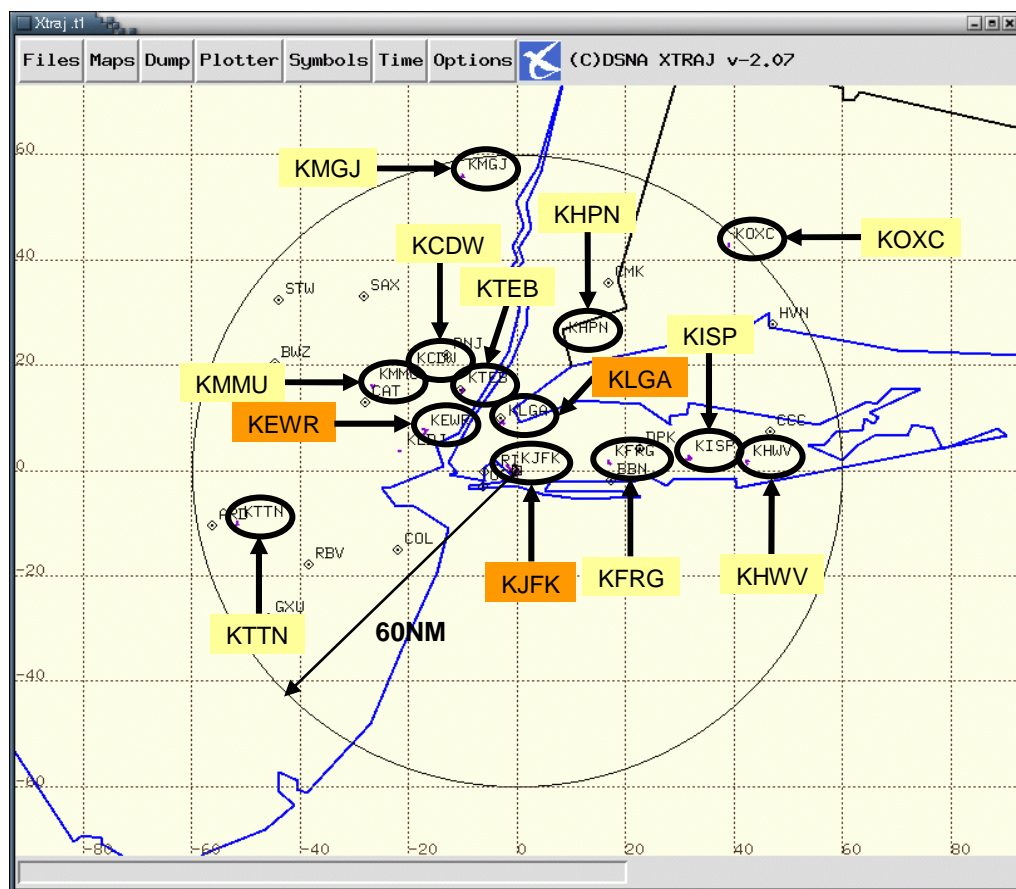


Figure 3: area covered by radar

- 3.1.4. The next table provides movement data for the 13 airports. This table also includes Downtown Manhattan Heliport which is not indicated on the above map and which number of movements is far below the other airports, but the traffic generated by the heliport is very specific.

| Airport | Movements |
|-----------------------------|-----------|
| Newark (KEWR) | 445,000 * |
| LaGuardia (KLGA) | 400,000 |
| J. F. Kennedy (KJFK) | 380,000 |
| Essex County (KCDW) | 245,000 † |
| Morristown (KMMU) | 220,000 |
| Republic (KFRG) | 190,000 |
| Teterboro (KTEB) | 190,000 |
| Westchester County (KHPN) | 180,000 |
| Long Island (KISP) | 175,000 |
| Waterbury-Oxford (KOXC) | 150,000 |
| Brookhaven (KHWV) | 135,000 |
| Orange County (KMGJ) | 120,000 |
| Trenton Mercer (KTTN) | 100,000 |
| Downtown Manhattan Heliport | 40,000 |

Table 1: main airports within area of coverage

- 3.1.5. The data provided by the FAA contain about 200,000 flight hours. This figure is an estimation based on an average radar update rate of 1 plot every 4.5 seconds. This total number of flight hours corresponds to transponder-equipped aircraft and, in the perspective of the present study, it is interesting to distinguish between Instrument Flight Rule (IFR) and Visual Flight Rule (VFR) flight hours, as well as between TCAS and non-TCAS flight hours. The computation of TCAS flight hours is based on the aircraft type information found in the radar data and on the US TCAS mandate. The result is provided in the following table.

* Source : Port Authority of New York and New Jersey – 2006 Airport Traffic Report

† Source : Federal Aviation Authority – Airport Master Records (Form 5010)

| Flight type | Flight hours |
|-------------|--------------|
| Total | 200,000 |
| TCAS | 143,000 |
| Non-TCAS | 57,000 |
| IFR | 155,000 |
| VFR | 45,000 |

Table 2: flight hour breakdown

3.2. Methodology

3.2.1. Required data for study objectives

3.2.1.1. As already mentioned in the introduction (cf. 1.1.3), the present study has three main objectives, which each require a different type of data:

- Operational performance of TCAS II in NY area: the understanding of TCAS operations in NY region requires all the TCAS events extracted from radar data, complemented by airspace and meteorological data. Analysis of these data can lead to the identification of possible TCAS RA hotspots.
- Operational performance of CP115 in single threat encounters: the computation of performance metrics for TCAS II Version 7 and CP115 is performed on a set of TCAS events in which an RA has been issued.
- Operational performance of CP115 in single threat encounters involving one or more third party aircraft: the risk of induced conflict with third party aircraft in response to RAs is assessed for both TCAS II Version 7 and CP115 over a set of events in which an initial AVSA RA has been issued and one or more additional traffic are found in the close vicinity. For this purpose, initial Monitor Vertical Speed (MVS) RAs followed by an AVSA RAs are also considered as initial AVSA RAs

3.2.1.2. Consequently, three different sets of TCAS events are required to support the present analysis and have to be extracted from the radar data provided by the FAA:

- A first set composed of encounters in which an RA has likely been issued,
- A second set consisting of encounters in which an initial AVSA RA has likely been issued,
- A third set with encounters in which an initial AVSA RA has likely been issued and additional traffic is found in the vicinity of the TCAS aircraft.

3.2.1.3. The following figure provides an overview of the methodology that has been set up to obtain the three required data sets.

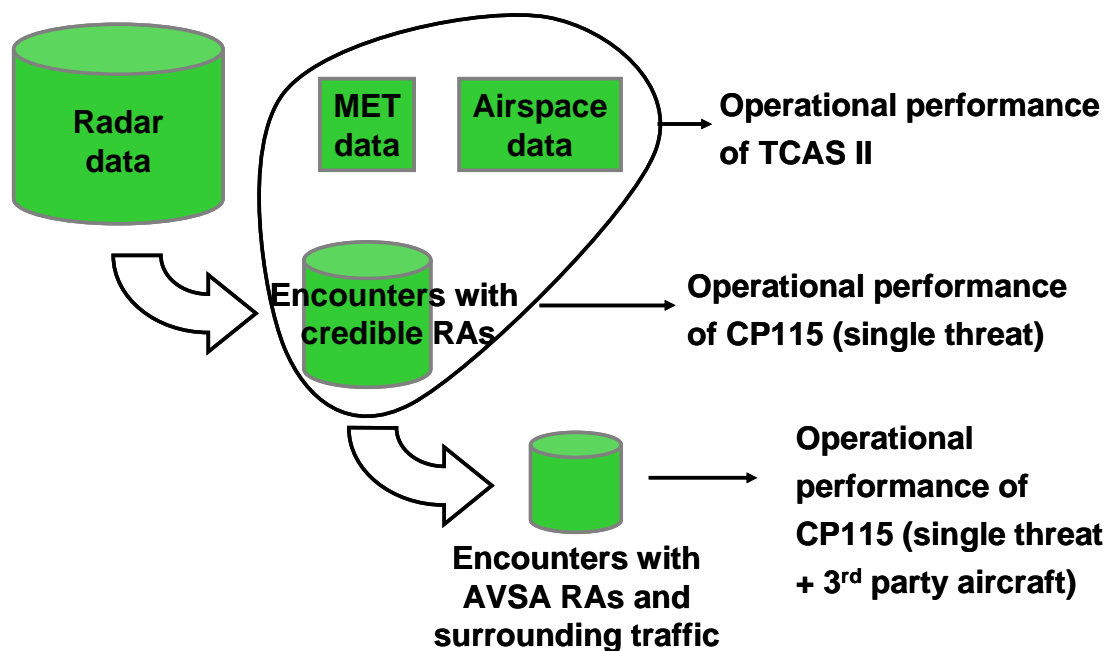


Figure 4: methodology overview

3.2.1.4. The following sections detail the methodology that has been set up in order to obtain these three sets of encounters from the available radar data.

3.2.2. Identification of encounters with likely RAs

3.2.2.1. The radar data provided by the FAA use the NOP format, which is not supported by the OSCAR test bench used by the EUROCONTROL SIRE+ project to perform TCAS simulations and RA analyses. Consequently, the first step of the methodology consists in the conversion of the NOP data to the MADREC format used by the SIRE+ tools. Among the different fields found in the NOP format, the following ones have been identified as necessary to the study and thus selected for conversion:

- time,
- callsign,
- aircraft id (acid),
- aircraft type,
- Mode A code,
- Mode C,
- ground speed,
- x position,
- y position,
- flight rule

3.2.2.2. Then, an automatic process of pair-wise encounter capture has been launched on the resulting MADREC files. This process is cyclic and examines all the possible pairs of aircraft to check if they meet a set of geometric criteria similar to those used by TCAS, although simplified and enlarged. These capture criteria have been used

in past EUROCONTROL ACAS study, notably in the development of the European safety encounter model ([ASA1]). The following table summarizes the criteria defined for this capture process.

| Altitude layers | 1,000 - 2,350 ft | 2,350 ft - FL50 | FL50 - FL100 | FL100 - FL200 | FL200 - FL420 | Above FL420 |
|-------------------------|------------------|-----------------|--------------|---------------|---------------|-------------|
| TAU-like criteria (s) | 21 | 26 | 31 | 36 | 41 | 41 |
| TAU RA (s) | 15 | 20 | 25 | 30 | 35 | 35 |
| ZTHR-like criteria (ft) | 700 | 700 | 700 | 700 | 800 | 900 |
| ZTHR RA (ft) | 600 | 600 | 600 | 600 | 700 | 800 |
| DMOD-like criteria (NM) | 0.6 | 0.75 | 0.95 | 1.2 | 1.5 | 1.5 |
| DMOD RA (NM) | 0.2 | 0.35 | 0.55 | 0.8 | 1.1 | 1.1 |

Table 3: enlarged TCAS criteria for pair-wise encounter capture

3.2.2.3. It has to be noted that the capture of pair-wise encounters is a time-consuming process, as every possible pair of tracks has to be checked against the above criteria over their whole duration, while also addressing all the issues that can be found in radar data (garbling, change of Mode A code, change of aircraft identification ...).

3.2.2.4. When applied on the whole 92 days of data, the pair-wise encounter capture process leads to an average of 940 captured encounters per day. However, the number of encounters captured on a given day varies a lot and essentially depends on the weather. Indeed, bad weather conditions lead to a decrease of VFR traffic and hence reduce the probability of close encounters. This is illustrated by the following figure, which gives the number of captured encounter (red histograms) as a function of the ceiling measured at JFK airport (blue graph) for the month of August.

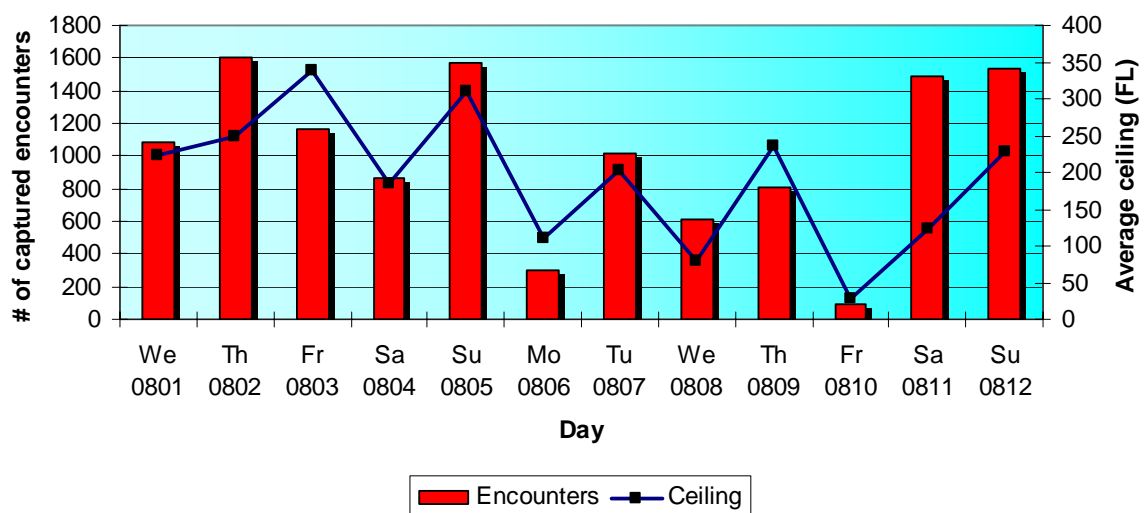


Figure 5: correlation between weather and number of captured encounters

3.2.2.5. The capture process described above is only based on geometric properties of the considered pairs of tracks. Consequently, it leads to the capture of some pair-wise encounters that are either not relevant in the context of the present study or incomplete. They notably include:

- Encounters between two aircraft not equipped with TCAS.
- Encounters where the Closest Point of Approach (CPA) occurs at the beginning of encounter. A typical example is provided in the next figure.
- Encounters where the CPA occurs at the very end of the encounter, typically when the encounter happens close to the 60 NM radar limit.

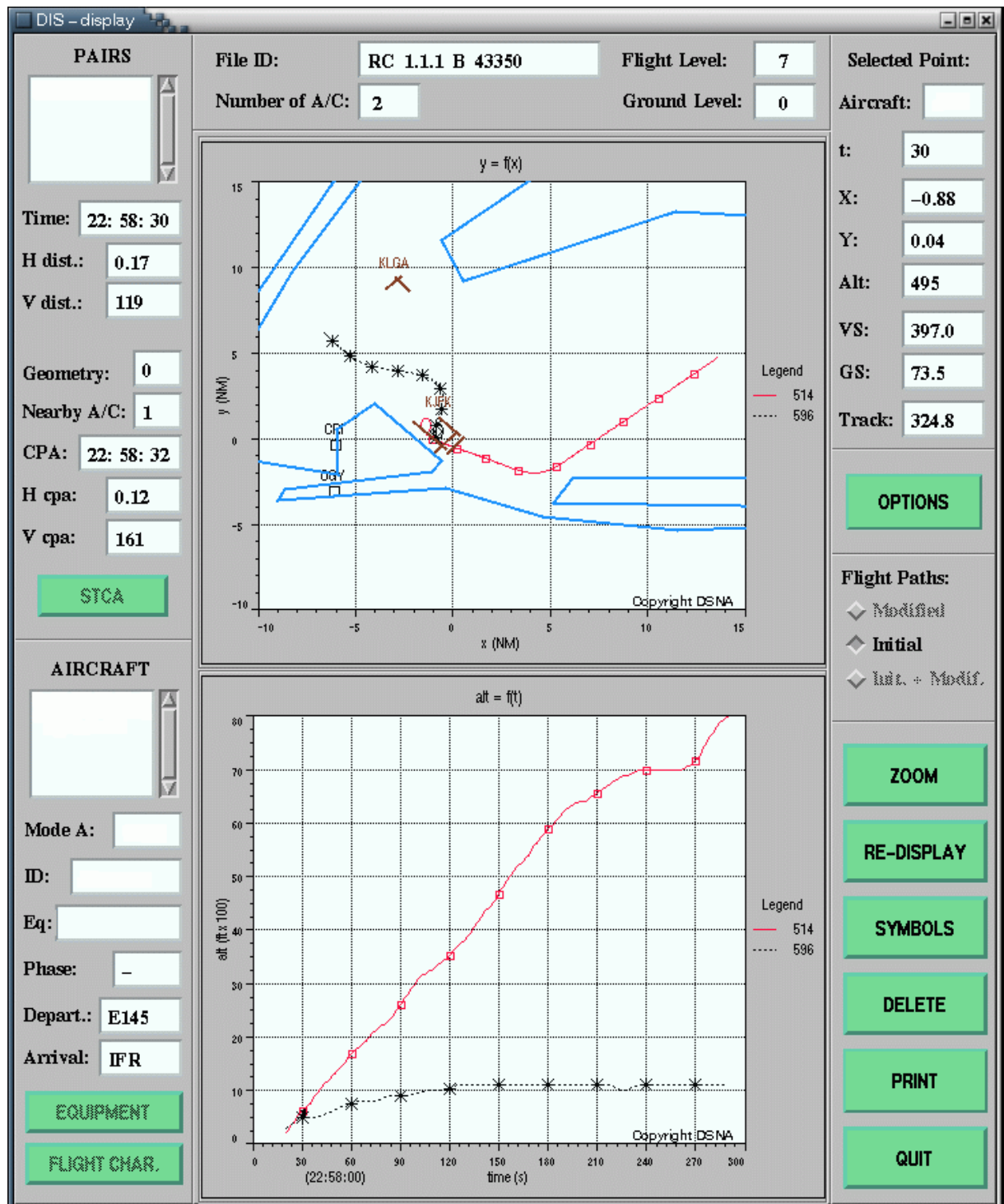


Figure 6: example of captured encounter with CPA at beginning

- 3.2.2.6. As a consequence of the above, the implementation of automatic filters is required to identify and discard these encounters. A first filter has been set up to identify encounters between aircraft not equipped with TCAS and a second one identifies encounters with a CPA too close to either end of the trajectories.
- 3.2.2.7. To identify an unequipped aircraft, several fields in the NOP format can be used, although they are not always given a value for a given radar track. Based on an assessment performed on a sample of data provided by the FAA, the "VFR" value in the flight rule field has been considered as reliable. Therefore, all captured encounters involving two aircraft under VFR were filtered. A 1200 Mode A code is also an indication of an aircraft flying under VFR and encounters between two aircraft with 1200 Mode A codes are thus filtered.
- 3.2.2.8. When one or both aircraft have an IFR value in the flight rule field, encounters between TCAS-unequipped aircraft are detected by checking the aircraft type value against the US TCAS mandate, which enables to determine if a given aircraft is equipped with TCAS (and with which version) or not. If either or both aircraft type values are missing from the radar data, the flight rule value is used instead and VFR is considered as unequipped. If either or both aircraft flight rule values are also missing in the radar data, a missing callsign value in the radar data is considered as indicating an unequipped aircraft.
- 3.2.2.9. The automatic filters described above enable to remove a significant proportion of unwanted encounters from the set of captured encounters and reduce it to about 150 encounters per day on average, i.e. about 14,000 for the 3 months of data.
- 3.2.2.10. Because the filtering process is entirely automatic and based on assumptions which might be wrong in a few cases, there are also probably some desirable encounters where one or both aircraft are missing the appropriate data and which have been filtered. However, these can only be identified by actually looking at the trajectories and assessing the likelihood of being TCAS-equipped through aircraft performance, flight level and such. Given the sheer number of captured encounters, this would not be possible in assigned time.
- 3.2.2.11. The next step consists in identifying encounters where an RA has occurred. In order to do so, automatic TCAS simulations are performed on the remaining encounters, equipping them with TCAS according to the US TCAS mandate. At this stage, about a daily average of 45 encounters with an RA has been found.
- 3.2.2.12. However, some RAs can be the result of a garbled radar plot, with an incorrect altitude reported, or artefacts caused by altitude quantization (cf. Figure 7 below). It is not possible to rely on automatic detection to identify these cases, so encounters have to be checked individually and the credibility of simulated RAs assessed by ATC experts.

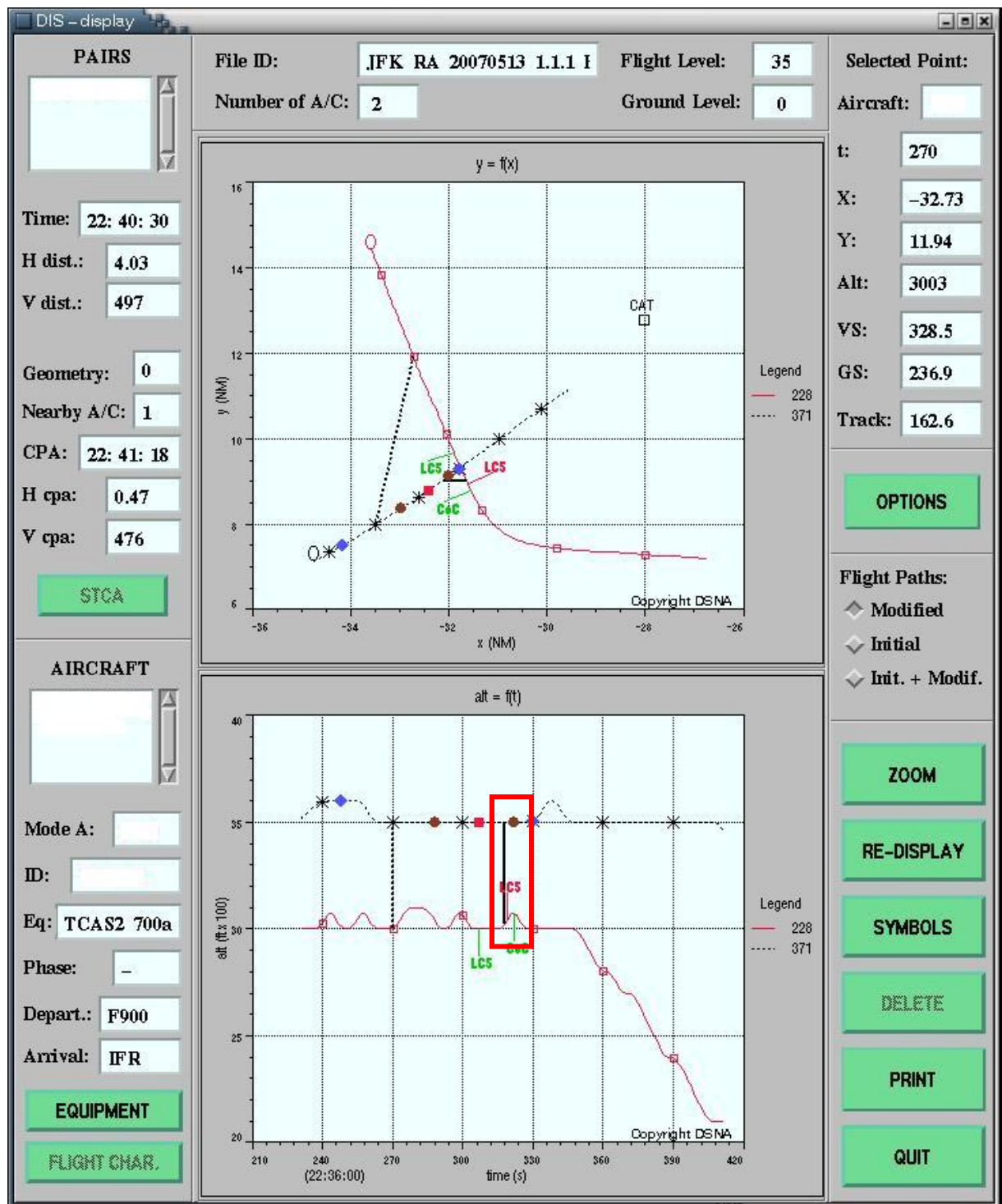


Figure 7: example of encounter with simulated RA caused by altitude quantization

3.2.2.13. Examining individual RA events allowed to identify on average 10 of them per day where the RA was the result of a garbled radar track or of 100 ft altitude quantization. Consequently, **the validation of the RA event set by ATC experts resulted in identifying about 35 encounters with a credible RA per day, or about 3,200 total.**

3.2.3. Identification of encounters with initial AVSA RA

3.2.3.1. Once the set of 3,200 encounters with a credible RA has been obtained in the previous step, selected encounters with an initial AVSA RA is a straightforward process. For the purpose of the present study, encounters with an AVSA RA following an initial MVS RA are considered as involving an initial AVSA RAs.

3.2.3.2. **Out of the set of encounters with credible RAs, about 870 have been identified where an initial AVSA RA has been simulated.** This is equivalent to about 10 encounters with initial an AVSA RA per day.

3.2.4. Identification of encounters with initial AVSA RA and surrounding traffic

3.2.4.1. This step is similar to the initial step of capturing pair-wise encounters, described in 3.2.2. The difference is that it requires a tool able to capture, according to pre-defined criteria, all the tracks located in the vicinity of the aircraft which received the initial AVSA RA.

3.2.4.2. Out of the set of encounters with credible RAs, about 870 have been identified where an initial AVSA RA has been simulated. For each of them, a short MADREC file has been extracted from the corresponding daily radar data file in order to focus on the corresponding tracks and time. This short file is 6-minute long (i.e., 4 minutes before CPA and 2 minutes after), which is sufficient to capture the track of any third party aircraft that would be involved in a conflict induced by the response to a Level-Off RA.

3.2.4.3. To achieve the present study's objective of investigating induced conflicts with third party aircraft, the capture criteria used are very large from the TCAS perspective, as they are based on roughly twice the maximum TA thresholds. The rationale behind this choice of values is that they allow capturing tracks with the potential to trigger a TA with the own aircraft when it would respond to a Level-Off RA. However, as demonstrated in previous studies ([SIRE+3]), these values are also sufficiently tight that they do not lead to the capture of a too large number of third party aircraft, which would make the output of this encounter capture step unusable.

3.2.4.4. To make sure that no aircraft potentially conflicting with the own aircraft would be ignored during the capture process, the software also automatically captures any traffic vertically crossing the own aircraft trajectory at any time within the 6-minute time window.

3.2.4.5. The following table indicates the values of the capture criteria that have been selected for the study, and also indicates the equivalent TCAS parameter used to trigger RAs in TCAS II Version 7, which is about three times smaller.

| Altitude layers | 1000 - 2350 ft | 2350 ft - FL50 | FL50 - FL100 | FL100 - FL200 | FL200 - FL420 | Above FL420 |
|-------------------------|-------------------|-------------------|-----------------|------------------|------------------|----------------|
| TAU-like criteria (s) | 50 | 60 | 80 | 90 | 96 | 96 |
| TAU RA (s) | 15 | 20 | 25 | 30 | 35 | 35 |
| ZTHR-like criteria (ft) | 1700 | 1700 | 1700 | 1700 | 1700 | 2400 |
| ZTHR RA (ft) | 600 | 600 | 600 | 600 | 700 | 800 |
| DMOD-like criteria (NM) | 0.66 | 0.96 | 1.5 | 2.0 | 2.6 | 2.6 |
| DMOD RA (NM) | 0.2 | 0.35 | 0.55 | 0.8 | 1.1 | 1.1 |

Table 4: enlarged TCAS criteria for surrounding traffic capture

3.2.4.6. **The application of this multiple track capture tool to the set of 870 encounters with an initial AVSA RA resulted in the capture of about 360 encounters with at least a third aircraft in the vicinity.** This is equivalent to about 4 encounters per day where an initial AVSA RA has been simulated and additional traffic has been captured close to the TCAS aircraft.

3.2.5. Summary of captured encounters

3.2.5.1. The following table provides an overview of the different sets of encounters that have been captured in the 3 months of radar data provided by the FAA and which were used to support the 3 objectives of the present study (i.e., operational performance of TCAS II, operational performance of CP115 in single-threat encounters and operational performance of CP115 in encounters with nearby traffic).

| Type of encounter | Number of encounters | Rate of occurrence |
|---|----------------------|--------------------|
| Encounter with credible RA | 3,200 | 35 / day |
| Encounter with initial AVSA RA | 870 | 10 / day |
| Encounter with initial AVSA RA and nearby traffic | 360 | 4 / day |

Table 5: rates of captured encounters by type

4. Operational analysis of TCAS II performance

4.1. Introduction

- 4.1.1. The purpose of this section is to provide an overview of the main characteristics of the RAs that have been observed in the TCAS simulations and complement these data with information on the NY airspace, so as to develop an understanding of current TCAS operations in this region.

4.2. RA type distribution

- 4.2.1. The following figure indicates the type of initial RAs that have been simulated in the set of 3,200 encounters with a credible RA.

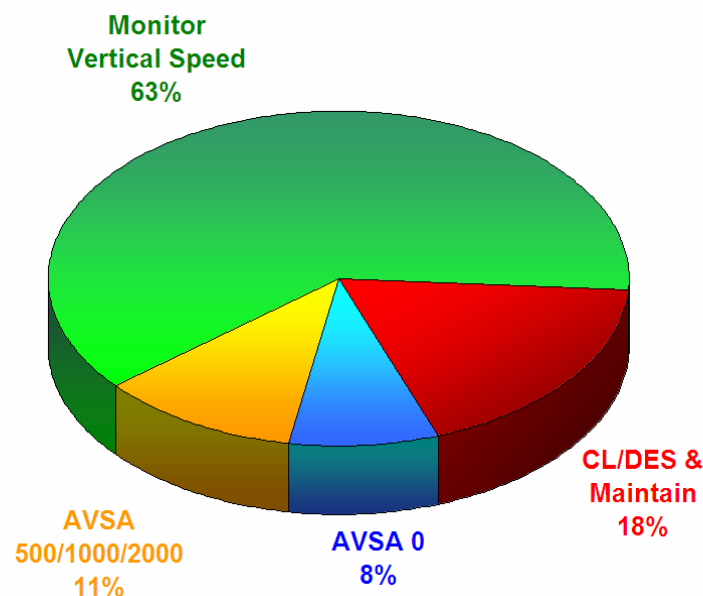


Figure 8: distribution of initial RAs

- 4.2.2. As indicated in the above pie chart, the most frequent initial RAs are Monitor Vertical Speed RAs, as they account for about two thirds of all initial RAs. This is a significant difference from Europe where initial AVSA RAs are the most frequent, with a proportion of two thirds of all RAs. The reason lies in the nature of the traffic in these two airspaces, as the NY TMA mixes VFR and IFR traffic, while they are generally segregated in Europe.
- 4.2.3. Accordingly, it has to be noted that 97% of these initial RAs are against unequipped threats, compared to about 90% in the Boston area and around 20% in Europe. This means that very few coordinated encounters occur in the NY region.
- 4.2.4. When focusing on the 870 encounters where an initial AVSA RA has been simulated (which includes encounters where an AVSA RA follows an initial MVS RA), the distribution of RAs by type is detailed in the following figure.

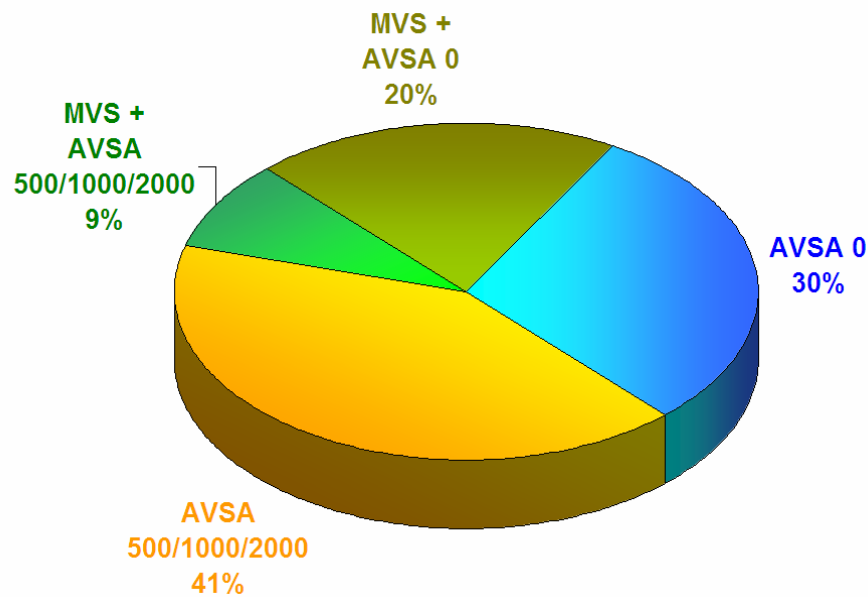


Figure 9: distribution of initial AVSA RAs

4.2.5. As indicated in the above figure, half of the initial AVSA RAs, i.e. 13% of the total number of RAs, require a change of vertical speed to 500, 1000 or 2000 fpm. These RAs would be affected by CP115 and replaced by a Level-Off RA. The other half would not be affected by the introduction of CP115, as they already require a level-off manoeuvre.

4.3. Geographic location of RAs

4.3.1. In order to identify any possible RA hotspot, the location of the simulated RAs has been plotted on a map of the NY area. Because of the number of RAs, showing them all on a single figure would make it unreadable, so only a one-day example is provided below.

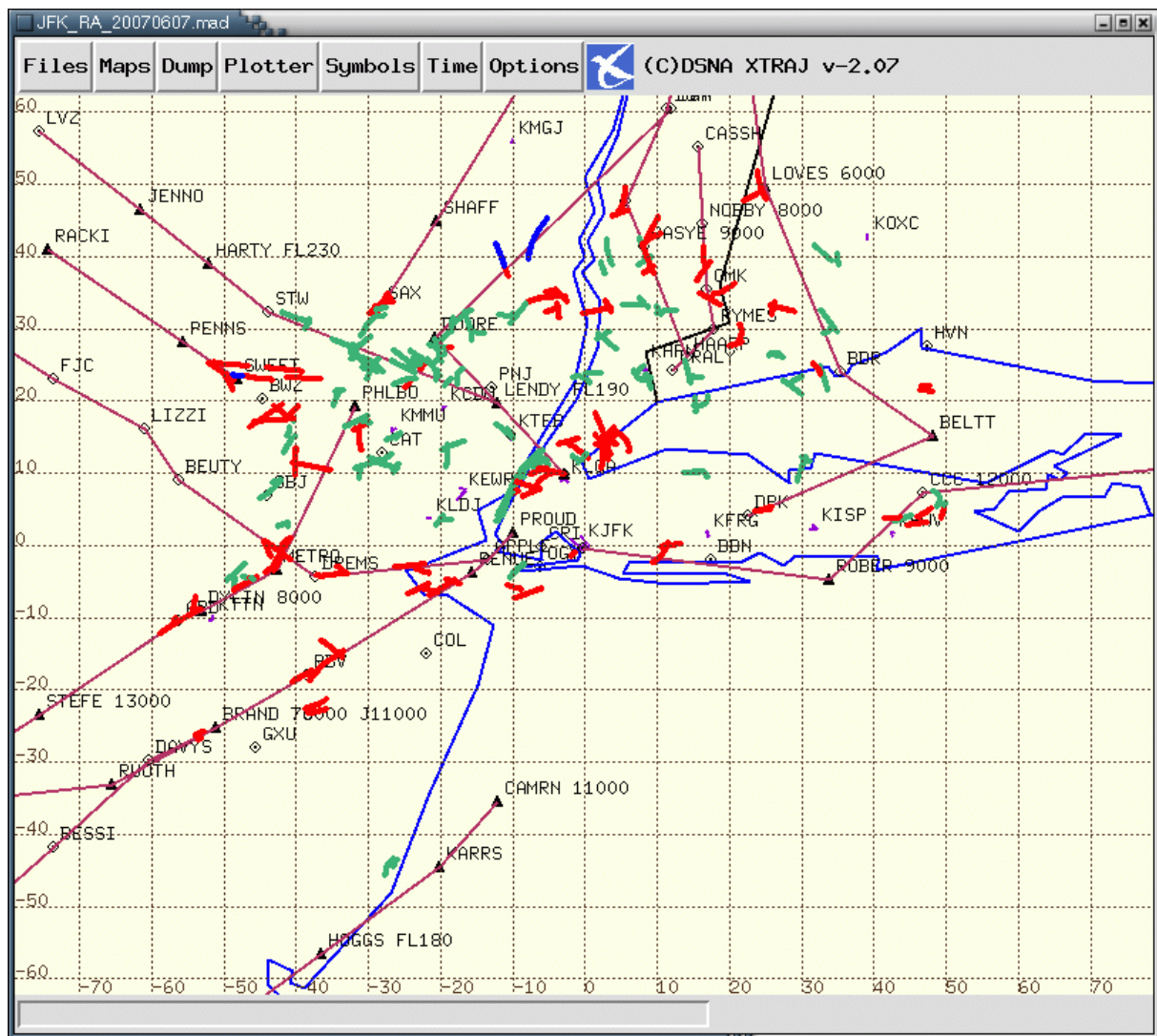


Figure 10: geographic location of RAs (7 June 2007)

4.3.2. As shown by the figure above, simulated RAs are spread out over the whole TMA and no specific hotspot can be identified.

4.4. Characterization of RAs

4.4.1. RA altitude distribution

4.4.1.1. The following figure shows the distribution of initial RAs by altitude, as they have been simulated in the set of 3,200 encounters with a credible RA.

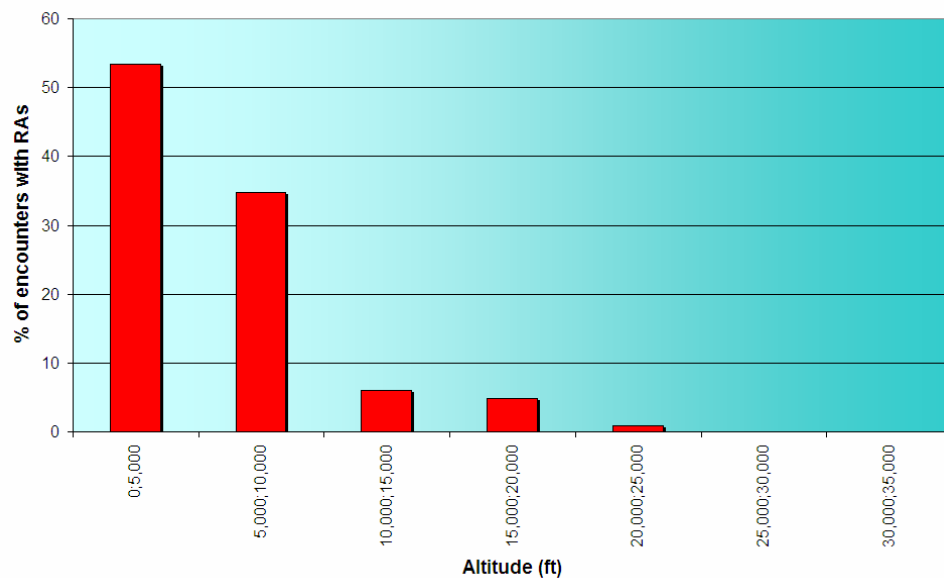


Figure 11: distribution of encounters with RA by altitude

4.4.1.2. The above figure shows that about half of the encounters with an RA occur between 1,000 and 5,000 ft, with an additional third occurring between 5,000 ft and 10,000 ft. The vast majority of encounters with an RA thus happen at low altitude, typically when TCAS-equipped aircraft are still in the approach or descent phase of flight. This distribution is in line with what has been observed in the Boston area ([SIRE+3]), and results from the mixed VFR / IFR traffic.

4.4.1.3. The peak is located in the [0; 5,000 ft] range, which roughly corresponds to the phase of flight where aircraft are being vectored on approach or performing visual approaches.

4.4.1.4. When focusing on the 870 encounters where an initial AVSA RA has been simulated, the distribution of RAs by altitude is given in the following figure.

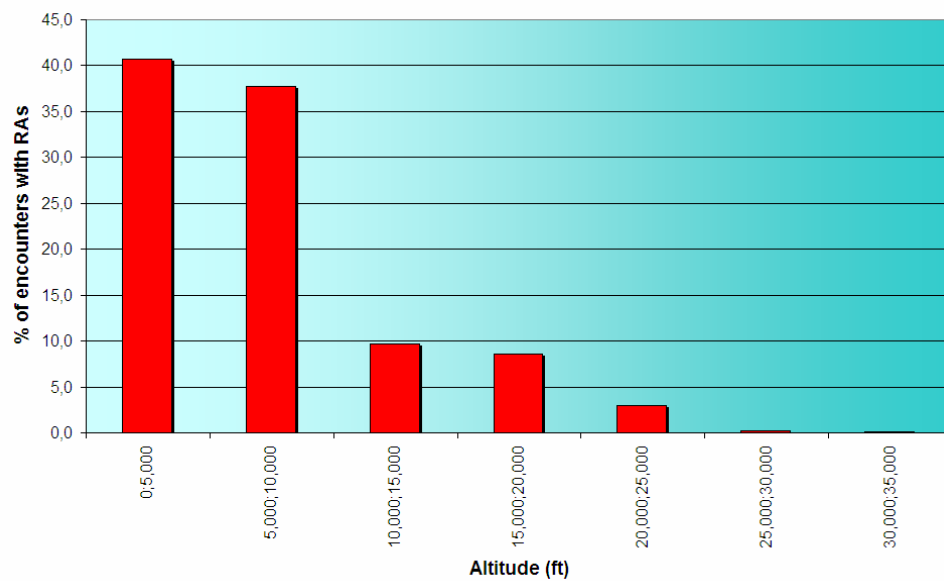


Figure 12: distribution of encounters with initial AVSA RA by altitude

4.4.1.5. Except for a slightly more balanced distribution below 10,000 ft, the distribution of initial AVSA RAs by altitude is very similar to the overall distribution of RAs, with about 80% of them occurring under 10,000 ft.

4.4.2. Miss distance distribution

4.4.2.1. The following figure gives the distribution of Horizontal Miss Distances (HMD) in encounters with RAs, measured at CPA.

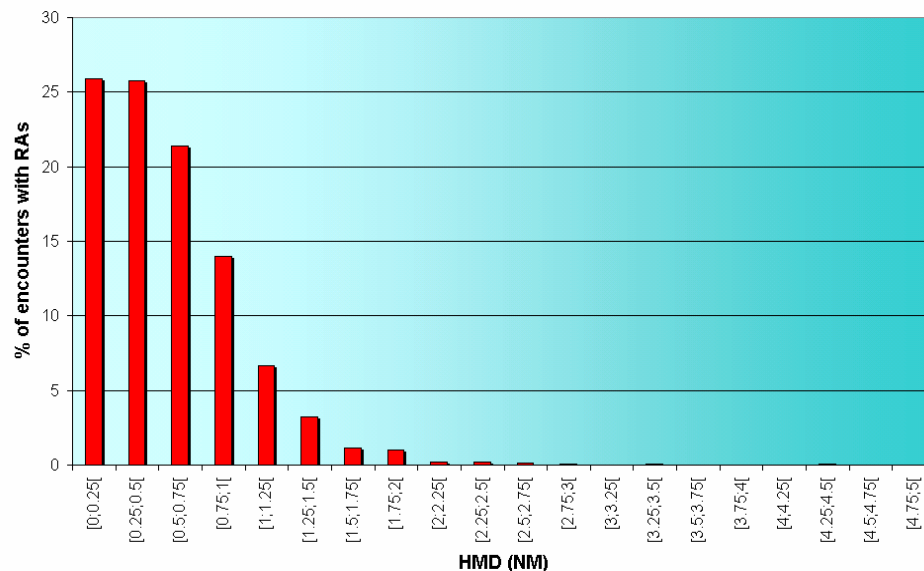


Figure 13: distribution of encounters with RA by HMD

4.4.2.2. As indicated above, about half of encounters with RAs end up with an HMD less than 0.5 NM at CPA. Close to 90% of these encounters have an HMD less than 1 NM.

4.4.2.3. The following figure shows the same distribution by HMD, focused on the 870 encounters where an initial AVSA RA has been simulated.

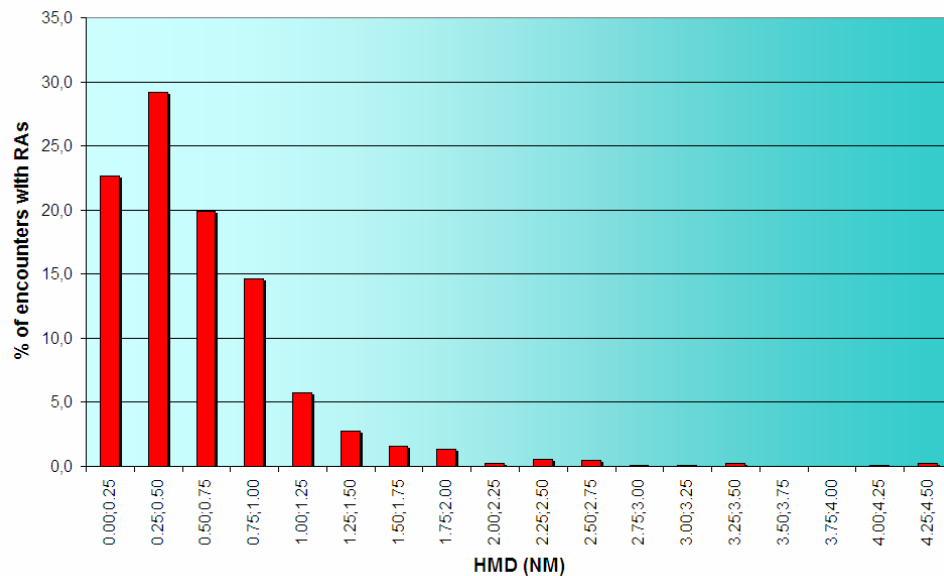


Figure 14: distribution of encounters with initial AVSA RA by HMD

4.4.2.4. The distribution of encounters with initial AVSA RAs by HMD is again very similar to the overall distribution of encounters, with about 50% of them ending up with a separation under 0.5 NM and close to 90% of encounters with a separation under 1NM.

4.4.2.5. The next figure gives the distribution of Vertical Miss Distances (VMD) in encounters with RAs, measured at CPA.

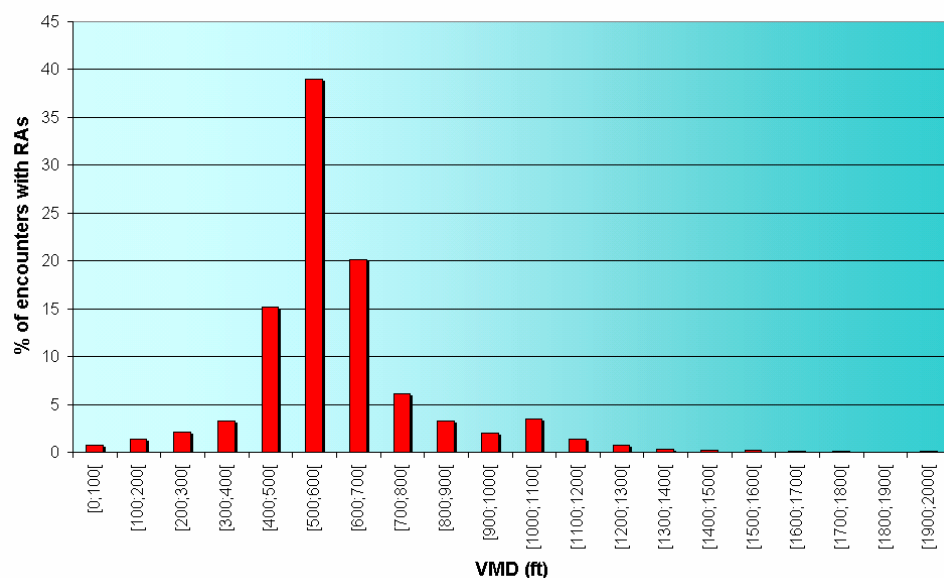


Figure 15: distribution of encounters with RA by VMD

4.4.2.6. The above figure shows significant peak around 500ft, with 75% of encounters ending up with VMD between 400 and 600 ft. This corresponds to RAs occurring in IFR / VFR encounters.

4.4.2.7. The following figure shows the same distribution by VMD, focused on the 870 encounters where an initial AVSA RA has been simulated

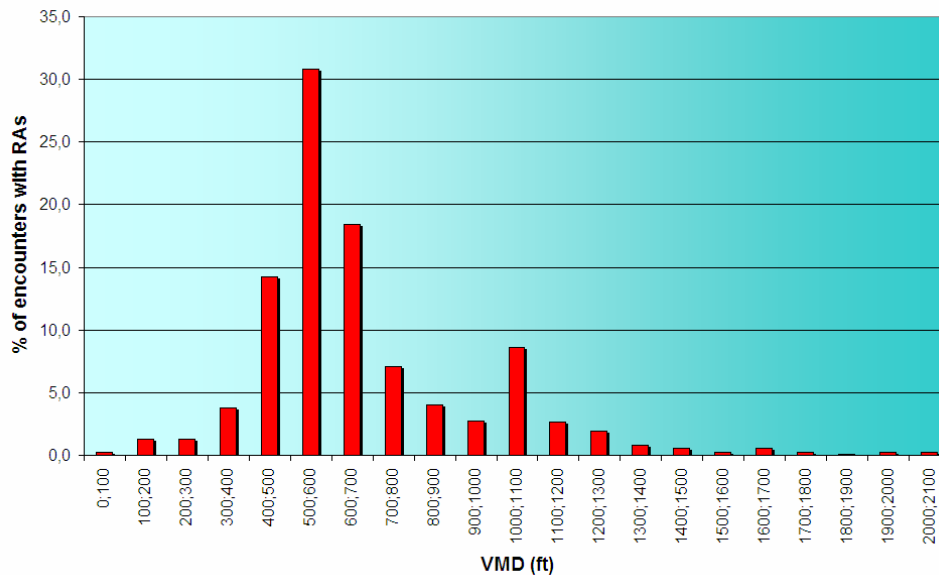


Figure 16: distribution of encounters with initial AVSA RA by VMD

4.4.2.8. The distribution of AVSA RAs by VMD is very similar to the overall distribution of RAs, with a significant peak around 500 ft, corresponding to IFR / VFR encounters. There is also a noticeable secondary peak around 1,000 ft, corresponding to IFR / IFR encounters. These are more significant than for the overall distribution (cf. Figure 15), as AVSA RAs are more probable in 1,000 ft level-off separation geometries, while the more frequent MVS RAs are more likely to occur in 500 ft IFR / VFR level-level separation geometries.

4.4.3. Typical encounters with RA

4.4.3.1. The following figure shows a typical encounter in which an RA has been simulated, i.e. below 5,000 ft, with an HMD less than 0.5 NM, a VMD around 500 ft and a Monitor Vertical Speed RA. The TCAS-equipped aircraft is a Gulfstream 3 on approach to Long Island airport, descending at about 1,000 fpm and heading south. When approaching 2,500 ft, it crosses a Piper Cherokee Arrow level at 2,000 ft and heading east.

4.4.3.2. Just after having levelled-off at 2,500 ft, the Gulfstream receives a preventive Monitor Vertical Speed requiring the pilot not to descend because of the Piper 500 ft below.

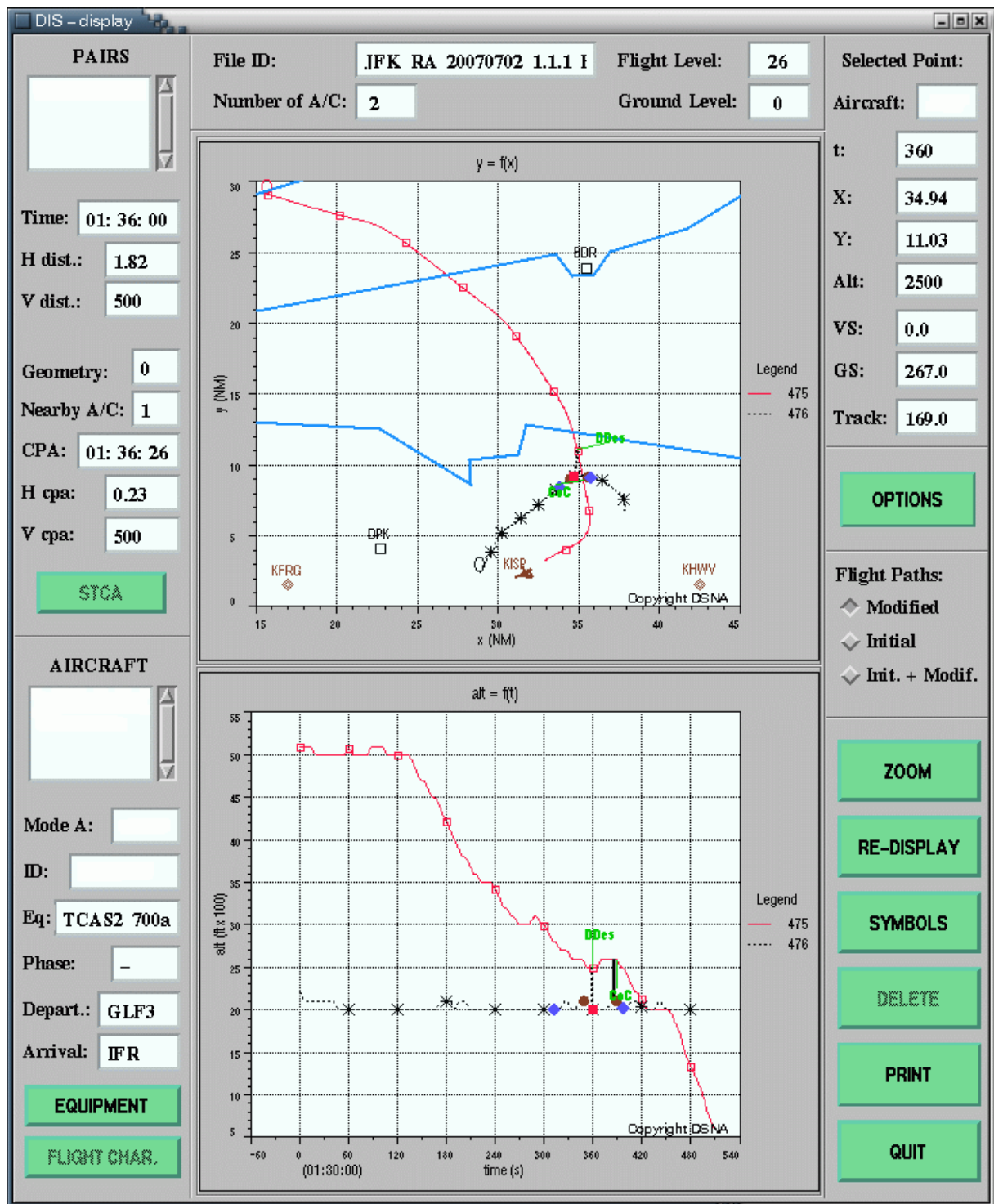


Figure 17: typical encounter with RA – IFR / VFR crossing on arrival

- 4.4.3.3. The miss distances at CPA are 0.23 NM horizontally and 500 ft vertically, which corresponds to the peaks seen in the HMD and VMD distributions (cf. Figure 13 and Figure 15).
- 4.4.3.4. The next figure provides another typical example of an encounter where an RA has likely been issued. It involves an Airbus A320 taking off from JFK and climbing at about 1,700 fpm with a South heading. Because of a crossing VFR flight on a west

route at 4,500 ft, ATC probably instructs the A320 to stop climbing at 4,000 ft. When both aircraft are 1.7 NM, the TCAS unit onboard the A320 issues a preventive MVS RA, requiring the pilot not to climb because of the traffic above.

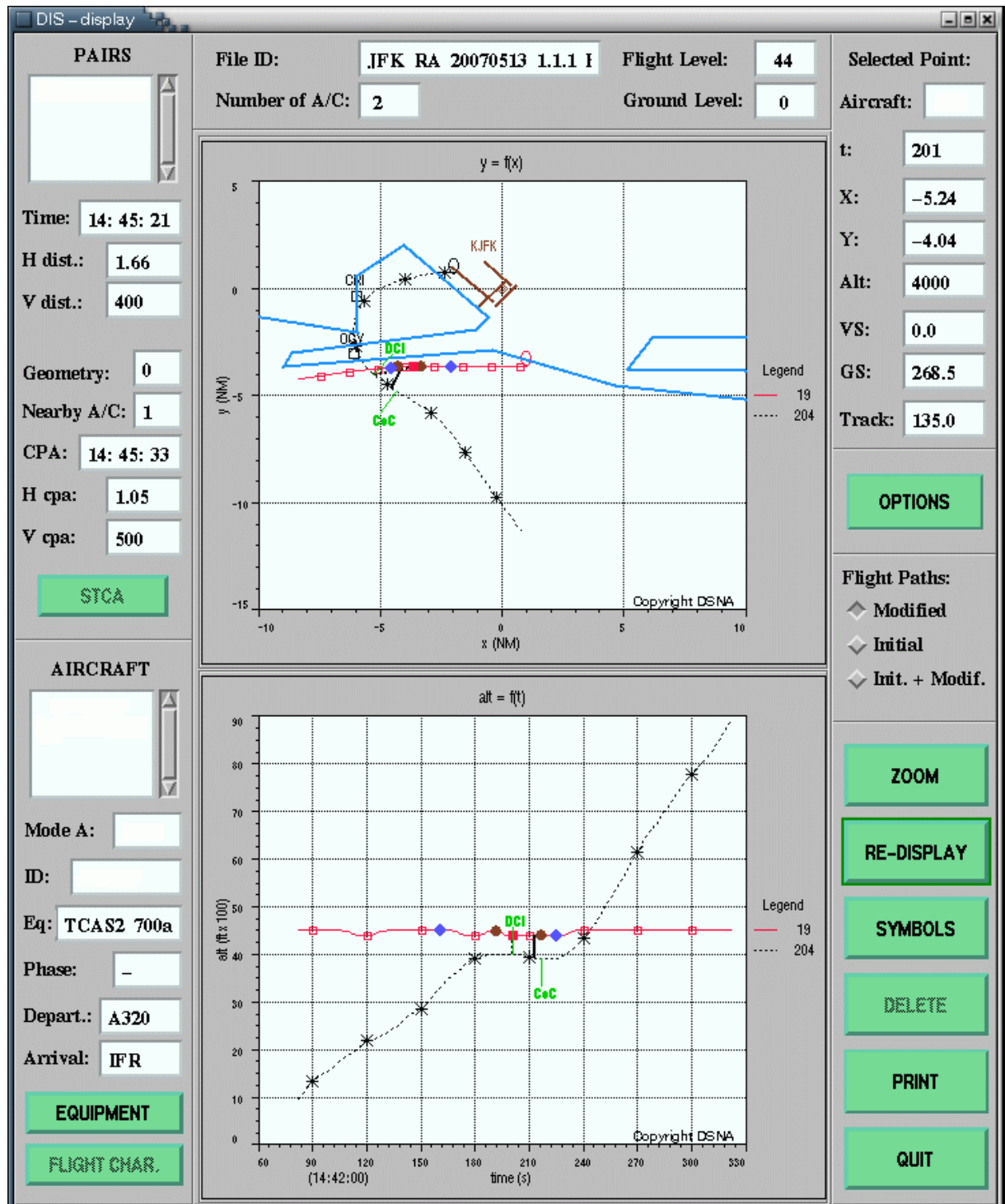


Figure 18: typical encounter with RA – IFR / VFR crossing on departure

4.4.3.5. As indicated in the above figure, the miss distances at CPA are 1.05 NM horizontally and 500 ft vertically.

4.4.3.6. The following figure shows a typical encounter in which an initial AVSA RA has been simulated. It involves a CRJ-200 on approach to Teterboro and descending at about 1,500 fpm with a south-eastern heading. When approaching 2,000 ft, it receives an AVSA RA against a Sikorsky S-76B helicopter on a head-on course, 600 ft below. The RA requires the pilot to reduce his rate of descent to 1,000 fpm.

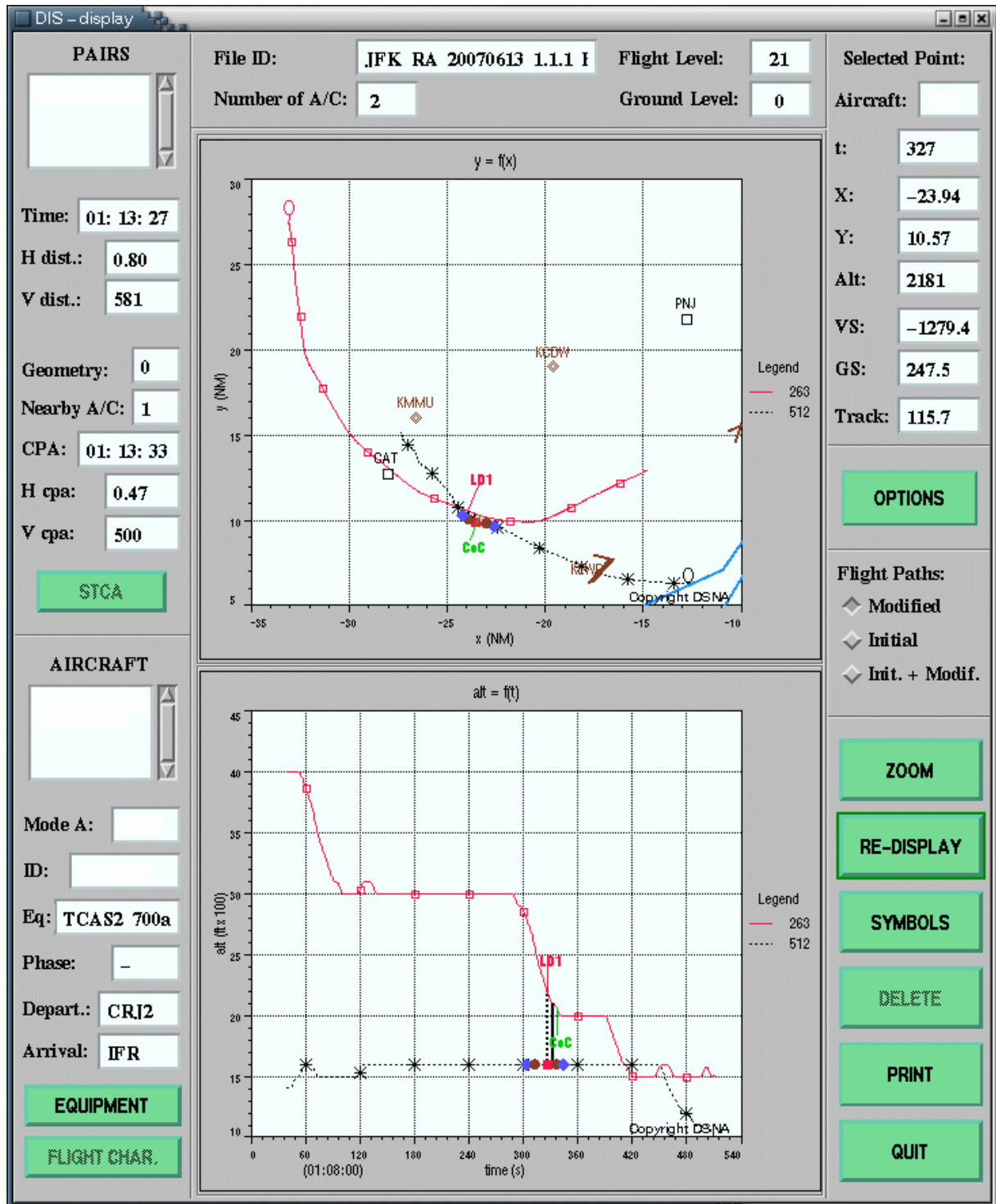


Figure 19: typical encounter with AVSA RA – IFR / VFR head-on on arrival

- 4.4.3.7. The miss distances at CPA are 0.47 NM horizontally and 500 ft vertically, which corresponds to the peaks seen in the HMD and VMD distributions of AVSA RAs (cf. Figure 14 and Figure 16).

4.5. *Estimation of RA response rate*

- 4.5.1. This section provides an estimation of the RA response rate. This response rate can only be estimated, as several limitations prevent a precise computation. First, no RA downlink data is available for the present study, which can only rely on results from TCAS simulations. Due to sampling and quantization of position and altitude data in the initial radar data, this can lead to no RA being simulated in encounters where one was actually issued, or on the contrary, to an RA being simulated in encounters where none was actually triggered.
- 4.5.2. In addition, the decision to fit a given aircraft with TCAS II in an encounter is based on the aircraft type data found in the initial radar data and on the US TCAS mandate. This process can be inaccurate, especially for smaller aircraft which may be fitted with either Version 7 or Version 6.04a.
- 4.5.3. Lastly, the actual operation of TCAS by airline or pilots is not known. More specifically, the current estimation assumes that all TCAS are operated in RA mode.
- 4.5.4. There is an additional difficulty in determining that a pilot is actually responding to an AVSA RA, for example, based on radar data only. Indeed, small variations of vertical rate are masked by the interpolation process used when transforming radar data into 1-second update rate encounters for TCAS simulations. Consequently, for an aircraft that is about to level-off and receives an AVSA RA, there may be no noticeable change in its vertical trajectory once the radar data have been processed, whether the pilot responded to the AVSA RA or not.
- 4.5.5. Consequently, the estimation of the RA response rate has only been performed on the subset of Climb and Descend RAs, as compliance with these RAs is fairly obvious when looking at the vertical trajectory of the aircraft.
- 4.5.6. Considering the above limitations and focusing on the Climb and Descend RA subset, the observed RA response rate is about 45%. As AVSA RAs are not considered in the estimation, this 45% figure is an over-estimation of the actual response rate. In addition, the process used for this estimate also points to a number of situations where no TCAS benefit was apparent.
- 4.5.7. It has to be noted that the estimated response rate in the NY area is far less than the RA response rate commonly observed in Europe, i.e. about 80%, but US regulations allow a pilot to disregard an RA if he can perform a visual separation from the threat ([FAA1]).

5. Operational performance of CP115

5.1. Introduction

- 5.1.1. The main objective of this section is to present the evaluation of CP115 operational performance, in order to assess the compatibility with ATC and the acceptability of having all AVSA RAs replaced by a single Level-Off RA.
- 5.1.2. The effect of this change on the flight crew and on the Air Traffic Controller (ATCO) in charge of the aircraft receiving the RA is assessed through a set of metrics defined by RTCA SC147 OWG and already used for previous operational validation of CP115. These metrics enable to quantify the change, notably using the airspace disruption perspective.
- 5.1.3. In addition, the probability of inducing a conflict with a third party aircraft in response to a Level-Off RA is also evaluated, as it is the main potential operational drawback associated to CP115 that has been identified by RTCA SC147 OWG

5.2. Pair-wise encounters

5.2.1. Operational performance metrics

- 5.2.1.1. The approach set up by RTCA SC147 for the safety evaluation of CP112E [RTCA2] and CP115 ([RTCA3]) has been retained for the validation of the operational aspects of the CP115 solution in the New York airspace. It consists in the definition of metrics and their computation on a common basis with both a reference CAS logic (i.e., Version 7) and a compared CAS logic (i.e., Version 7 including CP115).
- 5.2.1.2. The computation of these metrics has been performed on the set of 3,200 encounters in which an RA has been simulated. The TCAS equipage of individual aircraft involved in these encounters has been decided based on their type and according to the US TCAS mandate.
- 5.2.1.3. As for the validation of CP112E, the judgment should be made on a comparative basis rather than on absolute values. The objective of the proposed change is to solve a safety issue related to human factors (i.e., unintentional opposite reactions due to RA misinterpretation by flight crew). As a consequence, it is underlined that the validation objective for the operational performance study is not to show improved operational metrics (although, of course, this could be desirable), but rather to show that the proposed change does not debase compatibility with ATC by an increase of the airspace disruption nor degrade the airborne perspective (i.e. to show no metric degradation).
- 5.2.1.4. Even if some key operational performance metrics are not specifically related to only one topic, these metrics can be divided in two main sets:
 - A set related to Airspace Disruption and aiming at assessing the compatibility of the modified logic (i.e., Version 7 with CP115 included) with ATC operations. Metrics from this first set are referenced to as ADx.

- A set related to Airborne Perspective, with the objective of providing indicators on the acceptability of the modified logic by flight crews. Metrics from this second set are referenced to as APx.

5.2.1.5. The airspace disruption set includes metrics based on concepts already introduced in the ACAS performance SARPs [ANN10]. All the metrics from these two sets have been presented to RTCA SC147 OWG and amended to take into account the feedback they provided ([SIRE+4]).

5.2.2. Airspace disruption metrics definition

5.2.2.1. Metric AD1: RA alert rate

5.2.2.1.1. The rate of RA alerts is computed over a defined period of time (e.g., per flight hour, per year) and over a defined region (e.g., an entire airspace or a sector).

5.2.2.1.2. The RA alert rate provides a metric of the disruption caused by TCAS to ATC. Reducing the number of alerts while maintaining the equivalent level of safety delivered by TCAS improves TCAS operational performance. During a given TCAS conflict, a maximum of one alert by aircraft (whatever the number of advisories in the sequence) will be considered for the calculation of the number of RA alerts.

5.2.2.1.3. The RA alert rate computed with CP115 has to be equal to or lower than the RA alert rate computed with TCAS II Version 7. Indeed, one requires no degradation or little improvement in the RA alert rate with CP115.

5.2.2.2. Metric AD2: AVSA 0 fpm RA alert rate

5.2.2.2.1. The rate of AVSA 0 RA alerts is computed over a defined period of time (e.g., per flight hour, per year) and over a defined region (e.g., an entire airspace or a sector).

5.2.2.2.2. The AVSA 0 RA alert rate provides a metric characterising the proposed change. The metric may be of interest when comparing the rate induced by the change with the Version 7 rate (i.e., the rate of AVSA RAs that are limiting the rate of descent or climb to 0 fpm).

5.2.2.3. Metric AD3: Nuisance RA alert rate

5.2.2.3.1. An RA alert will be considered as a nuisance if the standard ATC separation is not infringed during the encounter. The calculation authorises a 200-ft tolerance on the vertical separation threshold. It is recognised that, in case of aircraft in vertical evolution, RAs triggered before a level-off manoeuvre 1000 ft apart from another aircraft can be qualified as useful RAs by pilots. Such RAs for level-off geometry are nevertheless considered as nuisance alerts by ATC.

5.2.2.3.2. The nuisance RA alert rate is defined as the probability, when an RA is issued, that the alert is a nuisance alert. The nuisance RA alert rate provides another metric of the disruption caused by TCAS to ATC. Reducing the number of nuisance alerts while maintaining the equivalent level of safety delivered by TCAS improves TCAS operational performance.

- 5.2.2.3.3. The nuisance RA alert rate computed with CP115 has to be equal to or lower than the nuisance RA alert rate computed with TCAS II Version 7. Indeed, one requires no degradation or little improvement in the nuisance RA alert rate with CP115.

5.2.2.4. Metric AD4: Vertical deviation average

- 5.2.2.4.1. The vertical deviation average is defined as the average of non-zero vertical deviations. The vertical deviation average provides a major metric of the disruption caused by TCAS to ATC. Minimising the altitude displacements makes TCAS more compatible with the ATC system
- 5.2.2.4.2. The crucial element in the calculation of vertical deviation is to identify deviations that have an impact on ATC. An aircraft that is limiting its rate of descent or climb does not deviate from its original flight path in the ATC general sense. The deviations will be computed as follows (cf. Figure 20 below). A box is modelled between the points at which the aircraft deviates from and then resumes its original flight path. A positive deviation is only considered if the modified flight path goes outside the box.

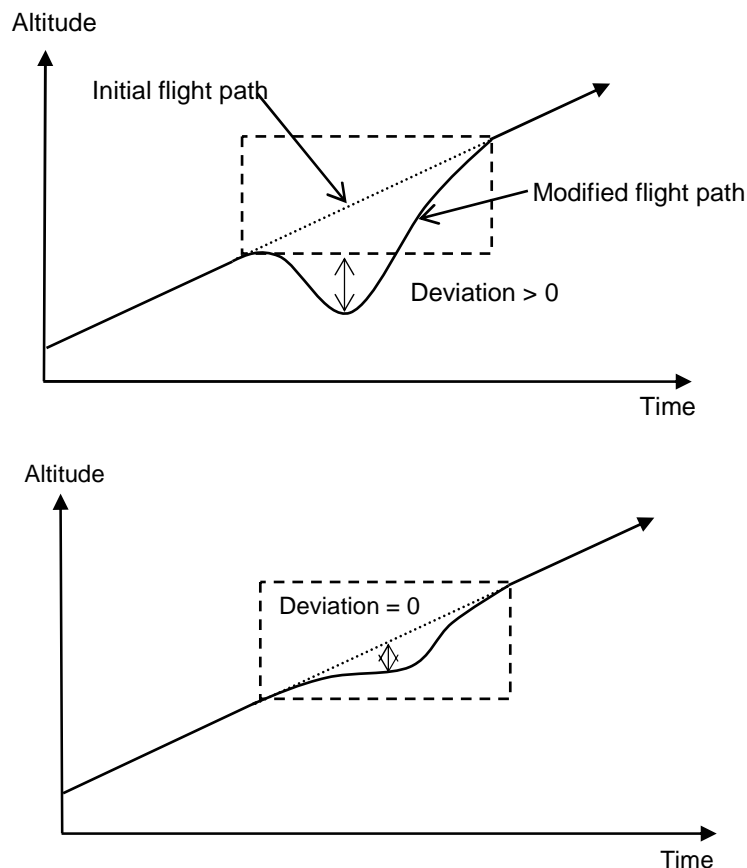


Figure 20: Vertical deviation calculation

- 5.2.2.4.3. The vertical deviation average computed with CP115 has to be equal to or lower than the vertical deviation average computed with TCAS II Version 7. Indeed, one requires no degradation or little improvement in the vertical deviation with CP115.

5.2.2.5. Metric AD5: Compatible RA sense rate

- 5.2.2.5.1. This metric measures the probability, when an RA is issued, that the advisory sequence leads to a vertical manoeuvre compatible with the ATC clearance (i.e., a vertical manoeuvre that does not change the sign of the VMD at CPA). It is usually less disruptive, more effective and safer for TCAS to be consistent with the original ATC intention. In particular, TCAS should avoid generating crossing RAs in encounters where no crossing was originally intended.
- 5.2.2.5.2. An RA can disrupt ATC or the normal operation of the aircraft by inverting (when compared to a situation without TCAS contribution) the relative vertical position of two aircraft at CPA. In this case, the RA will be qualified as not compatible with the ATC clearance.
- 5.2.2.5.3. The compatible RA sense rate computed with CP115 has to be equal to or higher than the compatible RA sense rate computed with TCAS II Version 7. Indeed, one requires no degradation or little improvement in compatible RA sense rate with CP115.

5.2.2.6. Metric AD6: 3rd party involvement rate

- 5.2.2.6.1. The rate of third party involvement in a TCAS conflict is computed over a defined period of time (e.g., per flight hour, per year) and over a defined region (e.g., an entire airspace or a sector).
- 5.2.2.6.2. It has been suggested that the proposed change may increase the probability of sequential conflicts with a third party aircraft, or even the probability of simultaneous multiple threat conflicts. This metric will help supporting (or not) the assertion through the comparison between the rate induced by CP115 and the rate induced by the Version 7.
- 5.2.2.6.3. The third party involvement rate computed with CP115 has to be equal to or lower than the third party involvement rate computed with TCAS II Version 7. Indeed, one requires no degradation or little improvement in third party involvement rate with CP115.

5.2.3. Airborne perspective metrics

5.2.3.1. Metric AP1: Positive RA alert rate

- 5.2.3.1.1. The positive RA alert rate is defined as the probability, when an RA is issued, that the advisory sequence includes a positive RA alert (i.e., a Climb or Descend RA). This metric is given as a rate per flight hour.
- 5.2.3.1.2. The positive RA alert rate provides a metric of the disruption caused by TCAS to the normal operation of the aircraft (e.g., an RA to climb while the aircraft is descending). Reducing the number of positive alerts while maintaining the equivalent level of safety delivered by TCAS improves TCAS operational performance.
- 5.2.3.1.3. The positive RA alert rate computed with CP115 has to be equal to or lower than the positive RA alert rate computed with TCAS II Version 7. Indeed, one requires no degradation or little improvement in positive RA alert rate with CP115.

5.2.3.2. Metric AP2: Complex RA sequence rate

- 5.2.3.2.1. The complex RA sequence rate is defined as the probability, when an RA is issued, that the advisory sequence is composed of more than one advisory. This metric is given as a rate per flight hour, and is counted for sequences of RAs beginning with AVSA RAs.
- 5.2.3.2.2. Assuming no degradation in the level of safety and in airspace disruption, the less complex an RA sequence, the better from a flight crew standpoint.
- 5.2.3.2.3. The complex RA sequence rate computed with CP115 has to be equal to or lower than the complex RA sequence rate computed with TCAS II Version 7. Indeed, one requires no degradation or little improvement in complex RA sequence rate with CP115.

5.2.3.3. Metric AP3: Strengthening RA rate

- 5.2.3.3.1. The strengthening RA rate is defined as the probability, when an RA is issued, that the initial advisory is strengthened through the issuance of a positive RA (with increased or reversal rate). This metric is given as a rate per flight hour.
- 5.2.3.3.2. The metric may highlight inadequate advisory sequences posted by a logic version (e.g., issuance of an initial advisory limiting the rate of descent while a climb RA is eventually triggered). In addition, stressful situations induced by strengthening RAs should be minimised.
- 5.2.3.3.3. The strengthening RA rate computed with CP115 has to be equal or lower than the strengthening RA rate computed with TCAS II Version 7. Indeed, one requires no degradation or little improvement in strengthening RA rate with CP115.

5.2.4. Operational performance metric results

- 5.2.4.1. The following table summarizes the results obtained in the computation of the airspace disruption metrics defined above over the NY area, for the 3 months for which radar data were provided.

| Ref | Metric name | V7.0 value | V7.0+CP115 value |
|-----|------------------------------|--------------------------------|--------------------------------|
| AD1 | RA alert rate | 2.29×10^{-2} per f.h. | 2.29×10^{-2} per f.h. |
| AD2 | AVSA 0 RA alert rate | 5.78×10^{-3} per f.h. | 9.54×10^{-3} per f.h. |
| AD3 | Nuisance alert rate | 0.045 | 0.045 |
| AD4 | Vertical deviation average | 116 ft | 116 ft |
| AD5 | Compatible RA sense rate | 0.99 | 0.99 |
| AD6 | Third party involvement rate | 7.0×10^{-6} per f.h. | 7.0×10^{-6} per f.h. |

Table 6: airspace disruption performance metrics

- 5.2.4.2. The above table indicates that CP115 meets the requirements for all the airspace disruption metrics, as it does not change the values obtained with Version 7, except for the increased rate of AVSA 0 RAs which results from the nature of CP115.

- 5.2.4.3. The rate of RA alerts (metric AD1) is significant, compared to Europe ([SIRE+2]) or to Boston TMA ([SIRE+3]), as there is about 1 RA every 40 flight hours. In addition, the nuisance alert rate indicates that almost all of these RAs can be considered as genuine. These results are related to the nature of the NY airspace, where traffic is extremely dense and mixes IFR and VFR flights. As a side note, computing the nuisance alert rate with a 500 ft, rather than 1,000 ft separation to take into account the very frequent RAs against VFR traffic leads to a rate of 0.609 for both versions.
- 5.2.4.4. The vertical deviation average has only been computed on the subset of encounters where an initial AVSA RA has been simulated, as introducing CP115 would have no effect on the vertical deviations in encounters where another type of RA has been issued.

5.2.5. Airborne perspective metric results

- 5.2.5.1. The following table summarizes the results obtained in the computation of the airborne perspective metrics over the NY area, for the 3 months for which radar data were provided.

| Ref | Metric name | V7.0 value | V7.0+CP115 value |
|-----|--------------------------|--------------------------------|--------------------------------|
| AP1 | Positive RA alert rate | 5.26×10^{-3} per f.h. | 5.15×10^{-3} per f.h. |
| AP2 | Complex RA sequence rate | 3.11×10^{-3} per f.h. | 2.74×10^{-3} per f.h. |
| AP3 | Strengthening RA rate | 2.80×10^{-4} per f.h. | 2.80×10^{-4} per f.h. |

Table 7: airborne perspective performance metrics

- 5.2.5.2. The above table indicates that CP115 meets the requirements for all the airspace disruption metrics, as it slightly improves the values obtained with Version 7 or does not change them. The rate of strengthening RAs is not affected by CP115 as it did not lead to the removal of Increase or Reversal RAs that were issued by Version 7.
- 5.2.5.3. The decrease in the rate of positive RAs can be explained by the fact that during level-off encounters, the vertical convergence between the aircraft decreases more rapidly when a pilot is responding to an AVSA 0 RA rather than an AVSA 2000, 1000 or 500 RA. Therefore, the likelihood of the RA strengthening to a positive RA is reduced.
- 5.2.5.4. In the same geometries, the Version 7 logic can post increasingly stronger AVSA RAs, possibly up to a positive RA, in quick succession if the vertical convergence rate is not decreasing as fast as expected, which constitutes a complex RA sequence. With CP115, this complex sequence can be replaced by a single Level-Off RA, as it is more efficient in rapidly reducing the vertical convergence. This explains the noticeable reduction in the rate of complex RA sequences.
- 5.2.5.5. The previous two improvements brought by CP115 to the airborne perspective metrics are illustrated by the following example, where two TCAS-equipped aircraft are about to perform a 1,000 ft level-off separation manoeuvre. Because of the significant vertical convergence rate between these aircraft, coordinated RAs are issued, requesting the red aircraft to reduce its rate of descent to 500 fpm and the black aircraft to reduce its rate of climb to 1,000 fpm. These initial RAs are then rapidly strengthened up to a Climb RA for the red aircraft and to a Don't Climb RA for the black aircraft.

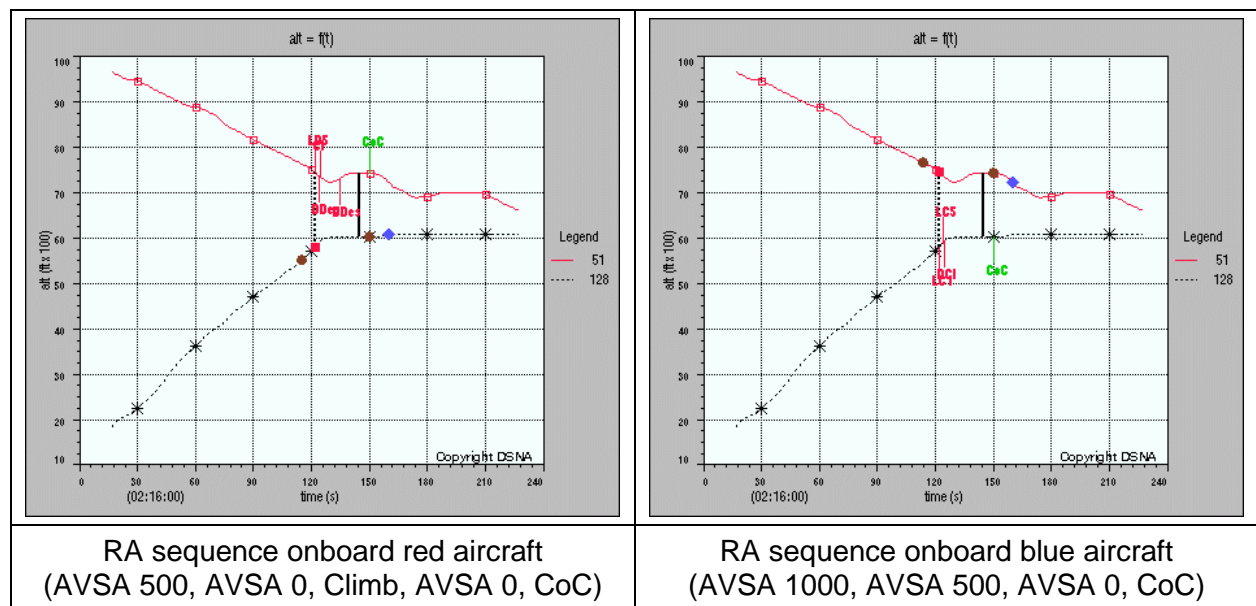


Figure 21: CP115 impact on airborne perspective metrics – Version 7 example

5.2.5.6. The next figure shows the RAs generated in the same encounter with CP115. Both aircraft receive only one Level-Off RA, instead of a sequence of RAs with Version 7. In addition, the positive Climb RA issued by Version 7 onboard the red aircraft is not issued anymore with CP115.

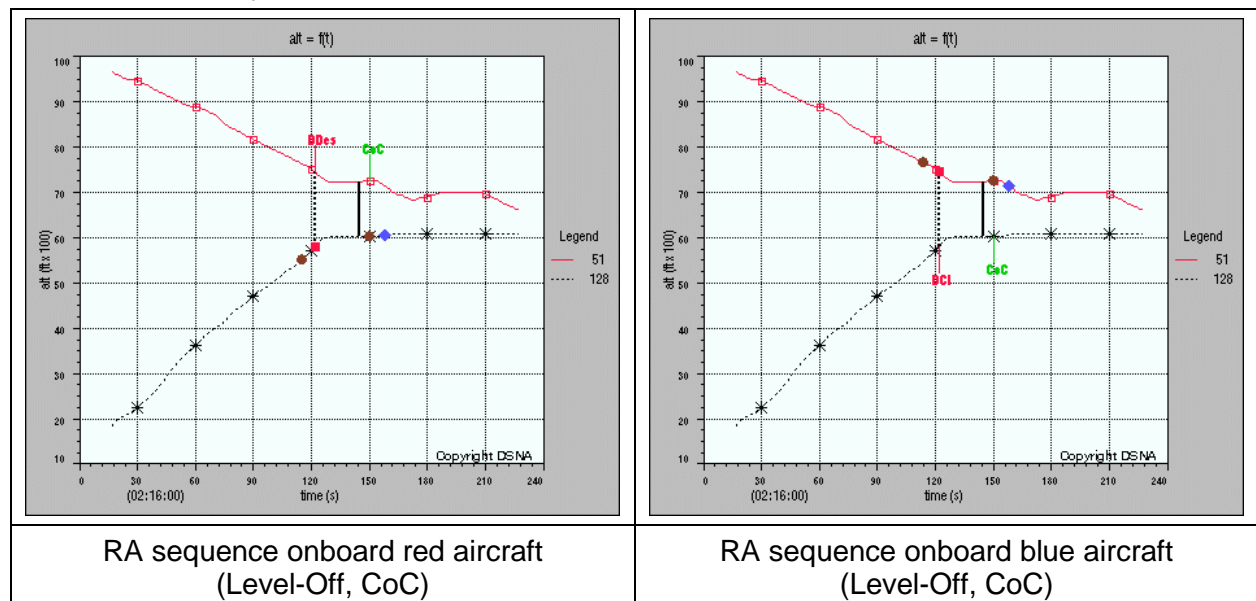


Figure 22: CP115 impact on airborne perspective metrics – Version 7+CP115 example

5.2.6. Vertical separation difference

5.2.6.1. The following diagram compares the vertical separation provided by Version 7 (on the X axis) and by CP115 (on the Y axis), for the same events simulated with both versions of the logic. The vertical separation is measured at CPA in both cases.

5.2.6.2. It is worth noting that dots above the diagonal line, in the green area, correspond to events where introducing CP115 would increase the vertical separation provided by

Version 7. Conversely, dots below the diagonal line, in the red area, correspond to events where CP115 would decrease the vertical separation provided by Version 7.

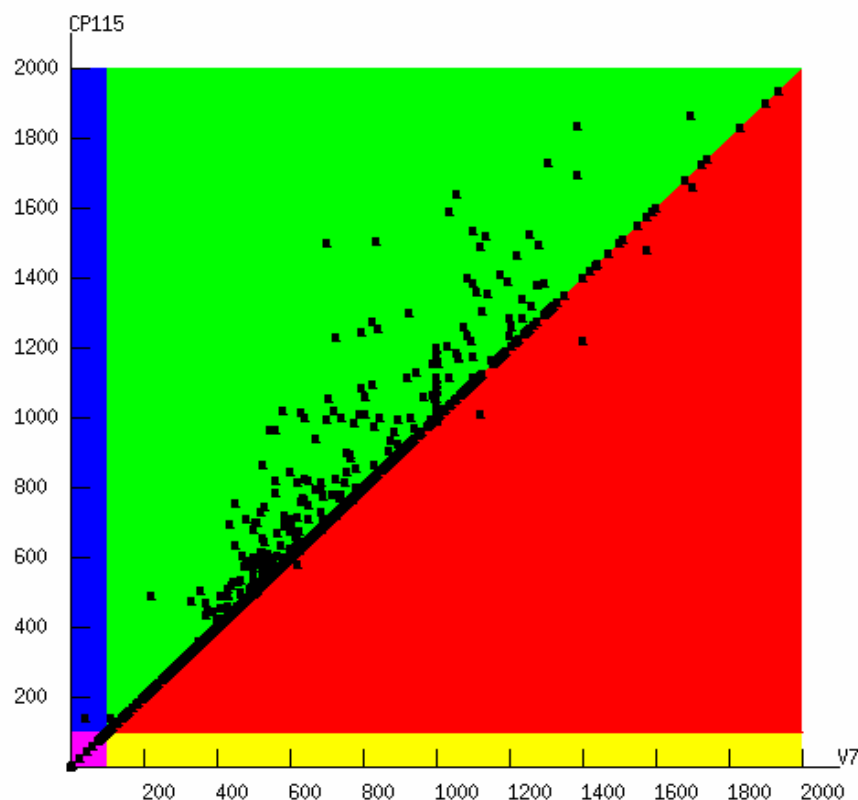


Figure 23: Version 7 / Version 7+CP115 separation difference diagram

5.2.6.3. As can be observed in the above figure, CP115 brings some significant improvements over current Version 7, as it generally improves the vertical separation provided by TCAS. The majority of encounters are however located on the diagonal lines, which indicate that they are unaffected by the introduction of CP115.

5.2.7. Duration of level-off-manoevrre

5.2.7.1. The average duration of the level-off manoeuvres induced by both Version 7 AVSA 0 RAs and CP115 Level-Off RAs has been computed on the subsets of encounters which received these RAs. The results are given in the following table.

| | Version 7 AVSA 0 | CP115 Level-Off |
|--------------------------|------------------|-----------------|
| Level-off phase duration | 12.6 seconds | 13.5 seconds |

Table 8: average duration of level-off manoeuvre

5.2.7.2. As indicated in the above table, both types of RAs induce level-off manoeuvres of similar duration. This explains why introducing CP115 into Version 7 does not

change the average vertical deviation induced by RAs, which has been computed through metric AD4 (cf. 5.2.4).

5.3. Third party aircraft issue

5.3.1. Introduction

5.3.1.1. The main point investigated in this section is the probability of inducing a conflict with a nearby third party aircraft by responding to a Level-Off RA. It is indeed the main potential operational drawback that has been highlighted by RTCA SC147 OWG. In fact, RA requesting to level-off already exist in the current Version 7, under the form of “Don’t Descend” or “Don’t Climb” RAs (i.e., AVSA RAs with a target vertical speed of 0 fpm), and therefore, the possibility of induced conflict with a nearby third party aircraft currently exists. However, this probability should not be made unacceptably higher by the introduction of CP115.

5.3.1.2. As a consequence, the investigation of this particular question is focused on events in which CP115 changes Version 7 initial AVSA 500 / 1000 / 2000 RAs to Level-Off RAs and where at least a third aircraft is found in the close vicinity of the pair of aircraft involved in the RA.

5.3.2. AVSA RAs with third party aircraft

5.3.2.1. Out of about 870 encounters with an initial AVSA RA, some involve at least one other traffic in the close vicinity that could be captured using TCAS-like criteria (cf. 3.2.4). The following figure shows the number of aircraft that have been captured in encounters with an initial AVSA RA (which include encounters where an AVSA RA has been issued after an initial MVS RA).

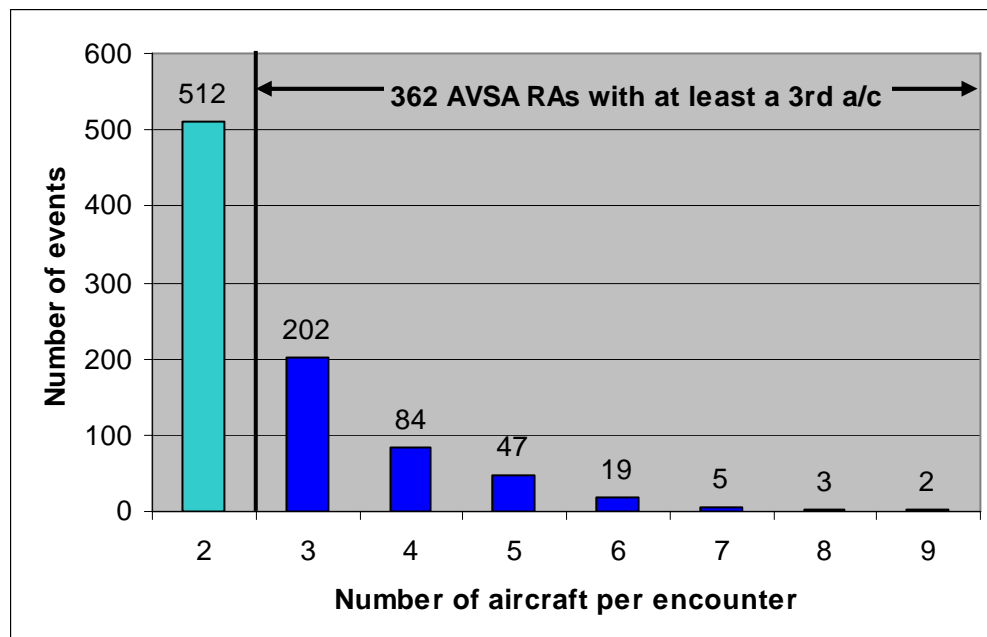


Figure 24: number of aircraft in encounters with initial AVSA RA

5.3.2.2. As indicated in the above figure, about 60% of encounters with an initial AVSA RA do not involve any additional aircraft in the close vicinity of the pair of aircraft

involved in the RA. Consequently, in these cases, introducing CP115 could not lead to an induced conflict.

- 5.3.2.3. Consequently, about 360 encounters with an initial AVSA RA involve at least one other aircraft in the vicinity, that could possibly enter in an induced conflict with the TCAS aircraft because of the response to the RA. Given the 92 days of data, this is equivalent to 4 per day.
- 5.3.2.4. The following figure shows the distribution of these 360 encounters with an initial RA and third party aircraft in the close vicinity by type of AVSA RA.

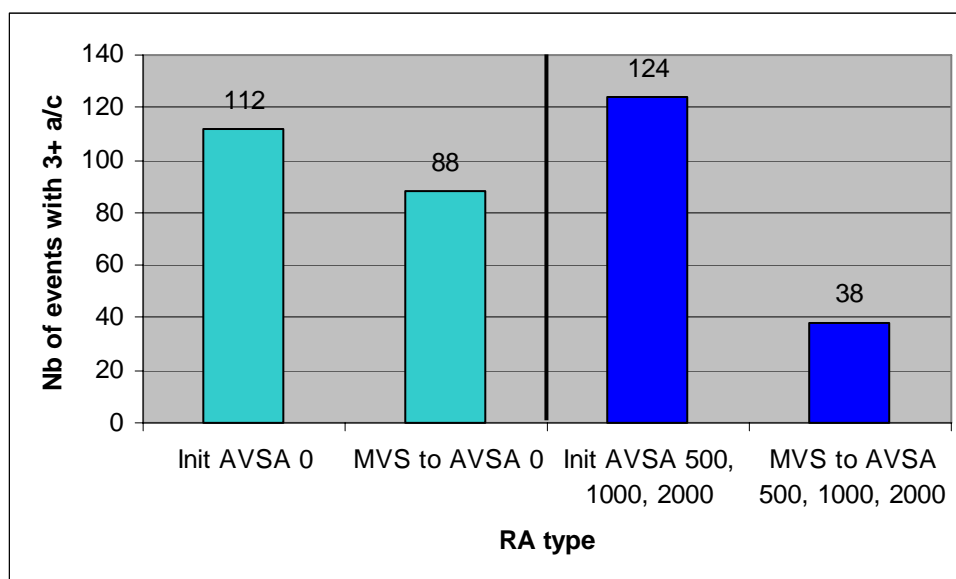


Figure 25: encounters with initial AVSA RAs and surrounding traffic by RA type

- 5.3.2.5. The above figure shows that among the encounters with an initial AVSA RA and surrounding traffic, about 200 of them already involve an RA requiring a level-off manoeuvre (i.e., an AVSA 0 RA). CP115 would require the same manoeuvre from these aircraft through Level-Off RAs.
- 5.3.2.6. Consequently, over the 3 months of data that have been analysed, only 160 events with some traffic in the close vicinity and in which CP115 would modify the Version 7 behaviour have been identified. **This is equivalent to less than 2 such events per day, out of the 35 encounters with credible RAs per day which have been identified.**
- 5.3.2.7. As a reminder, the analysis performed on the Boston area had indicated a similar ratio, with 15 events that would be modified by CP115 and with third party aircraft in the close vicinity, out of a total of 337 events with an RA.

5.3.3. Intruder proximity

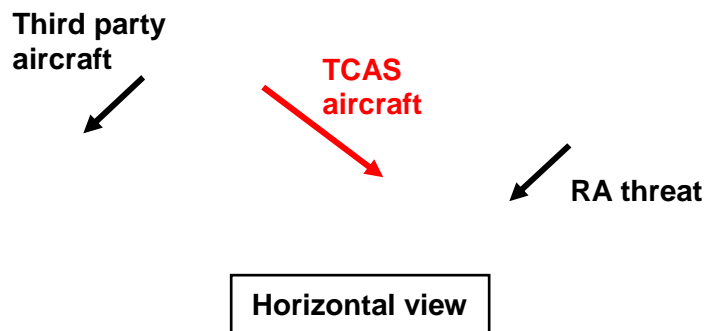
- 5.3.3.1. TCAS simulations have been performed with both Version 7 and CP115 on the 160 encounters with an initial AVSA RA and some traffic in the close vicinity. These simulations show that introducing CP115 in the TCAS logic would not induce any RA, or even any TA, with a third party aircraft because of the response to the Level-Off RA.

5.3.3.2. The purpose of the present section is thus to investigate how close neighbouring aircraft are relatively to the TCAS aircraft, in order to better assess the risk of inducing a TCAS alert with a nearby aircraft when responding to a Level-Off RA.

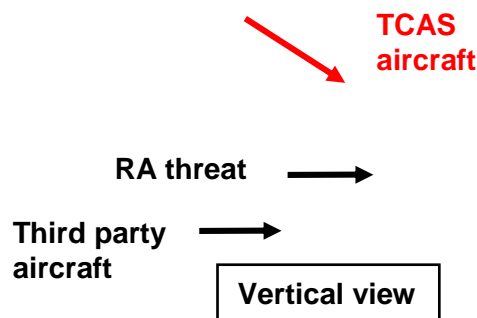
5.3.3.3. In order to do so, the outcome of the TCAS simulations has been used. Indeed, the proximity of the neighbouring aircraft has been evaluated through the computation of the modified TAU and predicted VMD at the time of the initial AVSA RA for all aircraft in the vicinity of the TCAS aircraft, so as to assess how far they are from triggering an alert. The values obtained have then been compared to the thresholds used by the CAS logic to trigger RA.

5.3.3.4. Depending on the relative position of aircraft, four categories of intruders are considered, listed below by increasing severity :

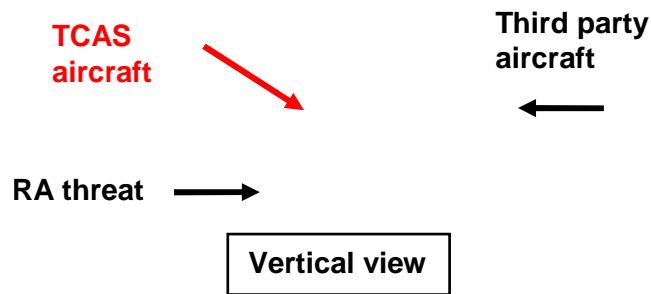
1. Third party aircraft diverging from the TCAS aircraft in the horizontal dimension. These can not become involved in an induced conflict in response to the RA. As illustrated below, this corresponds to the case when the TCAS aircraft has already crossed the path of an intruder when it receives the RA.



2. Third party aircraft converging towards the TCAS aircraft in the horizontal dimension and from which the TCAS aircraft would manoeuvre away in response to the RA. These can not be involved in an induced conflict either, as the TCAS aircraft will be also moving away from them when moving away from the threat aircraft. As depicted below, this corresponds to a situation where the TCAS aircraft is, for example, descending towards two level aircraft.



3. Third party aircraft converging towards the TCAS aircraft in the horizontal dimension and towards which the TCAS aircraft would manoeuvre in response to the RA. Only these can be involved in an induced conflict, as the TCAS aircraft will move closer to them. As shown below, this can happen when the TCAS aircraft is descending towards a level aircraft, with a second level aircraft at the same altitude.



4. Aircraft triggering the RA onboard the TCAS aircraft.

5.3.3.5. The next figure plots these categories of intruding aircraft on a modified TAU against predicted VMD graph, with aircraft belonging to the category 1 shown as black dots, those from category 2 as green squares, those from category 3 as red triangles and threat aircraft from category 4 as blue diamonds.

5.3.3.6. All the aircraft involved in the 160 encounters are not shown on the figure because the surrounding traffic capture process leads to some very far aircraft, in TCAS terms, being captured. The scale that has been chosen corresponds to twice the maximum TA thresholds (i.e. 96 seconds for modified TAU and 1,700 ft for predicted VMD) so as to focus on intruders that can possibly enter these TA thresholds.

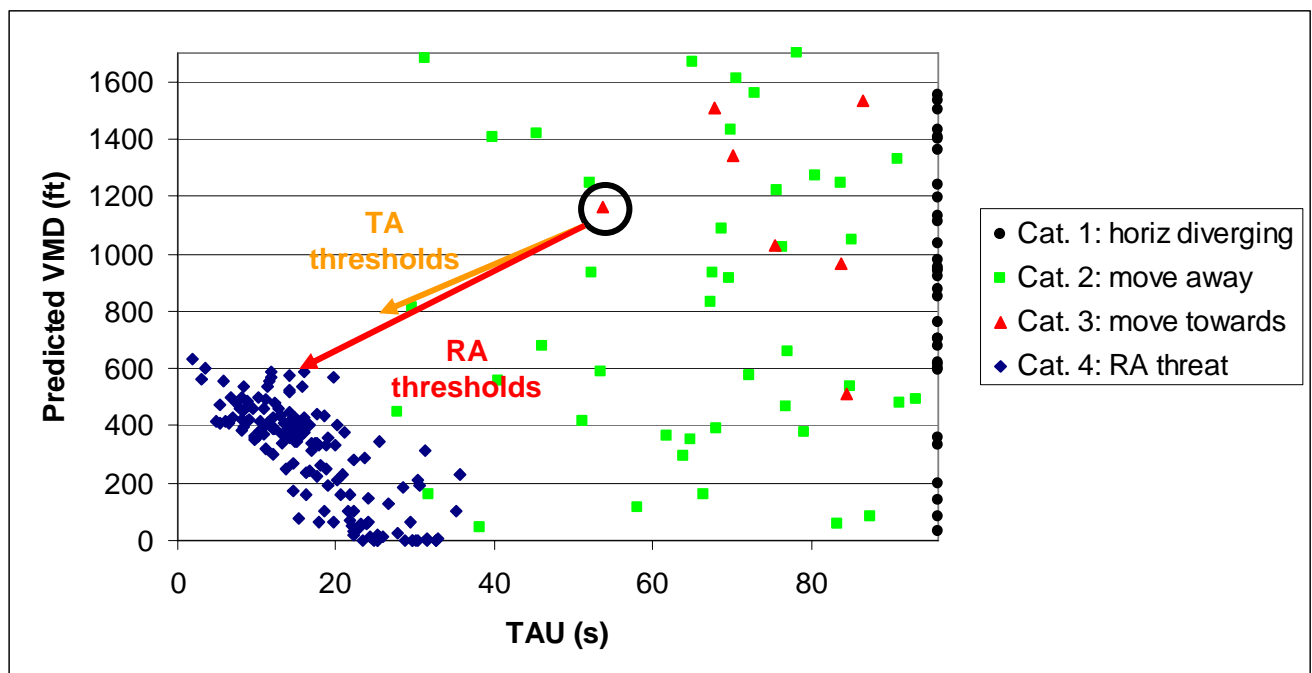


Figure 26: proximity of intruders in encounters with initial AVSA RA

5.3.3.7. The above figure shows that the four categories of aircraft are clearly differentiated in terms of proximity to the TCAS aircraft. The closest aircraft are, as expected, the threat aircraft against which the RA is issued.

5.3.3.8. Then, the next closest aircraft are intruders from the second category, i.e. those from which the TCAS aircraft would manoeuvre away when responding to a Level-

Off RA. They constitutes the majority of aircraft that are close to the pair involved in the RA and would not be involved in a conflict induced by the response to the RA.

5.3.3.9. The next closest aircraft are intruders from the third category, i.e. those towards which the TCAS aircraft would manoeuvre when responding to a Level-Off RA. **There are only seven cases in 92 days where such an intruder falls within twice maximum TA thresholds, and they are all outside the TA thresholds,** which explains why no additional alert have been observed in simulation

5.3.3.10. The circled intruder shows the third party aircraft which is the closest, in terms of likelihood of TCAS alert (with a 53.5 second TAU and a 1,165 ft predicted VMD), to a pair of aircraft involved in an initial AVSA RA. Because this encounter happens at low altitude, the TA and RA thresholds used by the CAS logic are much smaller, i.e. 15 seconds and 600 ft. The amber arrow shows where this intruder should be in order to trigger a TA onboard the TCAS aircraft, while the red arrow shows where it should be to trigger an RA. The closest intruder is thus still far in terms of TCAS alert criteria.

5.3.3.11. **In 3 months of radar data, no encounter has been actually identified where the response to a Level-Off RA would induce a TCAS alert with a nearby third party aircraft and in any event, the risk of doing so with CP115 is no greater than the risk found with the current Version 7.** In addition, ATC separation in the investigated events would not be compromised because of C115, **as no event has been identified where a loss of separation would have been induced by CP115.**

5.3.4. Illustration of CP115 most significant effect

5.3.4.1. The following series of figures illustrates the behaviour of both Version 7 and CP115 in the encounter highlighted in Figure 26, with the third party aircraft which has been found the closest to entering in an induced conflict.

5.3.4.2. The first of these figures shows the encounter simulated with Version 7 and from the perspective of the pair of aircraft involved in the RA (corresponding to the red and blue trajectories). The dashed and solid lines between the two trajectories indicate the positions of the aircraft, respectively at the time of the AVSA RA and at CPA.

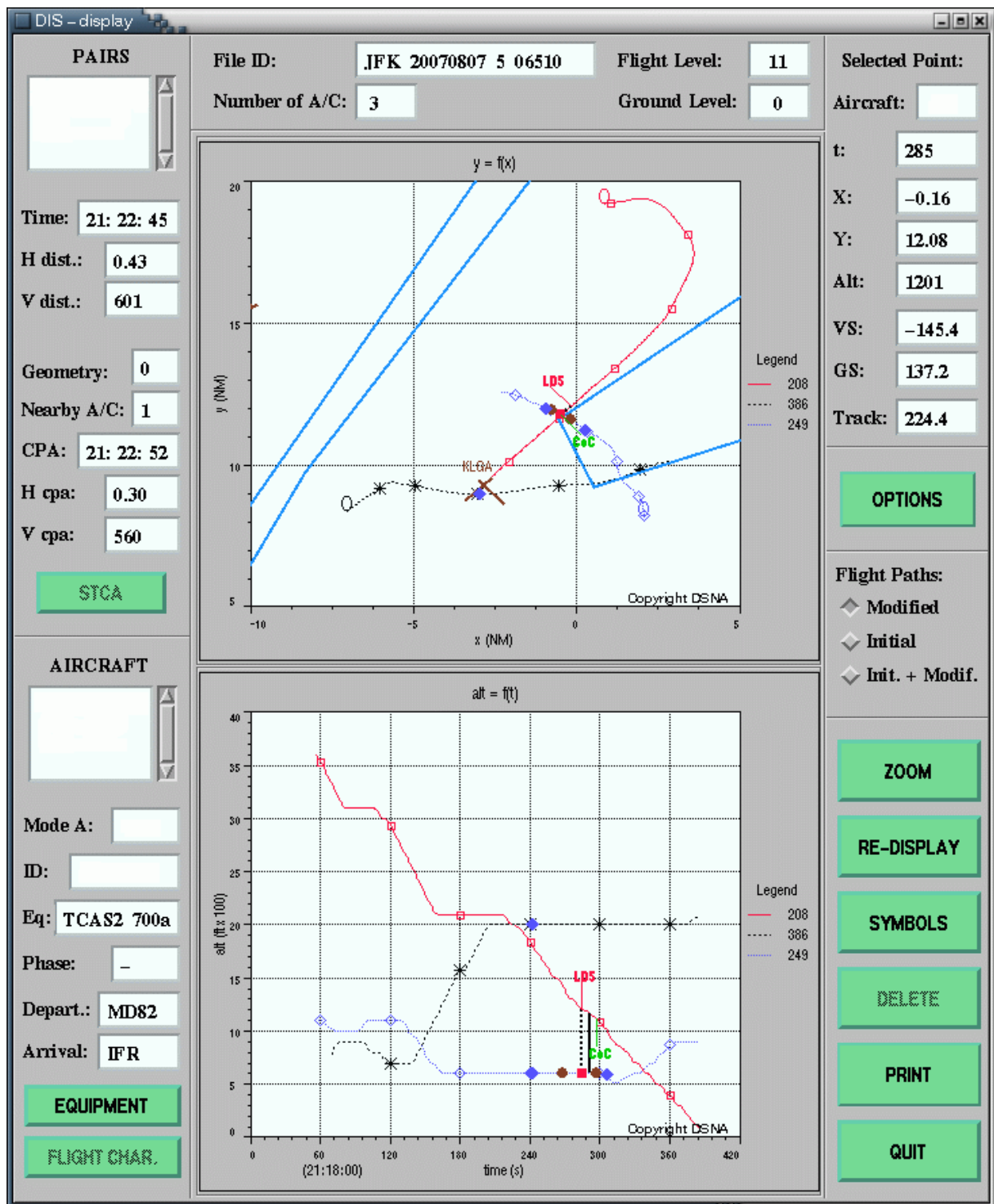


Figure 27: CP115 most significant effect – RA threat perspective – Version 7

5.3.4.3. The next figure shows the same encounter simulated with Version 7 and from the perspective of the pair formed by the TCAS aircraft and the third party aircraft (corresponding to the red and black trajectories).

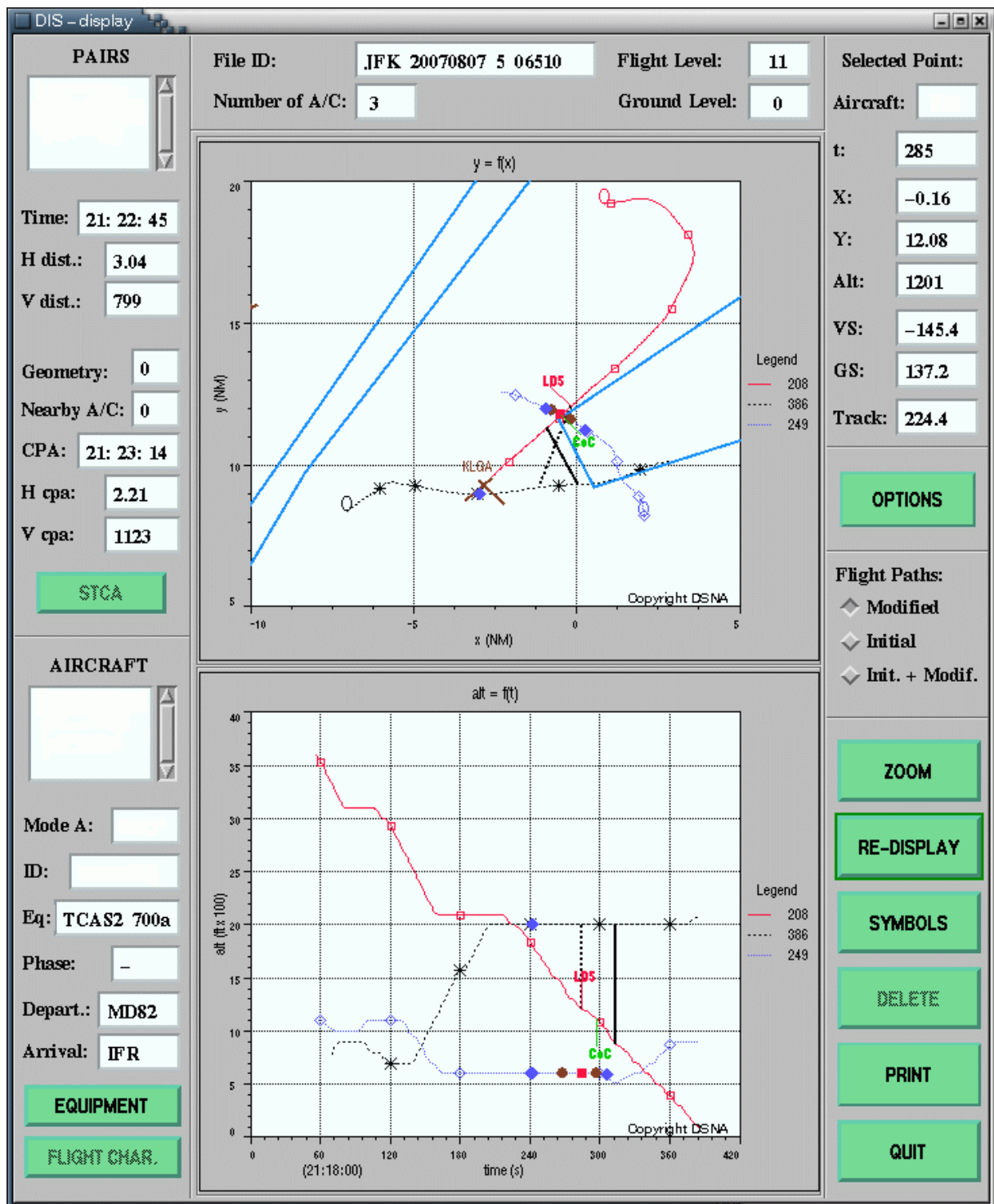


Figure 28: CP115 most significant effect – 3rd party perspective – Version 7

5.3.4.4. As can be seen in the above figure, the separation between the TCAS aircraft and the third aircraft is just over 1,100 ft at their CPA.

5.3.4.5. The next figure shows the encounter simulated with CP115 and from the perspective of the pair of aircraft involved in the RA (corresponding to the red and blue trajectories).

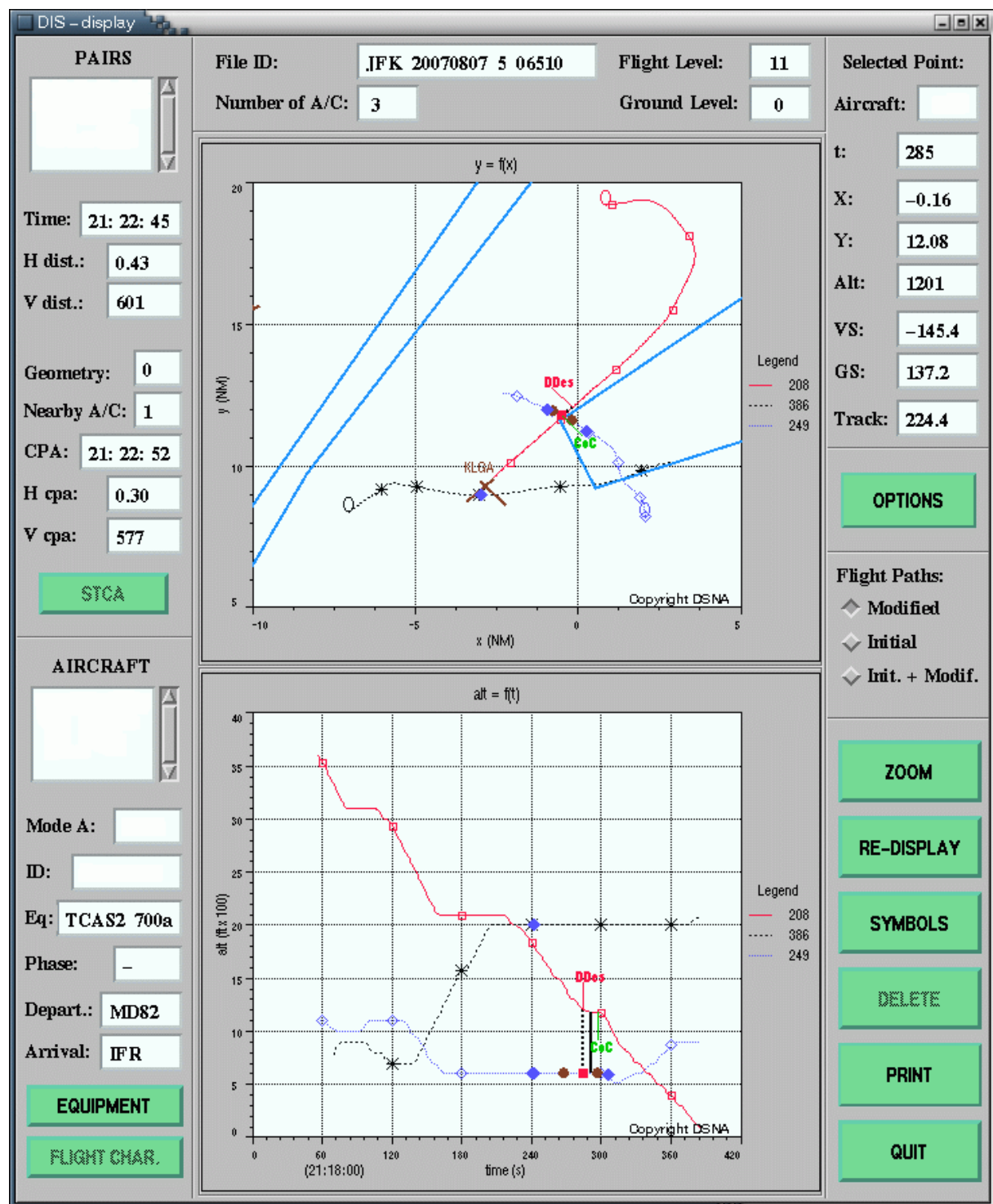


Figure 29: CP115 most significant effect – RA threat perspective – CP115

- 5.3.4.6. As indicated above, the vertical separation from the threat aircraft provided by CP115 is marginally larger than the separation obtained with Version 7 (i.e. 580 ft rather than 560 ft), as a result of the short duration of the Level-Off RA.
- 5.3.4.7. The last figure shows the encounter simulated with CP115 and from the perspective of the pair formed by the TCAS aircraft and the third party aircraft (corresponding to the red and black trajectories).

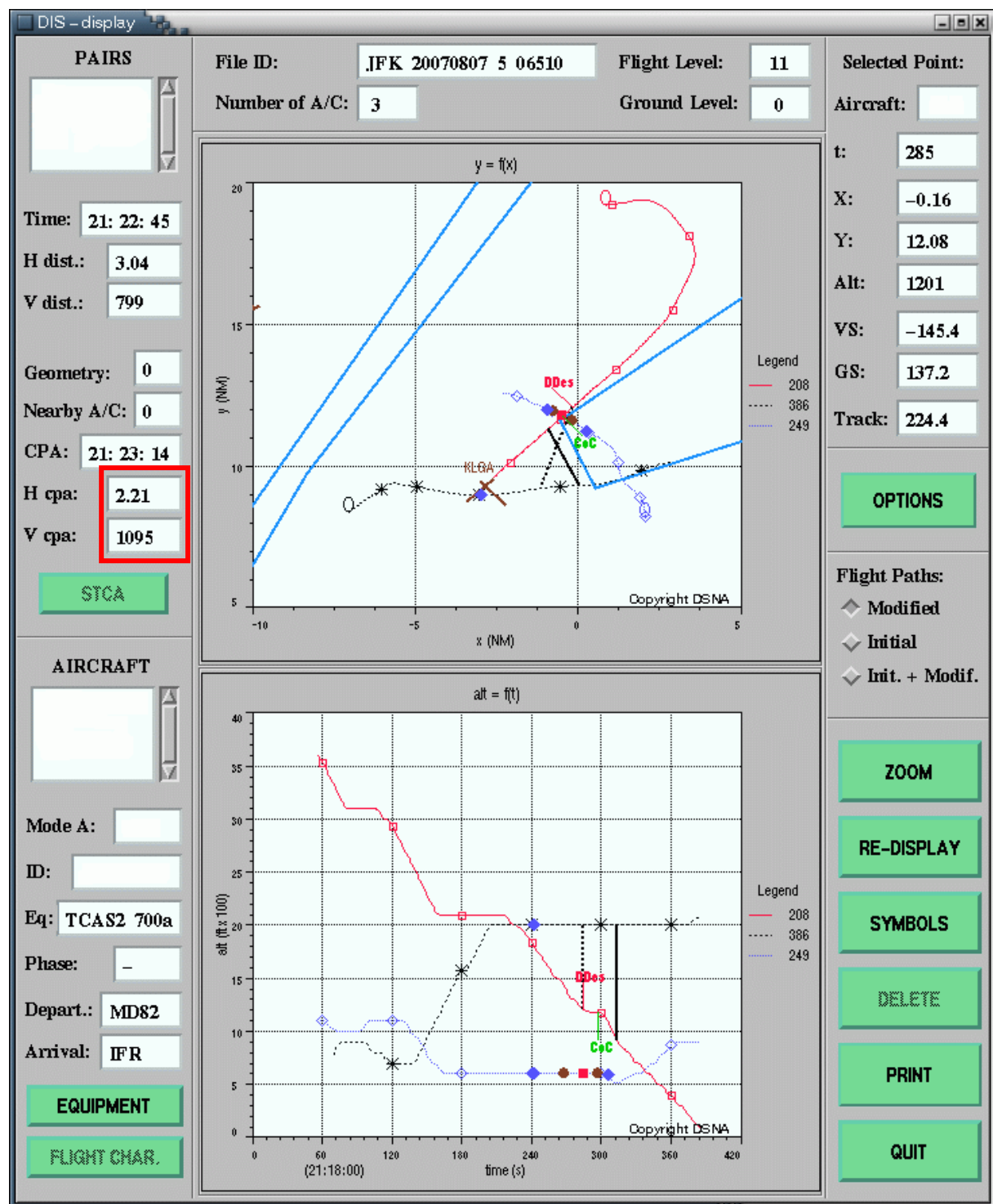


Figure 30: CP115 most significant effect – 3rd party perspective – CP115

- 5.3.4.8. As indicated by the above figure, in the only case that has been identified where CP115 would reduce separation from a close third aircraft, this reduction in vertical separation is only about 30ft (i.e., 1095 ft instead of 1125 ft with Version 7).
- 5.3.4.9. Additionally, it should be noted that the HMD at CPA between the TCAS aircraft and the third party aircraft is over 2 NM. This large horizontal distance can explain why the TCAS aircraft has been cleared to descend through the altitude of the third party

aircraft. Had this horizontal distance been smaller, the ATCO may have instructed the TCAS aircraft to level-off above the third party aircraft.

- 5.3.4.10. In all the other cases where the TCAS aircraft would manoeuvre towards a nearby third party aircraft when responding to the RA, the separation with this third aircraft would be unaffected by the introduction of CP115. The reasons for this result are the short duration of the level-off manoeuvre induced by the Level-Off RA issued by CP115 (cf. 5.2.7) and the fact that the third aircraft is fairly remote in terms of TCAS alert likelihood.

6. Conclusions

- 6.1. The analysis of the radar data collected during three months by the FAA in the New York area has allowed to identify 3,200 events in which an RA has likely been issued. This corresponds to about 35 RA events per day, a rate which is significantly higher than those observed in previous studies, in Europe or in the Boston region.
- 6.2. An investigation of the operational characteristics of the NY airspace has highlighted the density of the traffic, with 13 airports presenting more than 100,000 annual movements each within a 60 NM radius circle, and the fact that it mixes VFR and IFR traffic as the main reasons for this high rate of RA alerts.
- 6.3. The operational performance analysis of CP115 in the 3,200 RA events shows some operational benefits with no degradation of the overall TCAS performance. Indeed, CP115 reduces the positive RA alert rate and does not modify the other indicators computed for the current Version 7. In particular, it does not increase the average vertical deviation in response to RAs, essentially because of the short duration of the level-off manoeuvres induced by Level-Off RAs.
- 6.4. Out of the 3,200 credible RA events, about 870 are initial AVSA RAs. As CP115 only replaces those RAs which do not already require a 0 fpm vertical rate, CP115 has been showed to modify 13% of the RA events identified in the NY area, or about 5 per day.
- 6.5. The potential issue of an induced conflict with a nearby third party aircraft has also been investigated on the 360 initial AVSA RA events where a third party aircraft has been found in the close vicinity of the TCAS aircraft. This investigation has shown that introducing CP115 will not cause induced conflicts with third party aircraft more frequently than with the current version of TCAS. In fact, about 2 encounters per day have the geometry to potentially induce such a conflict, but none has been identified where responding to a Level-Off RA would actually create a conflict with a nearby third party aircraft (i.e. no additional RA, TA or loss of ATC separation was induced by CP115).
- 6.6. **The operational performance assessment of CP115 performed on the NY region confirms previous similar assessments** conducted in the European airspace and in the Boston area.
- 6.7. **CP115 proves to be a very effective solution to the safety issue of unintentional opposite responses to initial AVSA RAs which inclusion in the forthcoming 7.1 revision of TCAS II is supported by European stakeholders** (EASA, AEA, major European airlines, EUROCONTROL, EUROCAE, DSNA, Airbus, Egis Avia ...).

7. Acronyms

| | |
|-------|---|
| ATC | Air Traffic Control |
| ATCO | Air Traffic COntroller |
| AVSA | Adjust Vertical Speed, Adjust |
| CAS | Collision Avoidance System |
| CP | Change Proposal |
| CPA | Closest Point of Approach |
| DSNA | Direction des Services de la Navigation Aérienne |
| FAA | Federal Aviation Administration |
| fpm | feet per minute |
| HMD | Horizontal Miss Distance |
| IFR | Instruments Flight Rule |
| MVS | Monitor Vertical Speed |
| NM | Nautical Mile |
| OSCAR | Off-line Simulator for Collision Avoidance Resolution |
| OWG | Operations Working Group |
| RA | Resolution Advisory |
| SARPs | Standards And Recommended Practices |
| TA | Traffic Advisory |
| TCAS | Traffic alert and Collision Avoidance System |
| TMA | Terminal Control Area |
| VFR | Visual Flight Rule |
| VMD | Vertical Miss Distance |

8. References

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- [EMO1] ‘EMOTION-7 Final Report’ – EUROCONTROL ACAS Programme – ACAS/03-003 Edition 1 – January 2003.
- [FAA1] ‘Air Carrier Operational Approval and Use of TCAS II’ – FAA – AC 120-55B – October 2001
- [RTCA1] RTCA – ‘Minimum Operational Performance Standards for Traffic Alert and Collision Avoidance System II (TCAS II) Airborne Equipment’ – DO-185A, December 1997.
- [RTCA2] RTCA – ‘Safety Analysis of Proposed Change to TCAS RA Reversal Logic’ – DO-298, November 2005.
- [RTCA3] RTCA – ‘Assessment and Recommendations on Visual Alerts and Aural Annunciations for TCAS II’ – DO-299, March 2006.
- [SIRE+1] ‘Draft change proposal for simplified VSL RA list’ – EUROCONTROL Mode S & ACAS Programme, Sofréavia & DSN – SIRE+/WP2/15/D – Version 1.2, September 2006.
- [SIRE+2] ‘Operational performance of CP115 aka the “level-off, level-off” (LOLO) solution’ – EUROCONTROL Mode S & ACAS Programme, Sofréavia & DSN – SIRE+/WP2/32/D – Version 1.1, February 2006.
- [SIRE+3] ‘Operational performance of CP115 in Boston airspace’ – EUROCONTROL Mode S & ACAS Programme, Sofréavia & DSN – SIRE+/WP5/37/D – Version 1.0, March 2007.
- [SIRE+4] ‘Key Operational Performance Metrics and Decision Criteria - TCAS II Version 7 Vertical Speed Limit RA Logic’ – EUROCONTROL Mode S & ACAS Programme, Sofréavia & DSN – SIRE+/WP2/14/D – Version 0.4, June 2006.

9. Appendix A: General description of OSCAR displays

The OSCAR test bench is a set of integrated tools to prepare, execute and analyse scenarios of encounters involving TCAS II equipped aircraft. It includes an implementation of the TCAS II Version 7.

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

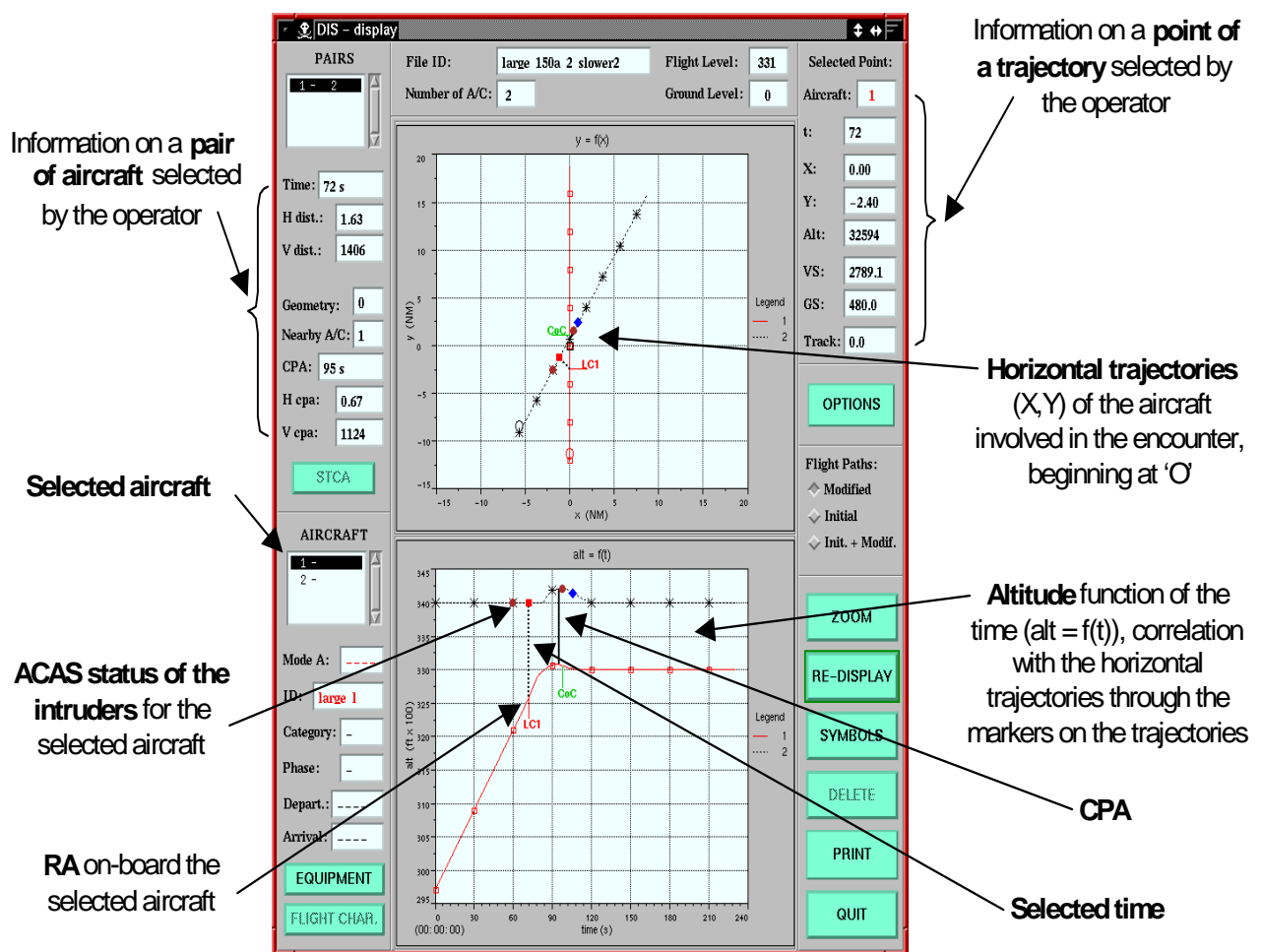


Figure 31: OSCAR display

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

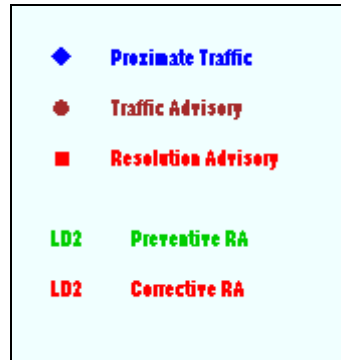


Figure 32: OSCAR symbols

| Label | Advisory |
|-----------------|-------------------------------------|
| CoC | Clear of Conflict |
| CI | Climb (1500 fpm) |
| DDes | Don't Descend |
| LD5 / LD1 / LD2 | Limit Descent 500 / 1000 / 2000 fpm |
| Des | Descend (1500 fpm) |
| DCI | Don't Climb |
| LC5 / LC1 / LC2 | Limit Climb 500 / 1000 / 2000 fpm |
| CCI | Crossing Climb (1500 fpm) |
| RCI | Reverse Climb (1500 fpm) |
| ICI | Increase Climb (2500 fpm) |
| MCI | Maintain Climb |
| CDes | Crossing Descend (-1500 fpm) |
| RDes | Reverse Descent (-1500 fpm) |
| IDes | Increase Descent (-2500 fpm) |
| MDes | Maintain Descent |

Table 9: OSCAR labels

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