

## **Operational performance of CP115 in Boston airspace**

## **Safety Issue Rectification Extension Plus Project**

### **SIRE+ Project**

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## RECORD OF CHANGES

Issue	Date	Detail of changes
0.1	06-03-2007	Initial draft
0.2	08-03-2007	Revised draft following internal review
1.0	09-03-2007	Document delivered to EUROCONTROL

**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 purpose***

- 1.1.1. Following the submission to RTCA of a change proposal to the TCAS Minimal Operational Performance Standards (MOPS), under the name CP115 ([SIRE+1]), designed to address the issue of opposite reactions to initial “Adjust Vertical Speed, Adjust” RAs, the EUROCONTROL SIRE+ project performed a significant body of work to validate CP115. This validation work addressed 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 paper is to complement the operational validation of CP115 that has already been performed on the European airspace ([SIRE+2]). It aims at confirming that the introduction of CP115 will not disrupt the current operations in a US TMA mixing various types of traffic.
- 1.1.3. This report investigates the operational behaviour of CP115 in the Boston TMA airspace, based on radar and RA downlink data provided by the FAA, and answers the specific question of whether the introduction of CP115 can induce conflicts with third parties in a US TMA.

### 1.2. ***Document overview***

- 1.2.1. Section 2 details the different steps of the methodology that has been used to conduct this operational analysis.
- 1.2.2. Section 3 provides the results of the analysis that has been performed on the events of interest identified through the methodology described in the previous section. It notably investigates the likelihood of CP115 inducing a conflict with a 3<sup>rd</sup> party aircraft flying in the vicinity of the TCAS aircraft.
- 1.2.3. Lastly, section 4 draws some conclusions from the analysis of the operational performance of CP115 in the Boston airspace.

## 2. Methodology and data description

### 2.1. Methodology overview

2.1.1. The MIT Lincoln Laboratory has set up a monitoring which uses a production Mode S sensor located close to Boston Logan international airport. The area covered by this sensor is delimited by a 60 NM radius circle depicted in the following figure, and is extending over most of Massachusetts and over parts of the neighbouring states.

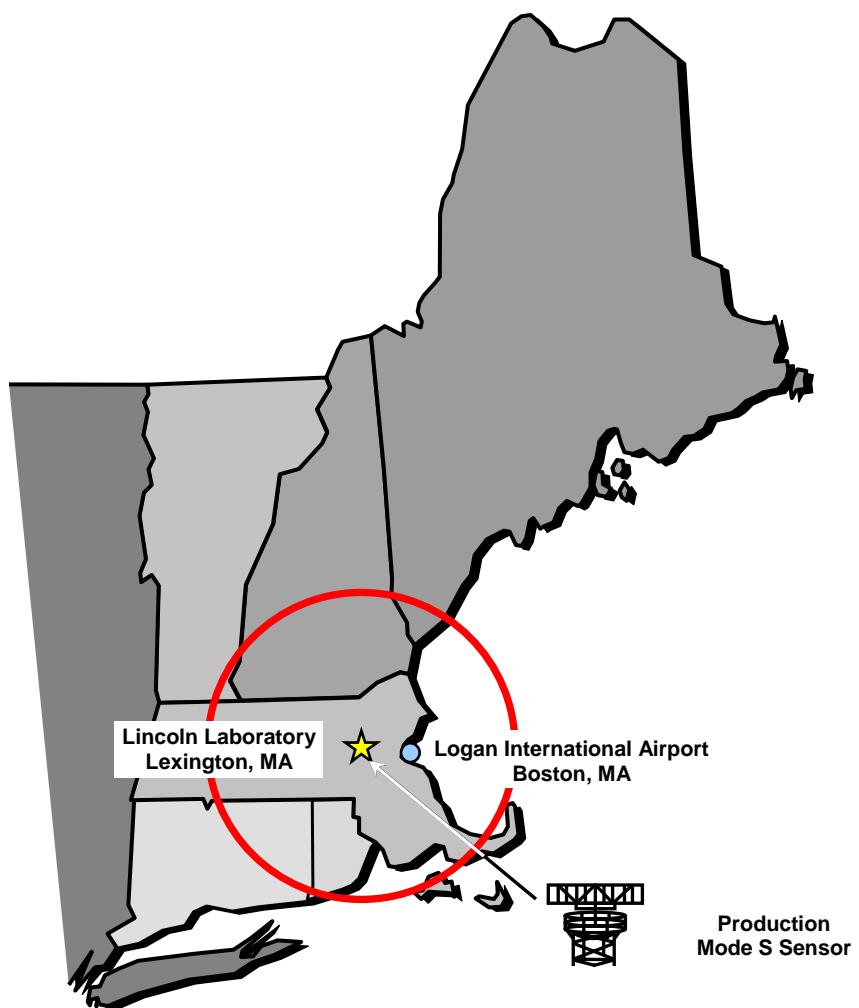


Figure 1: area of monitoring

2.1.2. The data collected through this monitoring are both radar tracks and downlinked RA reports. They allow the identification of all the encounters in which an AVSA RA has been recorded.

2.1.3. The MIT-LL supported the analysis of the operational performance of CP115 in Boston airspace by providing 6 months of data, spanning from February 2006 to July 2006. During this 6-month period, 3,912 hours (i.e. 163 days) of radar data were

recorded out of 4,344 possible hours (i.e. 181 days). This amounts to 90% of overall availability for the recording facility.

- 2.1.4. During the 6-month timeframe, 992 RA events of various types have been recorded through RA downlink. Out of these, 92 events have been identified that correspond to initial AVSA RAs (including AVSA RAs following a “Monitor Vertical Speed” RA). They account for 27 % of all Version 7 events that have been recorded in the Boston area. This figure is significantly less than the 60% ratio commonly observed in European airspace.
- 2.1.5. Based on these data, a methodology has been established to capture and reproduce the 92 events that are of interest in the scope of the present study. It first consisted in extracting the individual events from the radar data files. This was accomplished using the radar recordings provided by the FAA and extracting trajectories of aircraft in a time window of about 7 minutes centred on the time of the RA event.
- 2.1.6. Then, TCAS-like capture criteria were implemented to capture all the radar tracks potentially conflicting with the own aircraft (i.e. the aircraft that received the AVSA RA in the event) during the time window of the radar recording. Because the radar tracks collected contain one plot every 4 or 5 seconds, it was also necessary to smooth the trajectories captured so as to have 1 plot per second and allow the simulation of TCAS on them.
- 2.1.7. Once the trajectories of the aircraft involved in the RA and of the surrounding traffic had been captured, TCAS simulations were performed on the captured encounters to rebuild the RA sequences observed in the RA downlink data.
- 2.1.8. The following figure summarizes the different steps of the methodology used to identify and collect the encounters of interest for the current study.

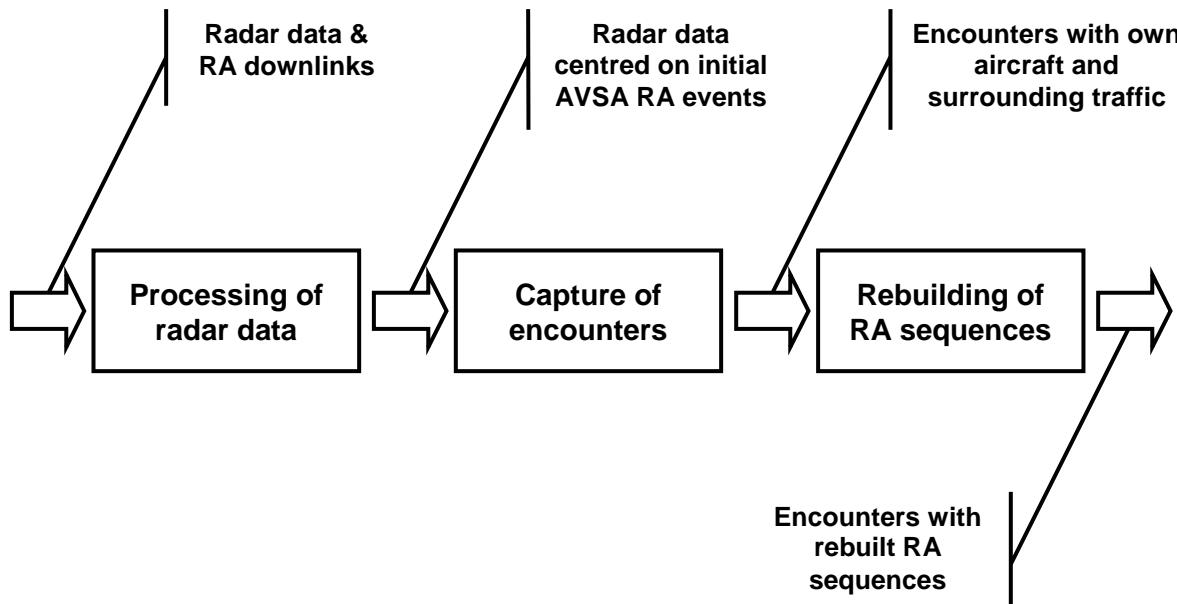


Figure 2: data processing methodology

## 2.2. **Capture criteria**

2.2.1. The radar data provided took the form of ASTERIX Cat. 48 files, one for each day of recording. In addition to these, one file of RA downlink data per day of recording was also available.

2.2.2. To capture the individual encounters of interest in the 6 months of radar data, the date and time of the RA report in the RA downlink data were used to extract a 7-minute long recording from the corresponding daily Cat. 48 file. This extract was centred on the time of the event as indicated in the RA downlink data.

2.2.3. The following step in the encounter capture process was to locate in each 7-minute extract the trajectories of:

- The own aircraft, as indicated by the MIT Lincoln Lab analysis,
- The threat triggering the RA,
- Any aircraft in the vicinity that could possibly be involved in an induced conflict, due to the response to a “Level-off, Level-off” RA.

2.2.4. To this effect, the DSNA OSCAR test bench has been used, as it allows identifying close encounters in radar data based on pre-established capture criteria. To achieve the present study’s objective of investigating induced conflicts with 3<sup>rd</sup> party aircraft, the capture criteria used were very large, based on twice the TA thresholds. The rationale behind this choice of values is that they would allow capturing trajectories with the potential to trigger a TA with the own aircraft while it would be responding to a “Level-off, Level-off” RA.

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

2.2.6. 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 are roughly 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 1: capture criteria**

2.2.7. Running the encounter capture tool on the 92 identified events that included an initial AVSA RAs led to the effective capture of 81 encounters. Of the 11 missing encounters:

- 8 were located at the limit of the radar coverage and the threat trajectory was not recorded,
- 1 happened within the silence cone of the radar, and
- 2 contained undetermined ASTERIX errors.

2.2.8. The following figure shows the trajectories of the aircraft captured this way for all of the events of interest, assembled on a map of the Boston area and with the Mode S sensor coverage area indicated.

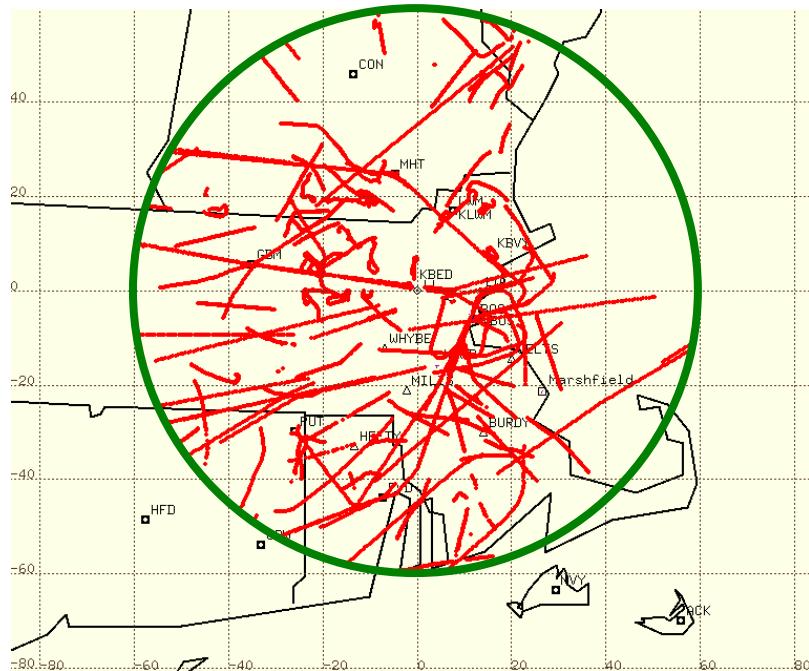


Figure 3: location of detected initial AVSA RAs

### 2.3. Set of captured encounters

2.3.1. As anticipated, the capture criteria that were used enabled to sometimes collect more trajectories than just the two involved in the RA. The following table gives the distribution of the number of aircraft captured in the 81 usable events.

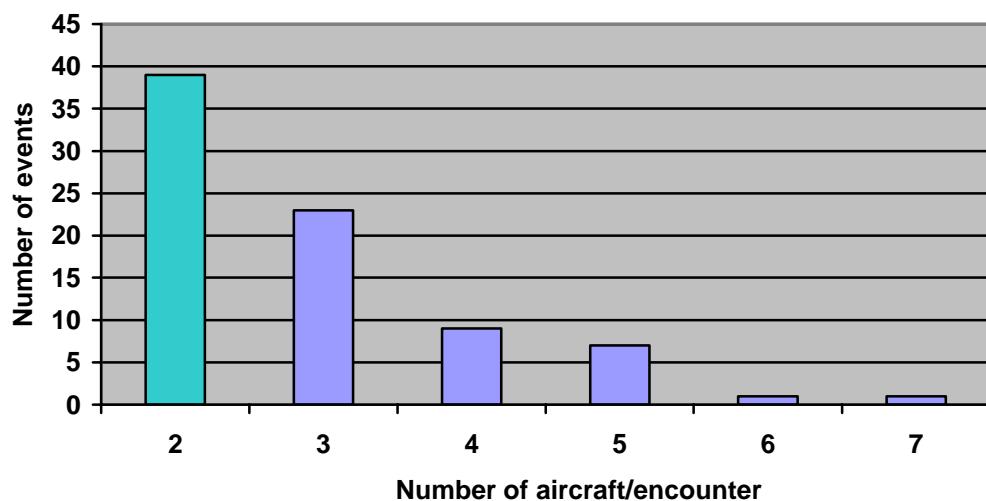


Figure 4: number of aircraft in captured encounters

2.3.2. As can be seen in the above graph, roughly half (i.e. 39) of the encounters captured are purely pair-wise, while the other half (i.e. 42) feature at least a 3<sup>rd</sup> aircraft in the vicinity. Given the 163 days covered by the available radar data, **this represents less than one initial AVSA RA with another aircraft in the vicinity per day in the Boston area.**

2.3.3. The next figure gives the distribution of initial AVSA RAs by altitude, for both single threat encounters and multiple aircraft ones.

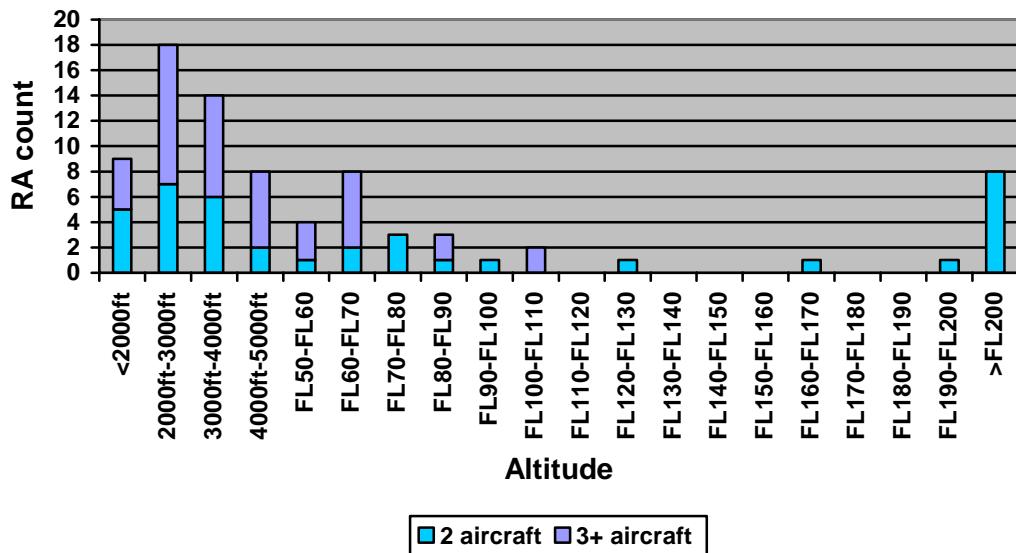


Figure 5: distribution of initial AVSA RAs by altitude

2.3.4. The next figure shows the distribution by altitude of all 992 RA events recorded by the MIT Lincoln Lab monitoring during the February 2006 to July 2006 timeframe. It shows no significant difference from the distribution of initial AVSA RAs above.

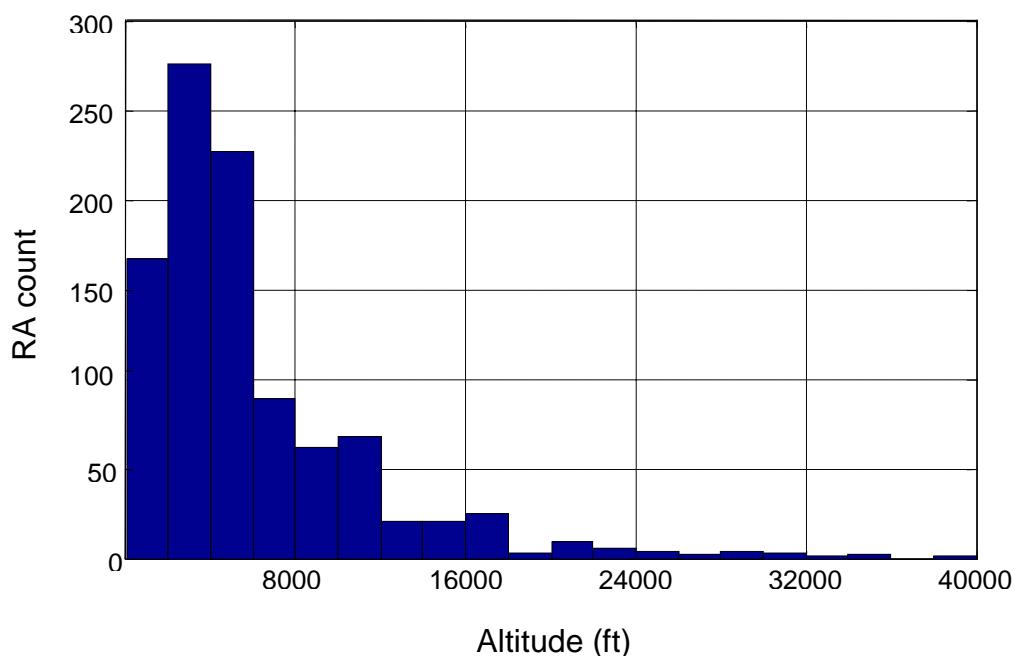


Figure 6: distribution of recorded RAs by altitude

2.3.5. The following chart provides a description of the RAs that have been obtained for the own aircraft when running TCAS II Version 7 simulations on the 81 captured encounters. In some cases, the trajectories had to be slightly adjusted in the vertical dimension, typically by a few feet, in order to obtain RA sequences that were consistent with those found in the RA downlink data. These required adjustments are a consequence of the interpolation that is necessary to transform 4- or 5-second update rate radar tracks into 1-second update rate TCAS surveillance plots.

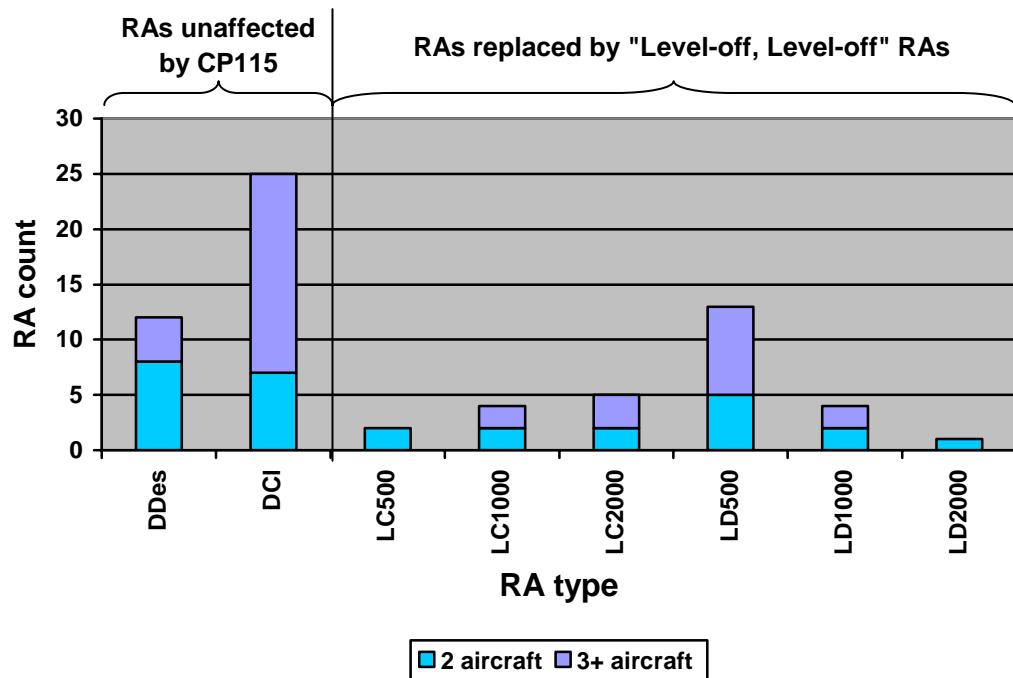


Figure 7: types of initial AVSA RAs in captured encounters

2.3.6. The above figure indicates that the RA sequences observed in the RA downlink data could be reproduced in 66 of the 81 events of interest. In the other 15 cases, no RA could be triggered, even after adjusting the trajectories.

2.3.7. As also indicated in the above figure, 37 of the initial AVSA RAs are either “Don’t Climb” or “Don’t Descend” RAs, which would be unaffected by CP115, as they already require the flight crew to level-off in response to the RA.

2.3.8. Consequently, introducing CP115 would change Version 7 behaviour in only 29 events. No surrounding traffic has been found in 14 of them, as they are purely pairwise, and introducing CP115 could consequently not induce any conflict with a 3<sup>rd</sup> party aircraft in those.

2.3.9. Therefore, **only 15 events with some traffic in the vicinity and in which CP115 would modify the Version 7 logic behaviour have been identified in the Boston area over 6 months**. The present operational performance study is focused on these 15 events, to answer the specific question of whether introducing CP115 can lead to induced conflicts with nearby 3<sup>rd</sup> party aircraft.

2.3.10. The next table extrapolates the above result by assuming that all aircraft in the Boston area would be fitted with TCAS II Version 7 and that the observed ratios between the different types of RAs would still apply in this case.

Type of RA	Current situation	Only Version 7 (extrapolation)
RA events in V7 format	337	992
Non weakening AVSA RAs	92	271
Non weakening AVSA RAs with no error	81	271
Non weakening AVSA RAs in multiple aircraft encounters	42	140
Non weakening AVSA RAs in multiple aircraft encounters (successfully reproduced)	37	140
<b>Non weakening AVSA RAs in multiple aircraft encounters modified by CP115</b>	<b>15</b>	<b>57</b>

Table 2: extrapolation of current situation

2.3.11. Given that the figures in the above table have been obtained over 163 days of recording, **the rate of potential CP115 involvement in events with other traffic in the vicinity is thus of once every 3 days, assuming that all TCAS aircraft would be fitted with TCAS II Version 7 including CP115**. For comparison's sake, there are about 18 RA events of any type recorded over 3 days in Boston TMA on average.

2.3.12. Subsequent simulations performed with CP115 on these 15 encounters showed that no conflict was induced by the level-off manoeuvre in response to the RA between the own aircraft and a 3rd party aircraft flying in its vicinity. Indeed, no 3rd party aircraft proved to be close enough to the own aircraft to trigger an RA, or even a TA.

### 3. Performance assessment

#### 3.1. General

- 3.1.1. The main point investigated in this section is the likelihood of inducing a conflict with a 3<sup>rd</sup> party aircraft in response to a “Level-off, Level-off” RA as it is the main operational drawback that could arise from the introduction of CP115 in Version 7. In fact, such RAs already exist in the current Version 7, under the form of “Don’t Descend” or “Don’t Climb” RAs, and therefore the likelihood of induced conflict with a 3<sup>rd</sup> party already exists. However, this possibility should not be made unacceptably more frequent by the introduction of CP115.
- 3.1.2. As a consequence, the investigation of the operational performance of CP115 is focused on the events in which it has shown to have a different behaviour from Version 7. The performance of CP115 is assessed through a set of indicators which are detailed hereafter and which have been computed on the 15 events identified through the methodology presented in the previous section.

#### 3.2. Quantitative results

##### 3.2.1. Duration of level-off manoeuvre

- 3.2.1.1. The following bar chart gives an indication of the length of the level-off manoeuvre in response to the “Level-off, Level-off” RA, i.e. the time during which the aircraft is actually level. The duration of the RA itself, measured from the time of the initial RA to the “Clear of Conflict” annunciation, is also provided.

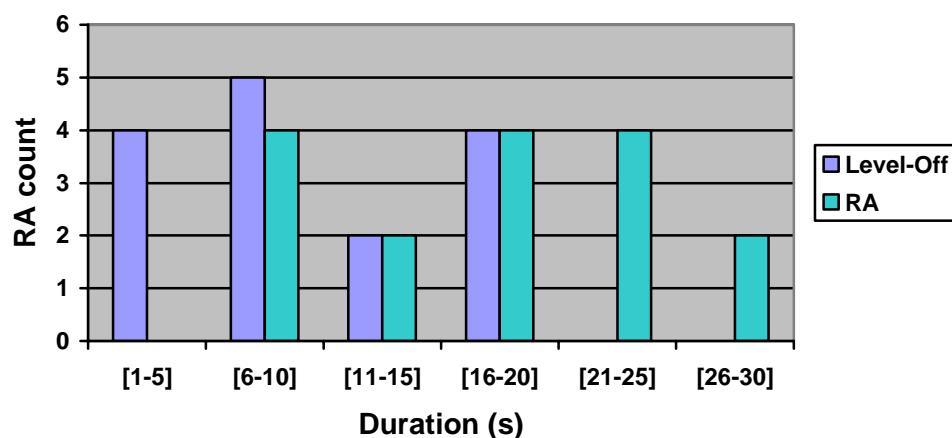


Figure 8: RA duration with CP115

- 3.2.1.2. When considering the whole RA, the above figure shows that its average duration is 17 seconds. The average duration of the level-off phase of the response is 9.7 seconds, with a maximum observed duration of 18 seconds.

- 3.2.1.3. As the duration of AVSA RAs modified by CP115 is already short, the duration of the level-off phase of the manoeuvre in response to the “Level-off, Level-off” RA is also very short. Consequently, **it is anticipated that introducing CP115 into Version 7 would have no effect on vertical deviations in response to the RA.**

### 3.2.2. Vertical separation due to level-off manoeuvre

#### 3.2.2.1. Actual threat

3.2.2.1.1. The following diagram compares the vertical separation provided between the TCAS aircraft and the surrounding threats by Version 7 on the X axis and by Version 7 including CP115 on the Y axis, for the same set of events simulated with both versions of the logic. The vertical separation is measured at CPA in both cases, and the diagram is focused on the separation between the TCAS aircraft and the threat triggering the RA.

3.2.2.1.2. Black dots show the vertical separation between the own aircraft and the intruder that triggered the RA, while grey dots show the separation between the own aircraft and 3<sup>rd</sup> party aircraft. This allows to provide a view of the vertical separations between the own aircraft and the surrounding traffic.

3.2.2.1.3. 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.

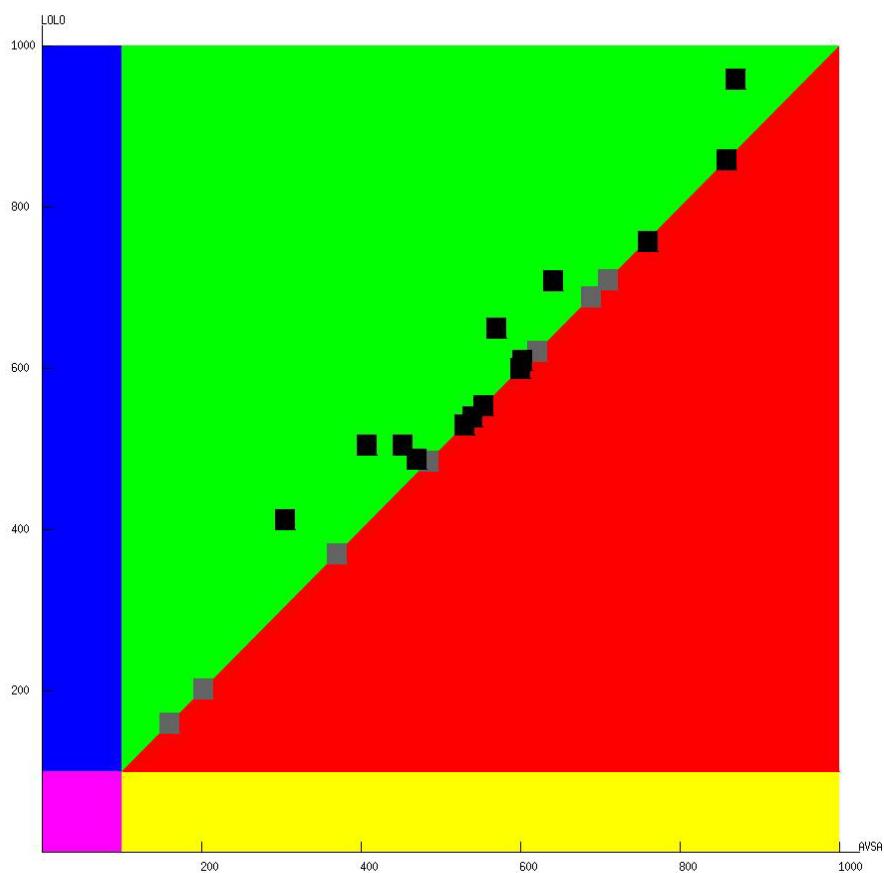


Figure 9: separation difference between own and its threat

3.2.2.1.4. As can be seen in the above figure, the introduction of CP115 in Version 7 always leads to an increased vertical separation between the own aircraft and the threat triggering the initial AVSA RA. **Because of the short duration of the level-off manoeuvre, this increase remains limited and averages to 65 ft.**

### 3.2.2.2. Third party aircraft

3.2.2.2.1. The next figure is a zoom out of the previous figure, in order to show the effect of introducing CP115 on the vertical separation provided with respect to the surrounding traffic (i.e. aircraft not involved in the RA), which are again displayed as grey dots.



Figure 10: separation difference between own and surrounding traffic

3.2.2.2.2. As indicated by the concentration of the grey dots around the diagonal in the above figure, vertical separations with 3<sup>rd</sup> party aircraft are largely unaffected by the introduction of CP115. Consequently, **in the 6 months of data recorded in the Boston TMA, no case has been identified where the introduction of CP115 would induce a conflict with a 3<sup>rd</sup> party aircraft.**

3.2.2.2.3. Based on the 15 events where replacing the initial AVSA RA with a “Level-off, Level-off” RA could possibly have an impact on a 3<sup>rd</sup> party aircraft, the comparison of the vertical separation provided by both Version 7 and Version 7 including CP115 in thus shows that CP115 provides an increased vertical separation over Version 7 without inducing a conflict with a nearby aircraft.

### 3.2.3. Third party proximity

3.2.3.1. The previous section has shown that introducing CP115 in TCAS II Version 7 logic would not induce a conflict with a 3<sup>rd</sup> party aircraft flying in the vicinity of the TCAS aircraft. The current section analyses the 15 multi-aircraft events in which the TCAS aircraft received an initial AVSA RA and investigates how close the 3<sup>rd</sup> party aircraft were at the time of this RA, in terms of triggering a TCAS alert.

3.2.3.2. The next figure gives an indication of how close the aircraft around the own aircraft are, in terms of possibility of being involved in an induced conflict, by providing the TAU value and the predicted vertical miss distance at the time of the RA. Four groups of intruder are indicated in the figure:

- Threat triggering the RA onboard own aircraft (blue diamonds),
- Converging 3<sup>rd</sup> parties from which the own aircraft will manoeuvre away because of the response to the RA (green boxes),
- Converging 3<sup>rd</sup> parties from which the own aircraft will manoeuvre towards because of the response to the RA (red boxes),
- Diverging 3<sup>rd</sup> party (black boxes).

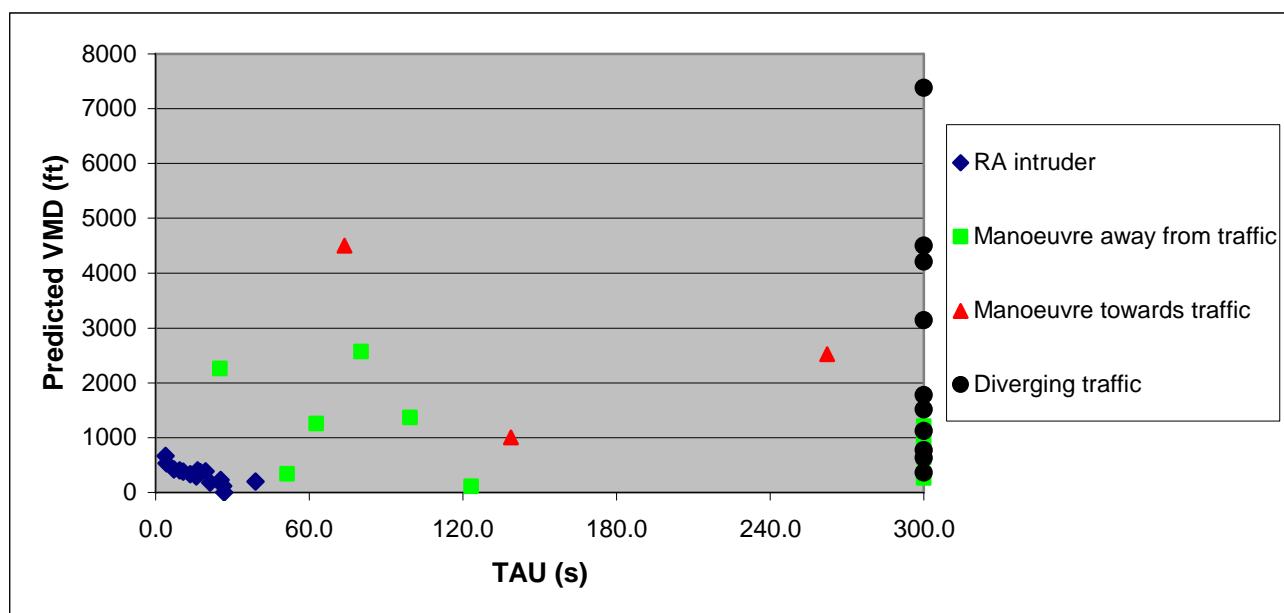


Figure 11: proximity of intruders

3.2.3.3. The above figure shows that the vast majority of 3<sup>rd</sup> party aircraft are of no concern at all for the own aircraft, because they are either already diverging at the time of the RA or going to move further away when the own aircraft manoeuvres in response to the “Level-Off, Level-Off” RA. This last point is a consequence of the number of encounters in which the own aircraft is descending towards Logan airport and approaches some VFR flights from above.

3.2.3.4. Only three 3<sup>rd</sup> party aircraft had a trajectory that could have involved them in an induced conflict, but were too far in time and/or geographically to even trigger a TA if the own aircraft had responded to a “Level-off, Level-off” RA. As a reminder, the thresholds used for issuing a TA at the sensitivity levels the TCAS typically operates

at in the encounters under study (i.e. below FL100) are 40 seconds or less for TAU and 850 ft for the predicted VMD. The closest converging 3<sup>rd</sup> party aircraft was predicted 140 s and 1000 ft away when the initial RA was triggered.

**3.2.3.5. Consequently, the likelihood of inducing a conflict with a 3<sup>rd</sup> party aircraft in response to a “Level-off, Level-off” RA is extremely remote, as no such event would have occurred, or would have been close to occur, in Boston TMA during the 6 months that have been under study.**

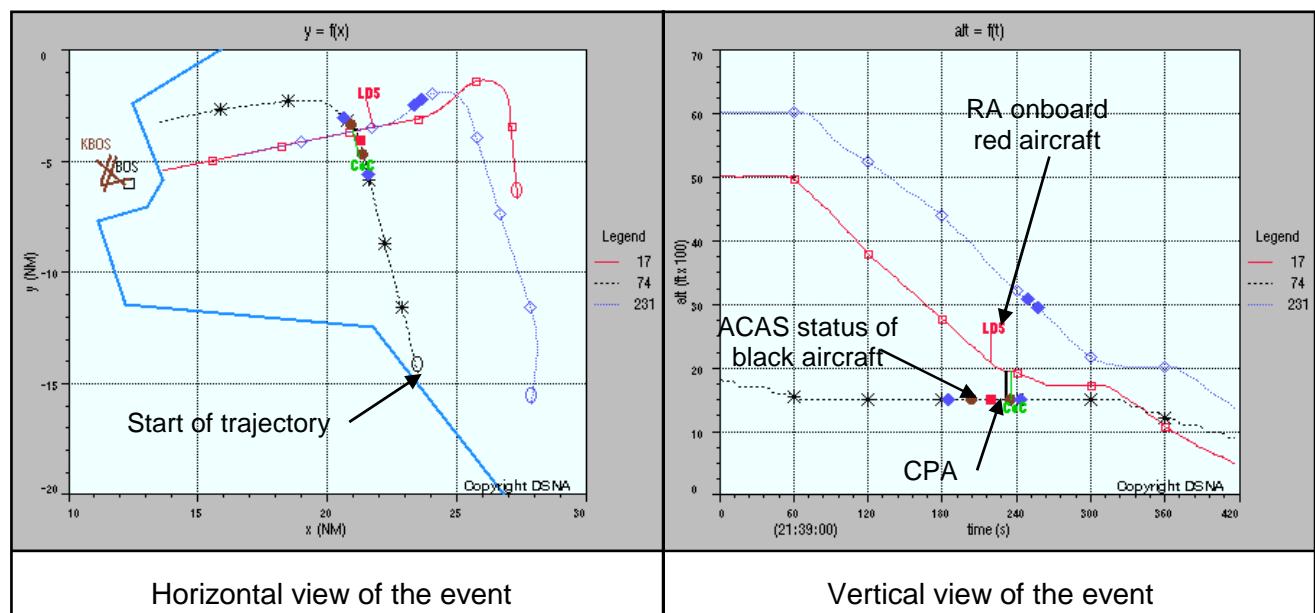
### 3.3. Result illustration

#### 3.3.1. Unaffected surrounding traffic

##### 3.3.1.1. General

3.3.1.1.1. This section illustrates the results presented previously through a few typical examples, presenting the most frequent situations observed in the 15 RA events that supported this study.

3.3.1.1.2. Each example is depicted by a horizontal view and a vertical view of the event, when simulated with the DSNA OSCAR test bench. The horizontal view, on the left-hand in the figure below, shows the trajectories on a Y against X basis, while the vertical view, on the right-hand in the figure below, shows the same trajectories on a Z against time basis. Each of these views contains some significant information which are explained in the following figure.



**Figure 12: example of an event displayed on the OSCAR test bench**

3.3.1.1.3. TCAS II simulation results are displayed on the horizontal and vertical trajectories. RAs are displayed on the trajectory of the reference aircraft and ACAS status of the intruders on their respective trajectories, according to the symbols and labels described in the following table.

- ◆ Proximate Traffic
- Traffic Advisory
- Resolution Advisory
- LD2 Preventive RA
- LD2 Corrective RA

Label	Advisory
CoC	Clear of Conflict
CI	Climb (1500 fpm)
DDes	Don't Descend or Level-off
LD5 / LD1 / LD2	Limit Descent 500 / 1000 / 2000 fpm
Des	Descend (1500 fpm)
DCI	Don't Climb or Level-off
LC5 / LC1 / LC2	Limit Climb 500 / 1000 / 2000 fpm

Table 3: OSCAR symbols and labels

### 3.3.1.2. Descent above traffic

3.3.1.2.1. The next figure provides an example of a typical event, in which a TCAS-equipped aircraft (in red) is on approach and descending towards some probably unequipped aircraft and receives an RA against the aircraft shown in black. The thick black line between the red and purple trajectories materializes the CPA between the own aircraft and the second closest aircraft.

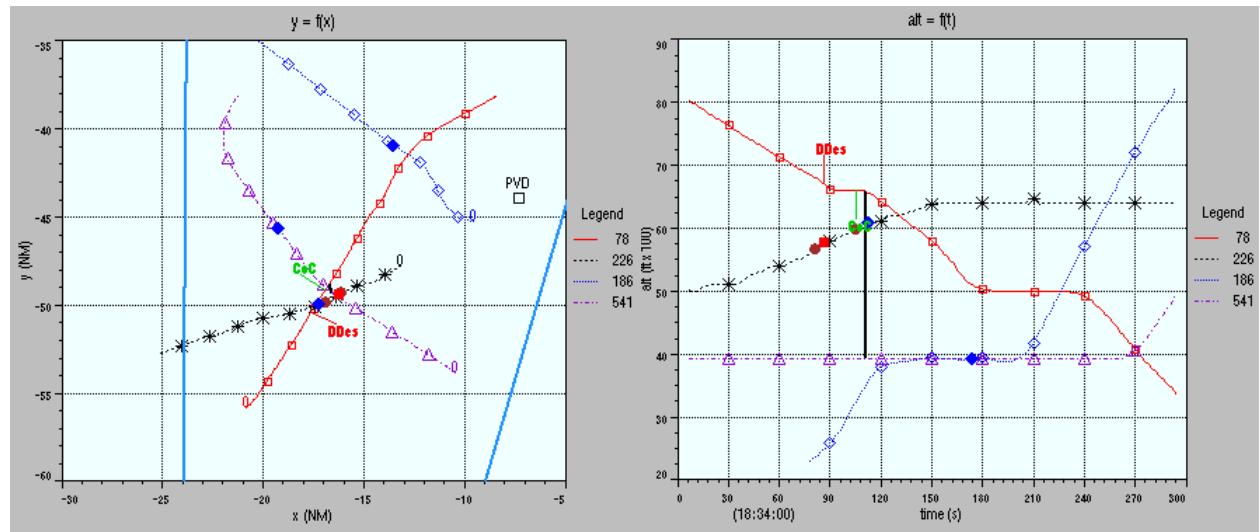


Figure 13: 14<sup>th</sup> July 2006 event - descent above traffic (with CP115)

3.3.1.2.2. In the actual event, the red aircraft received an AVSA requiring it to limit its rate of descent to 500 fpm and the separation at CPA would have been 0.5 NM horizontally and 640 ft vertically with a standard pilot reaction and Version 7. Introducing CP115 would replace the AVSA RA with a "Level-off, Level-off" RA, shown by the red "DDes" label in the above picture, and the resulting separation at CPA would be 0.5 NM and 710 ft.

3.3.1.2.3. The next figure illustrates the situation as it is perceived by the crew onboard the TCAS aircraft, through an IVSI representing the RA received by the red aircraft.

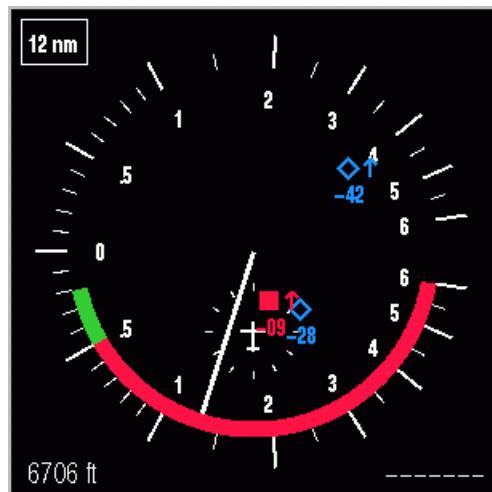


Figure 14: 14<sup>th</sup> July 2006 event - IVSI onboard TCAS aircraft

3.3.1.2.4. As can be seen in the figures above, the manoeuvre in response to the “Level-off, Level-off” RA will move the red aircraft away from both the black aircraft, triggering the RA, and the purple aircraft, which is the next closest aircraft in the red aircraft’s vicinity. Indeed, the separation at CPA between the red and purple aircraft is 0.5 NM and 2660 ft (at the time the RA is issued, this separation is 2.5 NM and 2780 ft). **In this event, there is thus no traffic that may interfere with the level-off manoeuvre proposed by CP115.**

### 3.3.1.3. Descent above VFRs

3.3.1.3.1. The next figure provides an example of another typical event, in which a TCAS-equipped aircraft (in black) is on approach and descending towards some VFRs and receives an RA against the aircraft shown in blue. The thick black line between the black and red trajectories materializes the CPA between the own aircraft and the second closest aircraft.

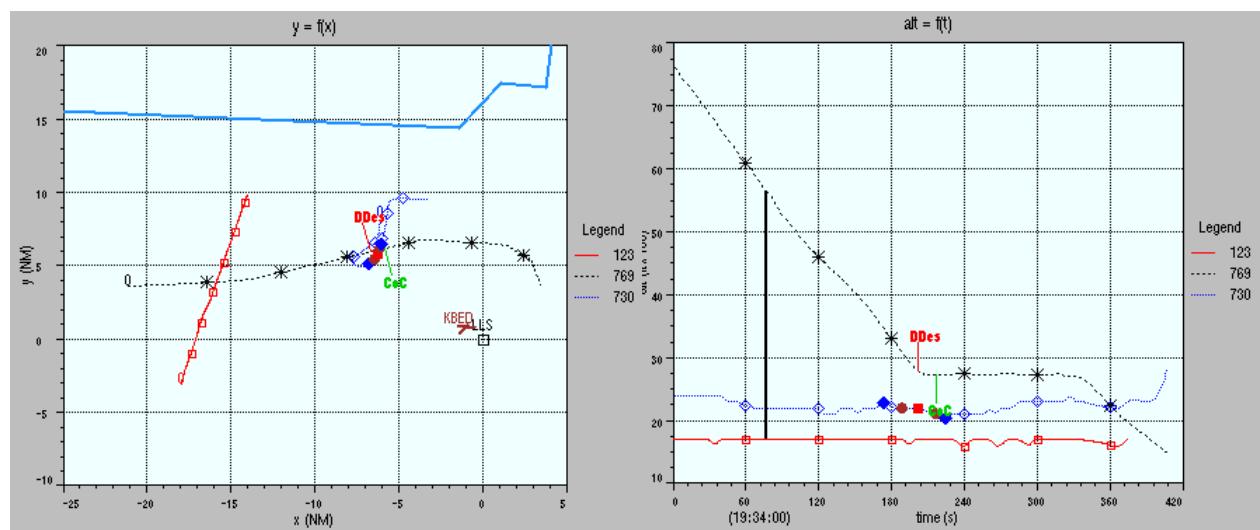


Figure 15: 30<sup>th</sup> March 2006 event - descent above VFRs (with CP115)

3.3.1.3.2. In this event, the black aircraft received an AVSA requiring it to limit its rate of descent to 1000 fpm and the separation at CPA would have been 0.1 NM

horizontally and 600 ft vertically with a standard pilot reaction and Version 7. Introducing CP115 would replace the AVSA RA with a “Level-off, Level-off” RA, shown by the red “DDes” label in the above picture, and the resulting separation at CPA would be 0.1 NM and 610 ft.

3.3.1.3.3. The next figure illustrates the situation as it is perceived by the crew onboard the TCAS aircraft, through an IVSI representing the RA received. As can be seen, the third aircraft (i.e. the red one) is too far away to appear on the display.

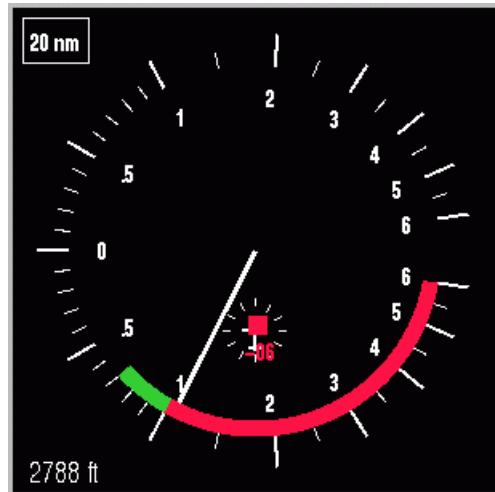


Figure 16: 30<sup>th</sup> March 2006 event - IVSI onboard TCAS aircraft

3.3.1.3.4. As can be seen in the figures above, the manoeuvre in response to the “Level-off, Level-off” RA will move the black aircraft away from both the blue aircraft, triggering the RA, and the red aircraft, which is the next closest aircraft in the black aircraft’s vicinity. Indeed, the separation at CPA between the black and red aircraft is 4.8 NM and 3950 ft (at the time the RA is issued, this separation is 9.4 NM and 1090 ft). **In this event, there is thus no traffic that may interfere with the level-off manoeuvre proposed by CP115.**

### 3.3.1.4. Climb below traffic

3.3.1.4.1. The next figure provides the converse example to the previous one, which remains the most frequent situation. Here, the TCAS-equipped aircraft (in red) is departing from Logan airport and climbing towards two level aircraft. The thick black line between the red and black trajectories materializes the CPA between the own aircraft and the second closest aircraft.

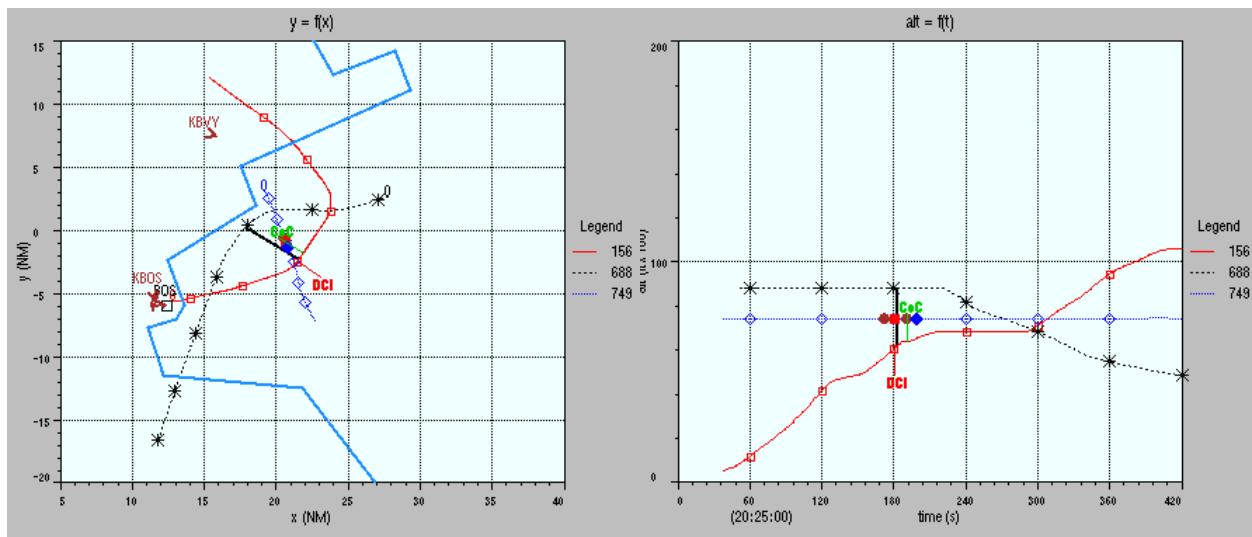


Figure 17: 31<sup>st</sup> May 2006 event - climb below traffic (with CP115)

3.3.1.4.2. In this event, the red aircraft received an AVSA requiring it to limit its rate of climb to 1000 fpm and the separation at CPA would have been 1.3 NM horizontally and 870 ft vertically with a standard pilot reaction and Version 7. Introducing CP115 would replace the AVSA RA with a “Level-off, Level-off” RA, shown by the red “DCI” label in the above picture, and the resulting separation at CPA would be 1.3 NM and 960 ft.

3.3.1.4.3. The next figure illustrates the situation as it is perceived by the crew onboard the TCAS aircraft, through an IVSI representing the RA received by the black aircraft. As can be seen, the third aircraft (i.e. the red one) is too far away to appear on the display.

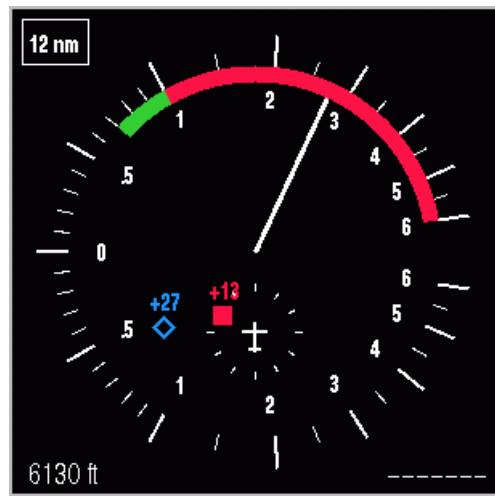


Figure 18: 31<sup>st</sup> May 2006 event - IVSI onboard TCAS aircraft

3.3.1.4.4. As can be seen in the figures above, the manoeuvre in response to the “Level-off, Level-off” RAs move the red aircraft away from both the blue aircraft, triggering the RA, and the black aircraft, which is the next closest aircraft in the red aircraft’s vicinity. Indeed, the separation at CPA between the red and black aircraft is 4.5 NM and 2610 ft (at the time the RA is issued, this separation is 4.5 NM and 2700 ft). In

this event, there is thus no traffic that may interfere with the level-off manoeuvre proposed by CP115.

### 3.3.1.5. False sandwich

3.3.1.5.1. The next figure shows an example in which the TCAS aircraft appears to be sandwiched between two other aircraft. In this case, two aircraft are departing from Logan airport within 90s of each other and, while flying eastward before taking South-bound routes, come in the vicinity of a North-bound aircraft over the Atlantic. The thick black line between the black and blue trajectories materializes the CPA between the own aircraft and the second closest aircraft.

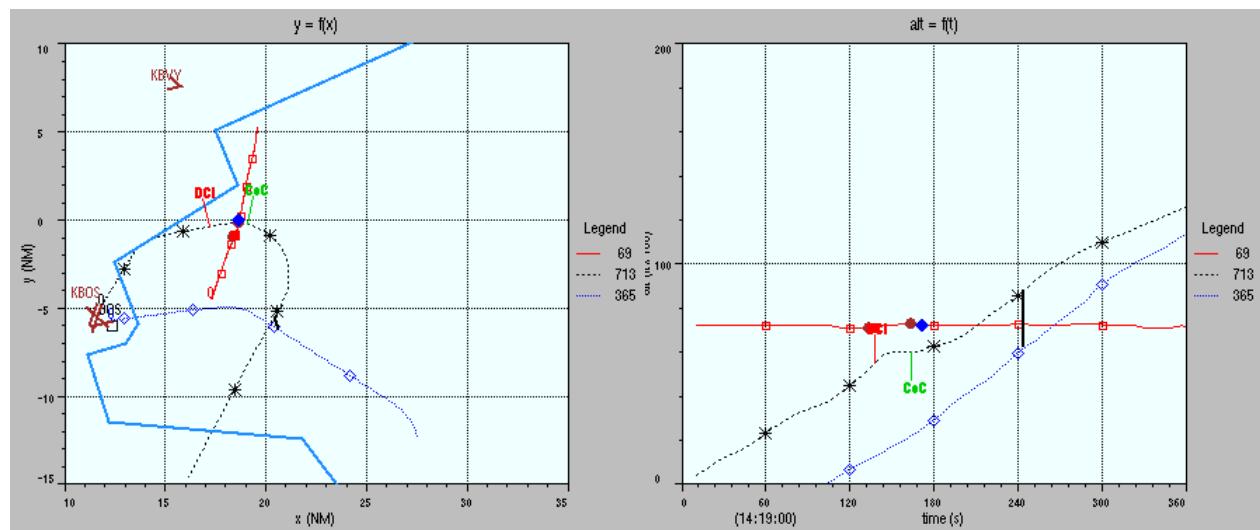


Figure 19: 29<sup>th</sup> March 2006 event - false sandwich (with CP115)

3.3.1.5.2. In this event, the red aircraft received an AVSA requiring it to limit its rate of climb to 2000 fpm and the separation at CPA would have been 0.8 NM horizontally and 930 ft vertically with a standard pilot reaction and Version 7. Introducing CP115 would replace the AVSA RA with a “Level-off, Level-off” RA, shown by the red “DCI” label in the above picture, and the resulting separation at CPA would be 0.8 NM and 1310 ft.

3.3.1.5.3. The next figure illustrates the situation as it is perceived by the crew onboard the TCAS aircraft, through an IVSI representing the RA received by the black aircraft.

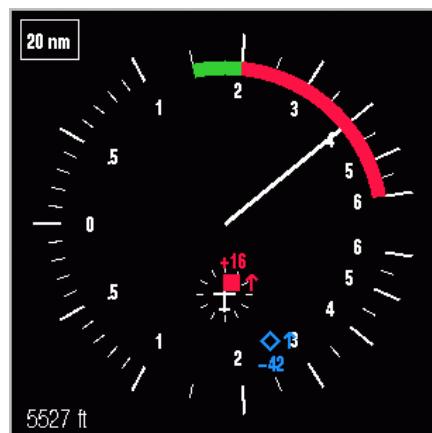


Figure 20: 29<sup>th</sup> March 2006 event - IVSI onboard TCAS aircraft

3.3.1.5.4. As can be seen in the horizontal view of the event in the figure above, the manoeuvre in response to the “Level-off, Level-off” RAs can not induce a conflict with the blue aircraft, as it is on a parallel track about 5 NM away. The separation at CPA between the black and blue aircraft is 0.8 NM and 2630 ft, but at the time the RA is issued, this separation is 6.1 NM and 4280 ft. **In this event, there is thus no traffic that may interfere with the level-off manoeuvre proposed by CP115**

### 3.3.2. CP115 safety benefit

3.3.2.1. The next series of figures illustrate one of the 3 events in which the manoeuvre proposed by CP115 will move the own aircraft towards a converging 3<sup>rd</sup> party aircraft. The picture below shows a horizontal view of the event, in which 3 aircraft are departing from Logan airport in succession and come in the vicinity of a North-bound aircraft over the Atlantic.

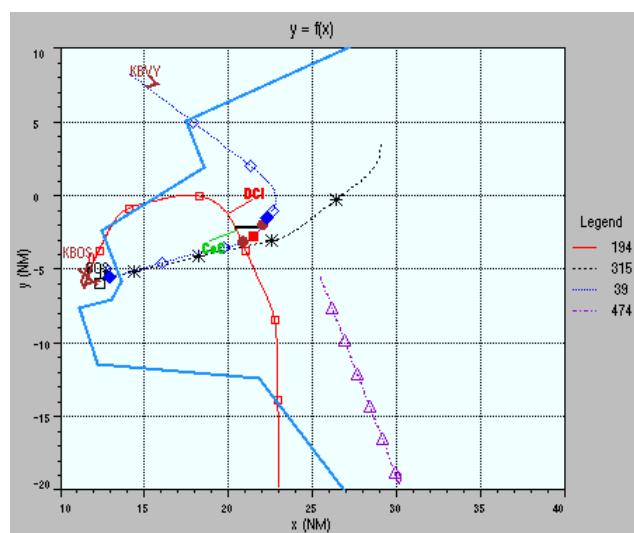


Figure 21: 14<sup>th</sup> April 2006 event - close encounter (horizontal view)

3.3.2.2. The following figure shows the RAs issued by TCAS II Version 7 when the red (on the left-hand side) and blue (on the right-hand side) aircraft came into conflict a few minutes after taking off.

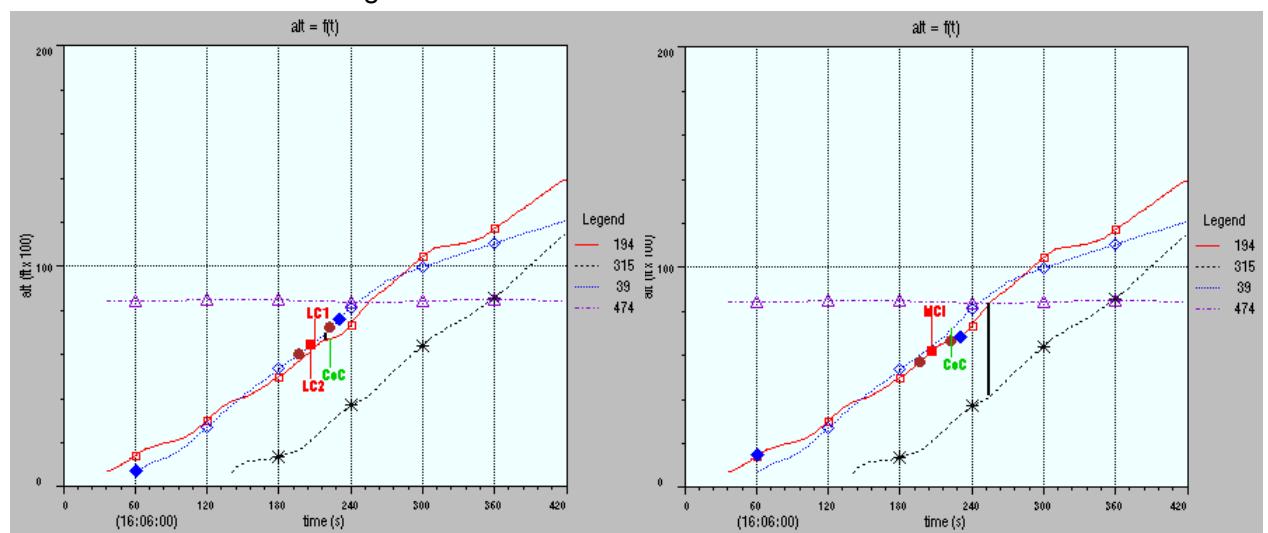


Figure 22: 14<sup>th</sup> April 2006 event - close encounter (with Version 7)

3.3.2.3. As can be see above, the solution to this conflict proposed by Version 7 is to leave both aircraft climbing with different vertical rates in order to achieve the target vertical separation (i.e. ALIM, which is 350 ft at the altitude the event occurs). The blue aircraft, which is the higher of the two, receives a Maintain Climb RA requesting that it keeps its 2500 fpm rate of climb, while the red aircraft receives an AVSA requesting that it limits its rate of climb to 2000 fpm.

3.3.2.4. This initial choice of solution is unsatisfying, because the first AVSA RA limiting the red aircraft's rate to 2000 fpm is strengthened to another AVSA, limiting its rate to 1000 fpm, only 3 seconds after the initial RA. As the pilots are given a 5 second delay to react to initial RAs, the TCAS logic thus posted initial RAs that it knew would be inadequate.

3.3.2.5. Next, this resolution of the conflict is hazardous as it requires the pilot to comply exactly with the expected standard reaction in order for ALIM to be achieved. Indeed, the vertical separation in the actual event was 300 ft despite appropriate pilot reactions, while ALIM was 350 ft.

3.3.2.6. Lastly, the solution chosen by Version 7 is very uncomfortable for the pilots, because the red aircraft crew is instructed to climb while their TCAS display shows a threat right above them. This is illustrated by the following picture, which represents the RA received by the red aircraft on an IVSI.

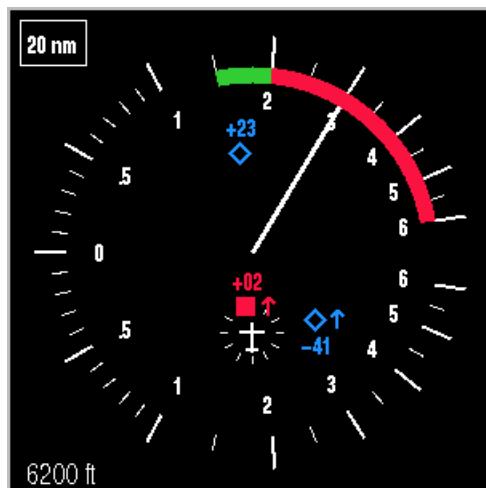


Figure 23: 14<sup>th</sup> April 2006 event - IVSI for lower TCAS aircraft

3.3.2.7. When simulating the same event with Version 7 including CP115, the RAs obtained are shown in the following figure.

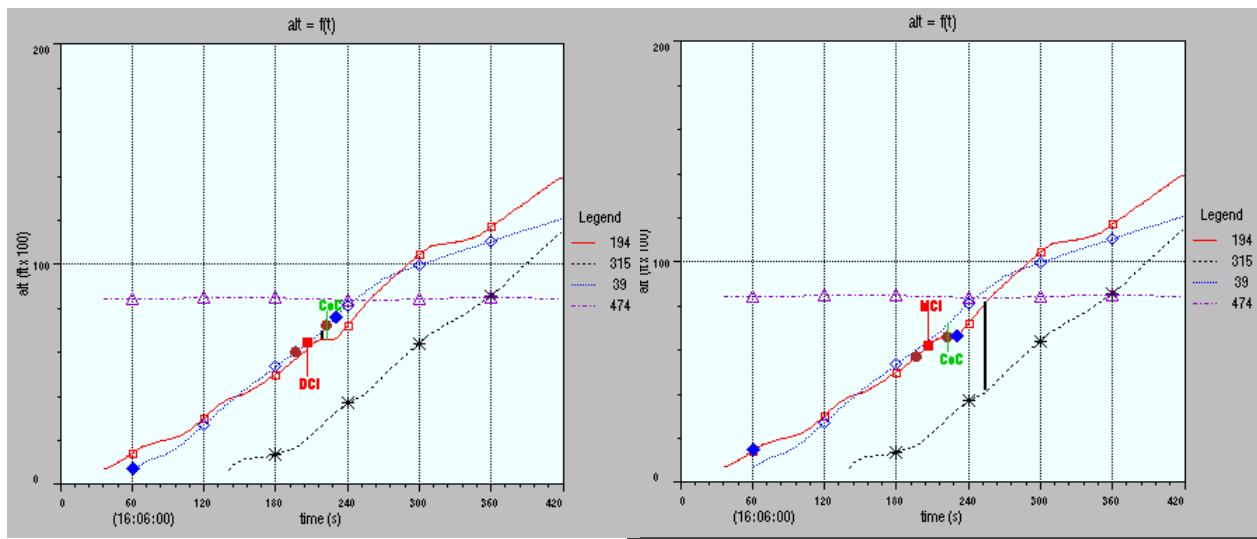


Figure 24: 14<sup>th</sup> April 2006 event - close encounter (with CP115)

3.3.2.8. As can be seen above, the red aircraft a single “Level-off, Level-off” RA instead of the two AVSA RAs, while the blue aircraft still receives a Maintain Climb RA. As a result, the vertical separation is 410 ft at CPA, meaning that ALIM is achieved with CP115 and not in the actual event with Version 7. Safety is generally improved in this event when CP115 is introduced, as the aircraft are not left evolving in the same vertical direction.

3.3.2.9. Regarding the possibility of the manoeuvre prompted by “Level-off, Level-off” RA inducing a conflict with one of the other aircraft, the separation with the second closest aircraft (i.e. the black one in the above picture) is 5.2 NM and 4100 ft at the time of the RA. At their CPA, this separation becomes 2.5 NM and 4050 ft. **In this event, there is thus no traffic that may interfere with the level-off manoeuvre proposed by CP115 and safety is improved when CP115 is introduced in Version 7.**

## 4. Conclusions

- 4.1. The analysis of the radar and RA downlink data collected over 6 months by the FAA in the Boston area has shown that 92 events, out of the 992 that have been recorded, featured an initial “Adjust Vertical Speed, Adjust” RA. Out of these 92 events, **CP115 would modify the Version 7 logic behaviour in only 15 events with some traffic in the vicinity of the aircraft involved in the RA.**
- 4.2. Given the number of days of data recording used in the present study, it can be extrapolated that **the rate of potential CP115 involvement in events with some traffic in the vicinity is once every 3 days**, assuming that all TCAS aircraft would be fitted with Version 7 including CP115.
- 4.3. Analysis of the “Level-off, Level-off” RAs issued by Version 7 including CP115 in those events where they would replace initial AVSA RAs confirmed the operational benefits that had been demonstrated with CP115 in the European airspace (cf. [SIRE+2]). Indeed, **it is anticipated that introducing CP115 into Version 7 would have no effect on vertical deviations, particularly because of the short duration of the level-off manoeuvre.**
- 4.4. Furthermore, TCAS simulations performed on these events featuring an initial AVSA RA showed that **introducing CP115 would not induce a conflict with any of these 3<sup>rd</sup> party aircraft, or would even be close to doing so**. No additional RAs or TAs would be issued against these 3<sup>rd</sup> party aircraft because of the manoeuvre induced by the “Level-off, 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.
- 4.5. The analysis performed also identified **one operational event in which safety would have been improved by the introduction of CP115** (in addition to solving the issue of unintentional opposite reactions to AVSA RAs). Indeed, TCAS II Version 7 issued RAs that left both aircraft evolving in the same vertical direction and, despite appropriate pilot responses, the target vertical separation of 350 ft was not achieved at their closest approach.

## 5. Acronyms

ACAS	Airborne Collision Avoidance System
ATC	Air Traffic Control
AVSA	Adjust Vertical Speed, Adjust
CP	Change Proposal
CPA	Closest Point of Approach
DSNA	Direction des Services de la Navigation Aerienne
FL	Flight Level
MOPS	Minimal Operational Performance Standards
NM	Nautical Mile
OSCAR	Off-line Simulator for Collision Avoidance Resolution
RA	Resolution Advisory
TA	Traffic Advisory
TMA	Terminal Control Area
TCAS	Traffic Alert and Collision Avoidance System
VMD	Vertical Miss Distance
VSL	Vertical Speed Limit

## 6. References

- [SIRE+1] 'Draft change proposal for simplified VSL RA list' – EUROCONTROL MSA Programme, Sofréavia & DSNA – SIRE+/WP2/15/D – Version 1.2, September 2006
- [SIRE+2] 'Operational performance of CP115 aka the "level-off, level-off" (LOLO) solution' – EUROCONTROL MSA Programme, Sofréavia & DSNA – SIRE+/WP5/32/D – Version 1.1, February 2007

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