TCAS II CHANGE PROPOSAL (CP)

DATE: October / 29 / 2007 **No.:** **116**

TCAS II Version: **DO-185A (v7)** X **Other (Specify)** _________

MOPS Function Area: **Surveillance** _____ **Display Req'ts** _____ **CRS** X

CAS Pseudocode X **Test Suites** _____ **Other** _____

Priority: **URGENT** _____ **Necessary** X **Optional** _____

CP Type: **ERROR** X **Enhancement** _____ **Evaluation Request** _____

Editorial (Logic) _____ **Editorial (Text)** _____

Description of Problem/Issue:

When an aircraft receiving a Descend RA descends through 1000 ft AGL, the Descend RA changes to a Don't Climb. When the "green arc on weakening" was added in Version 7, a green arc was added in this situation, changing what was (in 6.04A) a preventive VSL, annunciated "Monitor Vertical Speed," to (in Version 7) a corrective VSL, annunciated "Adjust Vertical Speed, Adjust." Encounters have occurred in the Boston airspace in which a TCAS aircraft is descending and receives a Descend RA in response to an intruder above. When the TCAS aircraft passes through 1000 ft AGL, the Descend changes to an AVSA, with a green arc that directs the TCAS aircraft to level off (into the path of the intruder above).

The RWG has agreed that the application of the green arc was not intended in this situation and is incorrect. This situation is not a true 'weakening' in the sense that the positive RA changes to a VSL not because the threat has diminished or resolved.

Proposed Resolution:

The case described above is first handled in the pseudocode PROCESS Extreme_altitude_check, DO-185A, Attachment A, pages 6-P30 and 6-P31. This code changes the positive RA to a 'don't' (i.e. VSL 0) RA. It does this by setting the VSL 0 bits in OWNTENT.

The second handling of this case is in PROCESS Set_up_display_outputs, DO-185A, Attachment A, pages 7-P34 and 7-P35. Here, if "(positive RA is weakening to negative Don't Climb or Don't Descend RA <u>AND</u> own has responded to previous pos. RA) <u>THEN</u> indicate that weakened RA is corrective; <results in green "fly-to" arc plus corrective aural annunciation for initial weakening>."

Currently there is no way to distinguish the extreme altitude cases once we have reached Set_up_display_outputs, so the agreed-upon solution is to add a variable G.EXTALT. G.EXTALT is set in Extreme_altitude_check when a descend RA has been selected and there is an extreme low altitude situation, and G.EXTALT is then checked in Extreme_altitude_check. If G.EXTALT is set, the weakened RA does not become corrective.

See the attached paper for detailed description of the pseudocode and statechart changes.

Requester: Ann Drumm

Organization: MIT Lincoln Laboratory

DISPOSITION OF CHANGE PROPOSAL (Per RWG):
DATE OF DISPOSITION 12 / 11 / 07

Rejected ______ **Deferred** ______ **[Review Date:** ____ / ____ / ____ **]**

Accepted X **Modified** ______ **Withdrawn** ______

DISPOSITION OF CHANGE:

On Hold _____ **Designing** _____ **Testing** _____ **Done** X **[Date:** 12 / 11 / 07 **]**

Final Approval of Changes:

Signature: Andy Zeitlin, RWG Chair
Date: 12 / 11 / 2007

Safety Analysis of the Proposed Change to the TCAS Display/Annunciation Logic

(CP 116)

Prepared by SC-147 Requirements Working Group

29 October 2007

Table of Contents

1. Introduction

This paper discusses Change Proposal 116, the object of which is to correct a situation that was introduced into the Version 7 TCAS display/annunciation logic. Specifically, CP116 proposes to remove the corrective annunciation and green arc when a positive Resolution Advisory (RA) weakens solely due to an extreme low-altitude condition.

Sections 2 through 6 below describe the issue in detail and discuss operational considerations, the proposed logic changes, and testing results. Section 7 gives a summary and recommendations. Appendix A contains plots of an encounter in the Boston airspace that prompted submittal of CP116. Appendix B contains the proposed pseudocode change in its entirety. Appendix C contains the proposed statechart change in its entirety.

2. Description of Problem/Issue

The TCAS logic has always prevented the issuance of positive RAs in extreme altitude conditions. For example, when an aircraft receiving a Descend RA descends through 1000 ft AGL, the Descend RA changes to a Don't Climb. Somewhat similarly, an aircraft above its climb ceiling is given a Don't Descend RA rather than a Climb. The extreme altitude logic was affected (the Requirements Working Group believes unintentionally) by a feature introduced in the Version 7 TCAS logic.

In order to reduce unnecessary altitude excursions in response to an RA, Version 7 added what is referred to as a "green arc on weakening." The following example shows the benefits of this feature. Prior to Version 7, after a pilot had correctly responded to a positive RA (say, in this example a Descend RA) and achieved ALIM feet vertical separation, the positive Descend RA changed to a preventive Limit Climb. This was annunciated as "Monitor Vertical Speed" and shown on IVSI displays as a red arc covering some portion of the upper half of the display. There were two problems noted. (1) RAs could weaken multiple times to 2000, 1000, 500, 0 fpm during the course of an encounter. This was perceived as a nuisance and/or distraction. (2) Altitude displacements could be larger than required by the CAS logic because pilots sometimes kept their initial descent rate after the RA had weakened.

Because of these problems, a change was made in Version 7 to allow positive RAs (climb/descend, maintain rate, and sense reversals) to weaken only to 0 fpm and to display a green arc at 0 fpm to guide the pilot to level off. The weakened RA thus became a corrective RA, annunciated as "Adjust Vertical Speed, Adjust" and showing a green arc to indicate the vertical rate to achieve. This instance of corrective RA is unique in that the corrective action is not required to achieve adequate separation but is desired to reduce unnecessary altitude displacement.

A problem arises with the Version 7 implementation, because not all positive RAs that weaken have the geometry assumed above. Specifically, during its monitoring of the

Boston airspace, Lincoln Laboratory noted an encounter in which the application of the green arc resulted in incorrect and possibly dangerous guidance to the pilot. The encounter involved a TCAS-TCAS coordinated encounter in which both aircraft were on final for a parallel approach into Logan International Airport. (See details in Appendix A.) The aircraft at the slightly lower altitude was receiving a Descend RA, which transitioned to Don't Climb as the aircraft descended through 1000 feet AGL. The intent was that the pilot not climb because the intruder was just above in altitude. However, because of the green arc on weakening, the RA was annunciated as "Adjust Vertical Speed, Adjust" with a green arc at 0 fpm, directing the pilot to level off. Had the pilot leveled off, it would have brought him into the path of the intruder above, who was descending to land.

The Requirements Working Group believes that the application of the green arc was not intended for this situation and is incorrect.

The first submission of CP116 applied to both the extreme low-altitude and high-altitude cases; however, detailed examination of the logic, described in Section 3 below, determined that only the extreme low-altitude case needed to be addressed. CP116 therefore proposes to revert back to the 6.04A logic only for the extreme low-altitude case (example encounter above). The annunciation in this case would become "Monitor Vertical Speed," and the display would show only a red arc.

3. Operational Considerations

During the Operations Working Group meeting held in Toulouse in May 2007, the group discussed operational implications of CP116 and concluded that there were no major issues associated with including CP116 in DO-185B. However, the OWG did identify three items to be completed in order for CP116 to be approved and implemented.

(1) The OWG needs to review its conclusion with ALPA, who was not able to attend the May meeting, and ensure that ALPA supports this change.
(2) The RWG needs to ensure that the handling of modifications to positive RAs when passing through an RA inhibit altitude are consistent for Increase Rate RAs as well as the Climb and Descend RAs.
(3) The RWG needs to include CP116 in its final end-to-end validation of the CAS logic.

Item (1) was completed by one of the OWG co-chairs following the completion of the OWG meeting. The ALPA representative to the OWG was briefed on the discussions held during the OWG meeting and on the conclusions reached by the OWG during the meeting. At the completion of this discussion, the ALPA representative expressed its concurrence with the decisions reached and recommendations made by the OWG during their May meeting.

Item (2) is described in section 3.1 below. Item (3) is described in detail in Section 6, "CP116 Testing and Results."

3.1 Summary of current Version 7 operation in extreme altitude cases

Detailed examination of the Version 7 logic revealed that there is little or no symmetry between the operation of climb inhibits and descend inhibits. The climb inhibits reflect aircraft capability limitations and are not implemented as hard cut-offs. If a Climb RA or Increase Climb RA is already active, that RA will not weaken due to the activation of the climb inhibit or increase climb inhibit. Therefore, the inappropriate green arc on weakening that CP116 is meant to address does not occur with the climb inhibits.

In contrast, the descend inhibits reflect nearness to the ground and are implemented as hard cut-offs. If a Descend RA or Increase Descend RA is active as the aircraft passes through 1000 ft AGL, the RA changes immediately to a Don't Climb. A summary is given in Tables 1 and 2 below.

Altitude	Restrictions
>= 1450 ft AGL	No restriction on descend RAs
< 1450 ft AGL and >= 1000 ft AGL	No new increase descend RAs can be issued An existing inc des RA is allowed to continue A new descend RA can be issued An existing des RA is allowed to continue
< 1000 ft AGL	No new descend or increase descend RAs can be issued All existing descend or increase descend RAs change to 'don't climb'

Table 1.
Summary of Version 7 Descend Inhibit Logic

Situation	Restrictions
Climb inhibit not set and increase climb inhibit not set	No restriction on climb RAs
Climb inhibit is set (doesn't matter whether increase climb inhibit is set or not set)	No new climb RAs or increase climb RAs can be issued Existing climb RAs or increase climb RAs are allowed to continue
Increase climb inhibit is set; climb inhibit is not set	No new increase climb RAs can be issued An exist. inc climb RA is allowed to continue New climb RAs can be issued An existing climb RA is allowed to continue

Note: The climb inhibit discrete is set when the aircraft is above the climb inhibit altitude or the aircraft cannot climb at 1500 fpm
The Increase climb inhibit discrete is set when the aircraft cannot climb at 2500 fpm

Table 2.
Summary of Version 7 Climb Inhibit Logic

Based on the above material, it was determined that implementation of CP116 would provide consistency in the handling of all positive and increase rate RAs when passing through an RA inhibit altitude in the sense that in no case would the transition cause a corrective VSL RA, i.e., green arc on weakening, to be generated.

After reviewing this material, the RWG (with OWG representation) agreed in a telecom on 19 July 2007 that CP116 would apply only to the situation in which a Descend RA or Increase Descend RA changes to a Don't Climb RA when the aircraft descends through 1000 ft AGL. In this case, and in this case only, the Version 7 logic would be modified so that the Don't Climb RA is considered preventive. That is, the RA would be annunciated as "Monitor Vertical Speed," the green and red arcs corresponding to the positive RA would be removed, and only a red arc indicating 'don't climb' would remain.

4. Overview of Proposed Pseudocode Changes

Extreme altitude cases are first handled by the TCAS logic in the pseudocode PROCESS Extreme_altitude_check, DO-185A, Attachment A, Chapter 6. This code changes the positive RA to a 'don't' (i.e. VSL 0) RA. It does this by setting the VSL 0 bits in OWNTENT.

The second handling of these cases is in PROCESS Set_up_display_outputs, DO-185A, Attachment A, Chapter 7. Here, if "(positive RA is weakening to negative Don't Climb or Don't Descend RA) <u>THEN</u> indicate that weakened RA is corrective; <results in green "fly-to" arc plus corrective aural annunciation for initial weakening."

Because Version 7 has no way to distinguish the extreme altitude cases once the logic has reached Set_up_display_outputs, it was decided that CP116 would use a new global flag, G.EXTALT, that would be set in Extreme_altitude_check and tested in Set_up_display_outputs, allowing the corrective designation to be avoided for the extreme low-altitude cases.

A concern was raised during development of the CP116 pseudocode regarding involvement of the inhibits in the multi-aircraft logic. To resolve the concern, it was decided to 'turn off' the CP116 logic during a multi-aircraft encounter. A similar technique was used for CP112E.

Detailed suggested pseudocode is shown in Appendix B. This includes high-level and low-level code for both PROCESS Extreme_altitude_check and PROCESS Set_up_display_outputs.

5. Overview of Proposed Statechart Changes

As described in Section 2 above, in order to avoid excessive vertical rates following a positive RA, TCAS Version 7 found it desirable to change a subsequent weakened RA from preventive to corrective so that the pilot could be guided to level off by the green arc on the TCAS display.

The TCAS 6.04a pseudocode tried to accommodate the TCAS Version 7 change by adding logic in PROCESS Set_up_display_outputs to set variables G.CORRECTIVE_DES and G.ANYPRECOR after they have been cleared in PROCESS Corrective_preventive_test, thus transitioning from corrective to preventive (Corrective_preventive_test) and then from preventive back to corrective (Set_up_display_outputs) in the same processing cycle.

A thorough understanding of how the TCAS Version 7 "green arc" change is implemented in the pseudocode is important in determining where CP116 will affect the statecharts. Does the state Corrective_Descend also transition from Yes (i.e., corrective) to No (i.e., preventive) and then No to Yes? The answer resides in these transitions' condition tables, which are available on pages 124 and 125 in DO185A and modified by CP54.

The transition from No to Yes is examined first against the pseudocode. If this transition's condition table matches the portion of Corrective_preventive_test that sets G.CORRECTIVE_DES, the transition from Yes to No must host the TCAS Version 7 "green arc" change.

The following pseudocode sets G.CORRECTIVE_DES:

```
PROCESS Corrective_preventive_test;

   …

   IF (G.CORRECTIVE_CLM EQ $FALSE AND MIN(G.ZDOWN, P.MAXDRATE)
      LE GOALCL)
      THEN IF …
      ELSE IF (G.CORRECTIVE_DES EQ $FALSE AND MAX(G.ZDOWN,
               P.MINDRATE) GE GOALDES)
               THEN IF ((GOALDES NE 0) OR (GOALDES EQ 0 AND
                        G.ZDOWN GT P.HYSTERCOR))
                        THEN SET G.CORRECTIVE_DES, G.ANYPRECOR;
                             CLEAR G.CORRECTIVE_CLM;
END Corrective_preventive_test;
```

G.CORRECTIVE_DES will change from false to true if the two conditions below are both true:

(1) `MAX(G.ZDOWN, P.MINDRATE) GE GOALDES)` **and**
(2) `(GOALDES NE 0) OR (GOALDES EQ 0 AND G.ZDOWN GT P.HYSTERCOR)`

Boolean algebra suggests that G.CORRECTIVE_DES will also be true if either of the following two conditions is true:

(1) `(MAX(G.ZDOWN, P.MINDRATE) GE GOALDES) OR (GOALDES NE 0))` **or**
(2) `(MAX(G.ZDOWN, P.MINDRATE) GE GOALDES) OR (GOALDES EQ 0 AND G.ZDOWN GT P.HYSTERCOR)`

The above condition matches the macro Not_Meeting_Descend_Goal in the condition table of the state Corrective_Descend's No to Yes transition, suggesting that the pseudocode and statecharts match for the No to Yes transition. CP116 must apply to the Yes to No transition.

Unlike the pseudocode implementation of the "green arc" change, the statecharts do not transition back and forth between preventive and corrective. Instead, the statecharts introduce new conditions in the Yes to No's condition table to exclude weakening from a Descend RA to a Don't Climb RA.

The following pseudocode clears G.CORRECTIVE_DES:

```
PROCESS Corrective_preventive_test;

   IF (G.CORRECTIVE_CLM EQ $TRUE … )
      THEN …;
      ELSE IF (G.CORRECTIVE_DES EQ $TRUE AND G.DESTRONG LT
               G.DESTROLD AND ((GOALDES NE 0 AND G.ZDOWN LT
               GOALDES) OR (GOALDES EQ 0 AND G.ZDOWN LT
```

```
              P.HYSTERCOR)))
              THEN CLEAR G.CORRECTIVE_DES;
   IF (G.CORRECTIVE_CLM EQ $FALSE AND MIN(G.ZDOWN, P.MAXDRATE)
      LE GOALCL)
      THEN IF ((GOALCL NE 0) OR (GOALCL EQ 0 AND G.ZDOWN LT -
              P.HYSTERCOR))
              THEN SET G.CORRECTIVE_CLM, G.ANYPRECOR;
                   CLEAR G.CORRECTIVE_DES;
…

END Corrective_preventive_test;
```

A comparison between the above pseudocode and the condition table of the Yes to No transition indicates that the fifth and sixth conditions evaluated in the second column are not in Corrective_preventive_test and therefore must implement the "green arc" change. The fifth condition, $\texttt{Own\_Tracked\_Alt\_Rate}_{f-549} \geq \texttt{-300 ft/min}_{(HYSTERCOR)}$, requires a Don't Climb RA that is weakened from a Descend RA to also not be descending faster than the hysteresis correction. The sixth condition, $\texttt{Climb\_Goal}_{f-452} = \texttt{0 ft/min}$, is true only in multi-threat situations where the composite RA is Don't Climb and Don't Descend. In single-threat encounters, the climb goal of a Don't Climb RA defaults to some large negative value.

In order to allow a weakened zero-rate descend RA to transition from corrective to preventive in CP116's low extreme altitude situations without modifying TCAS behavior in non-CP116 situations, a new column should be added. The new column should be similar to the second column except that the fifth and sixth condition are no longer required to be true and two new CP116 conditions, the aircraft is in low extreme altitude situation and single-threat encounter, must be true.

Detailed statecharts changes are shown in Appendix C.

6. CP116 Testing and Results

To evaluate previous proposed changes to the CAS logic, safety simulations were run by four different organizations in order to produce safety metrics, primarily risk ratio, to compare performance of the current and proposed logic versions. The four organizations were Egis Avia (formerly Sofréavia) / DSNA on behalf of Eurocontrol, FAA William J. Hughes Technical Center, MIT Lincoln Laboratory, and MITRE/CAASD. However, these safety simulations, as run previously, were not sufficient to cover the special case treated by CP116. There were two reasons.

(1) In three of the four simulations (all except Egis Avia / DSNA), the simulation's pilot response model does not differentiate between the presence or absence of a green arc. CP116 does not change the RA issued. With or without CP116, the RA issued is a 0 fpm vertical speed limit, i.e. Don't Climb. CP116 removes the green arc and changes the annunciation in the extreme low-altitude cases, but these changes have no effect on the three simulations' outputs.

(2) In three of the four encounter models used in previous simulation testing (all except MITRE/CAASD) encounters are not generated below 1000 feet. This prevented testing of CP116.

Four actions were agreed:

(1) Johns Hopkins would develop CP116 tests to be used with the statechart simulation, TSIM. This is covered in section 6.1.1.

(2) The Eurocontrol SIRE+ team would develop low-altitude encounters specifically to test CP116 in their safety simulation. This is covered in section 6.1.2.

(3) The Logic Understanding Group would review both state charts and pseudocode to provide additional assurance that CP116 produces the desired result without affecting other aspects of the logic. This is covered in section 6.1.3.

(4) Safety simulations would be run with existing encounter models to demonstrate that CP116 does not adversely affect other parts of the logic. This topic is covered in section 6.2.

6.1 Testing Specific to CP116

Two organizations developed specific encounters to test the operation of CP116. Johns Hopkins University/Applied Physics Laboratory developed tests to be used with the statechart simulation, TSIM. The Eurocontrol SIRE+ team developed low-altitude encounters to be used with their safety simulation. In addition, the construction of state charts and review of both state charts and pseudocode by the RWG Logic Understanding Group provided additional assurance that CP116 produces the desired result without affecting other parts of the logic.

6.1.1 TSIM

The TCAS collision avoidance logic test suite distributed in TSO119B Mod 2 and new test cases developed for CP112E were run in TSIM with and without CP116. Two TSIM baselines were used: (1) TCAS Version 7 TSIM plus CPs 1 to 112E and (2) TCAS Version 7 TSIM plus CPs 1 to 112E & 115. These baselines allowed determination of CP116's efficacy and potential interactions with CP112E and CP115.

For each baseline, four comparisons were conducted and listed below. The first three comparisons were intended to catch all effects of CP116, intentional or unintentional, and the last comparison ensured that CP116 was correctly implemented in TSIM.

(1) Compare the End-of-Cycle (EOC) outputs generated by running TSIM in the pseudocode mode with or without CP116;

(2) Compare the EOC outputs generated by running TSIM in the statecharts mode with or without CP116;
(3) Compare the transition outputs generated by running TSIM in the statecharts mode with or without CP116;
(4) Compare the EOC outputs generated by running TSIM with CP116 in both the pseudocode and statecharts mode.

Table 3 summarizes the test case affected by CP116 in the two TSIM baselines and four comparison methods described above. The output of only one test case was altered by CP116, testifying that no adverse side effect was introduced by CP116. Test case EN02TS47 demonstrates the intended effect of CP116: a corrective Don't Climb RA was changed to a preventive Don't Climb RA in the low extreme altitude condition. Figures 1a and 1b illustrate the change in the pilot display and RA annunciation with and without CP116 in test case EN02TS47.

	TSIM (CPs 1 to 112E)	TSIM(CPs 1 to 112E & 115)
Comparison (1)	EN02TS47	EN02TS47
Comparison (2)	EN02TS47	EN02TS47
Comparison (3)	EN02TS47	EN02TS47
Comparison (4)	Match	Match

Table 3.
TSIM Evaluation of CP116

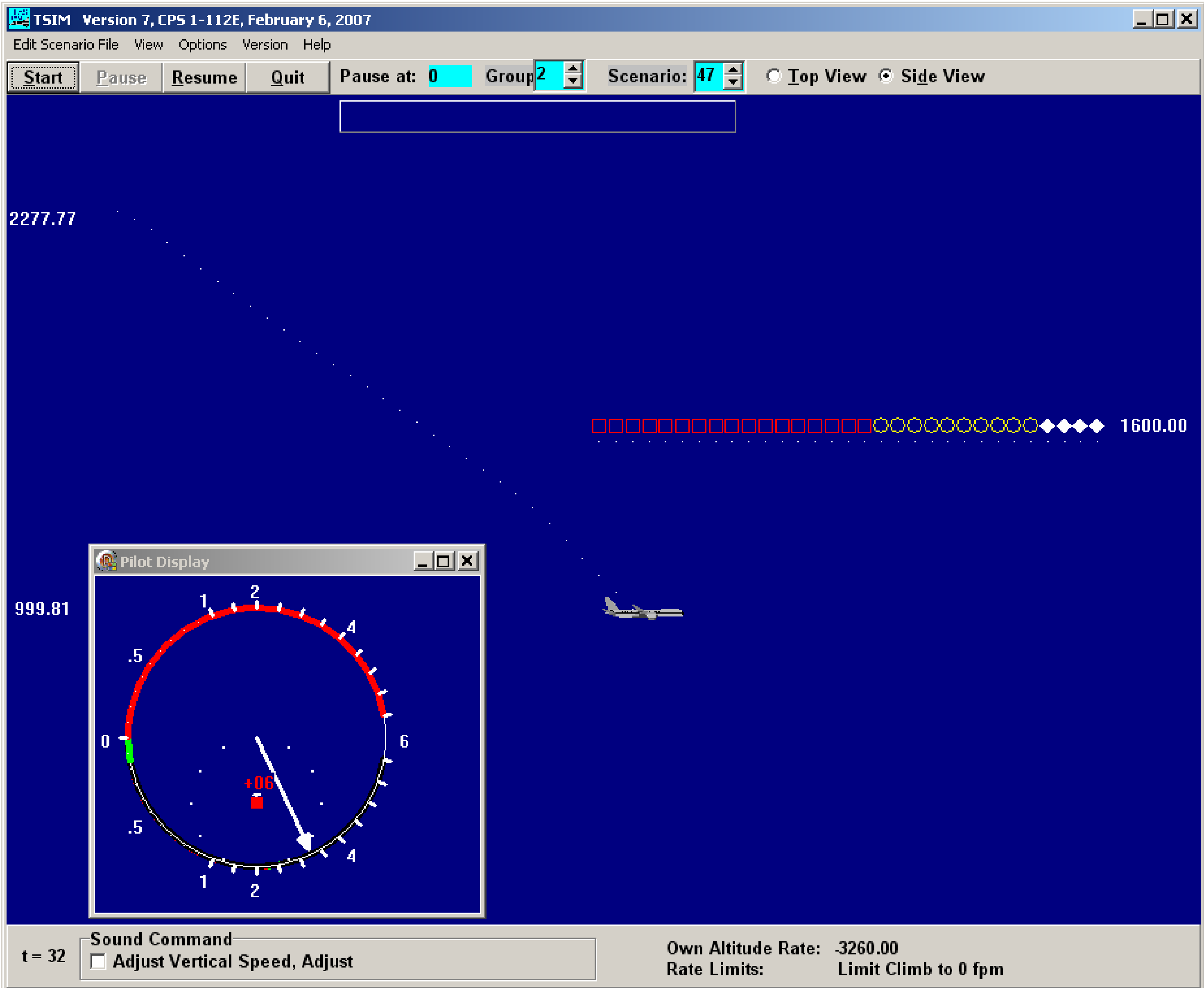


Figure 1a.
Test Case EN02TS47 Without CP116

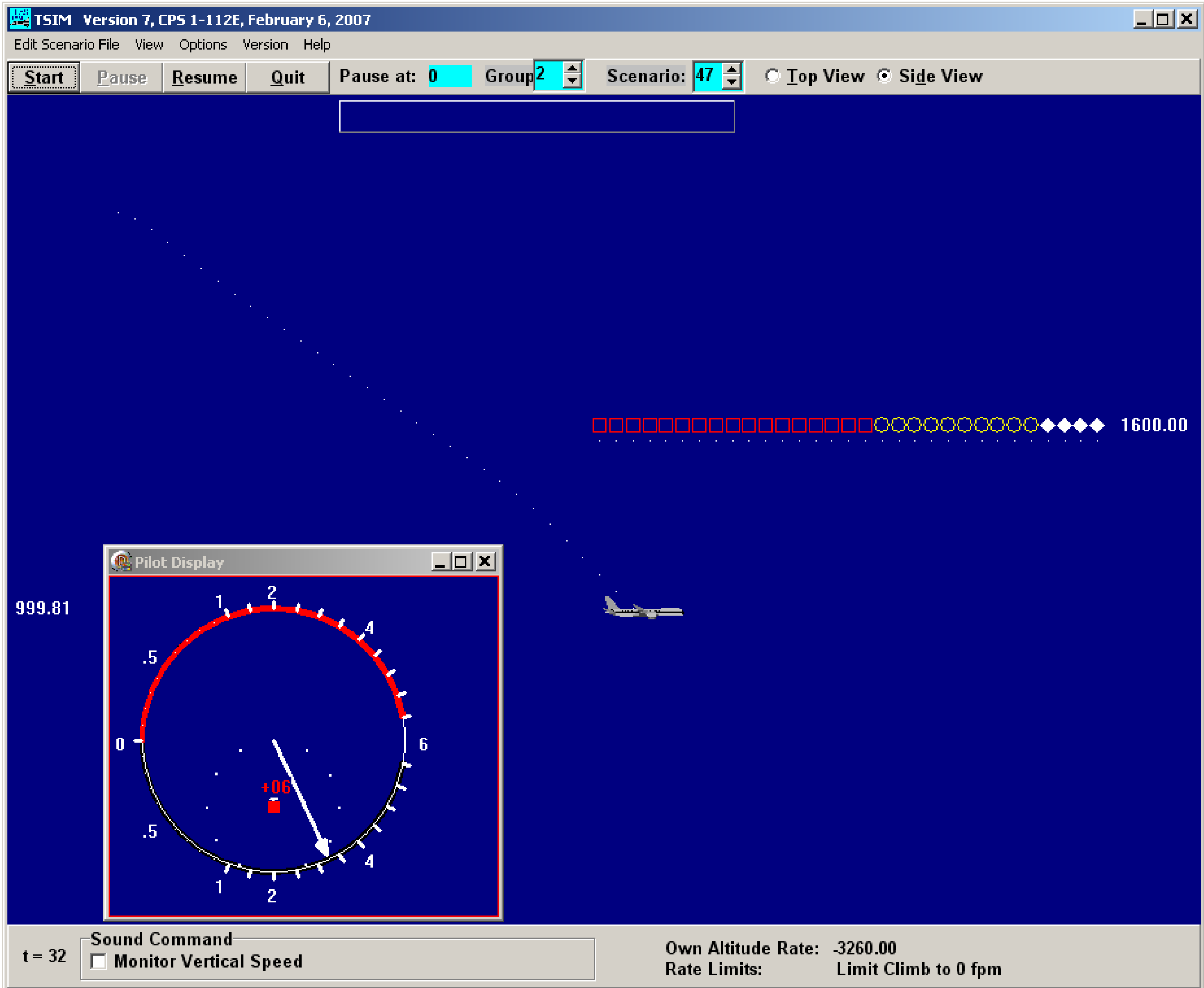


Figure 1b.
Test Case EN02TS47 With CP116

6.1.2 Egis Avia / DSNA (Eurocontrol SIRE+ team)

As a part of the safety validation of the final CP112E, CP115, and CP116 logic [ref 1], the Eurocontrol SIRE+ team generated a specific low-altitude set of 100,000 encounters between 500 ft and 4500 ft, in order to provide a significant number of cases in which CP116 could apply. The low-altitude set was created using the same generator as for the European model and by constraining all generated encounters into the [500 ft, 4500 ft] altitude range. The scenario used for assessing TCAS performance was the SIRE+ reference scenario, which is representative of current operations in Europe. It includes a realistic mix of TCAS equipage based on aircraft performance classes and a range of pilot responses to RAs, derived from observation.

Table 4 indicates the risk ratios obtained when running the simulation with the low-altitude set of encounters and the SIRE+ reference scenario, using the indicated TCAS logic versions, where V7.1 is defined as V7+CP112+CP115+CP116.

	V7	**V7+CP112E**	**V7+CP112E+CP115**	**V7.1**
Risk ratio	59.7%	59.7%	59.5%	57.5%

Table 4.

Risk ratios computed on the low-altitude set

As indicated by the noticeable reduction in risk ratio between the two right-most columns, CP116 provides safety benefits when evaluating it in specific encounters where it can apply.

To further assess the effect of CP116 in the set of low-altitude encounters, the encounters' vertical miss distances (VMD) were compared when simulating V7+CP112E+CP115 vs. V7.1. The result of this VMD comparison is represented in the separation difference diagram, Figure 2, below. The x axis shows VMDs provided by V7+CP112E+CP115, and the y axis shows VMDs provided by V7.1. Encounters unaffected by CP116 are plotted on the diagonal line.

Plots found in the red area correspond to encounters where the VMD is reduced because of CP116, while those in the green area have their VMD increased by CP116. Most notably, the yellow area contains NMACs induced by CP116 (i.e. encounters with a VMD greater than 100 ft without CP116 and less than 100 ft with CP116), while the blue area contains CP116 "saves" (i.e. encounters resulting in an NMAC without CP116, and not with CP116).

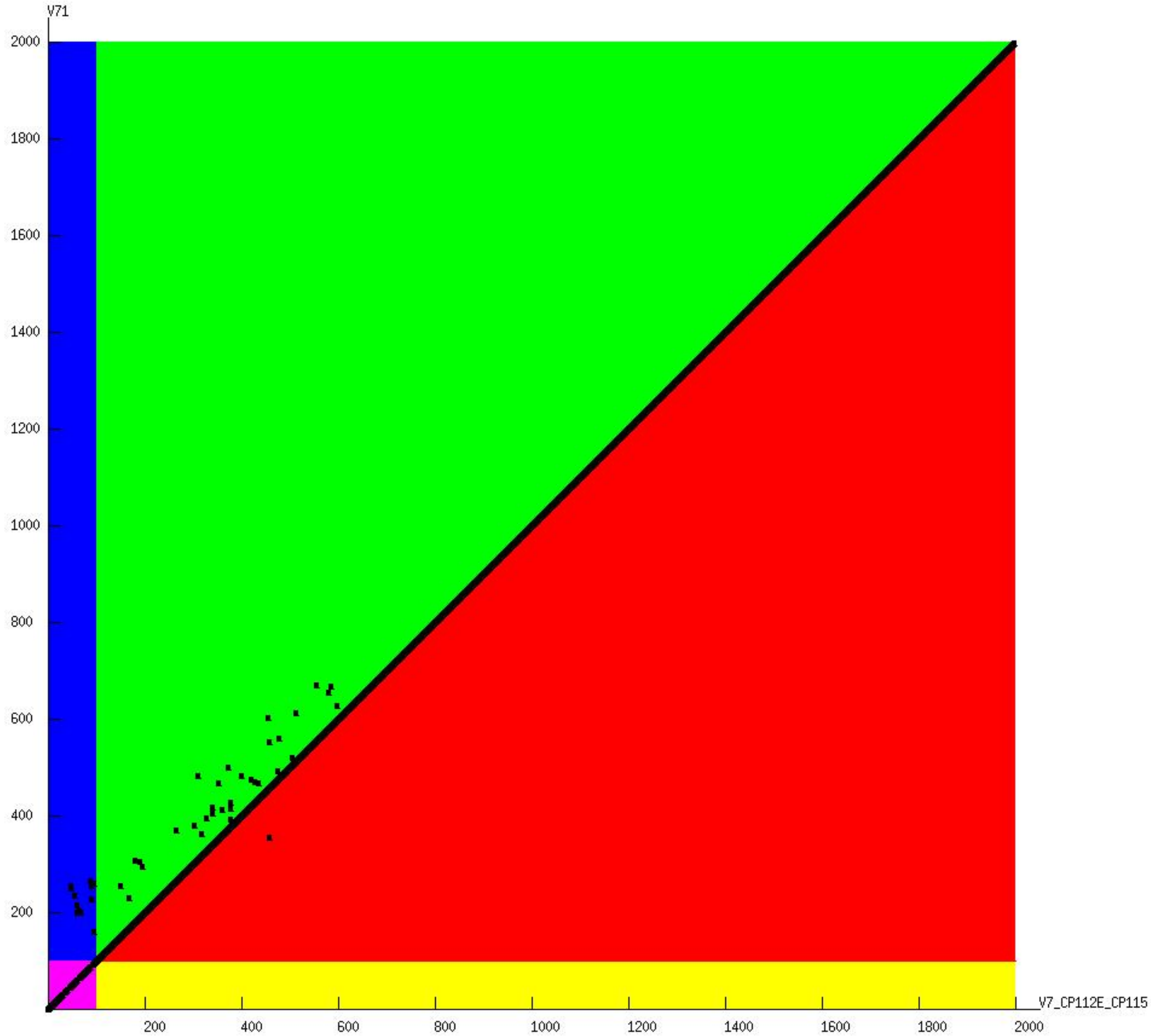


Figure 2.

Separation Difference diagram

As can be observed in Figure 2, CP116 increases the VMD provided by V7+CP112E+CP115 in 44 encounters, including 12 saves. Although the number of cases where CP116 has an effect is relatively small (45 encounters out of 100,000), it includes a significant proportion of saves without inducing additional NMACs. This explains the noticeable decrease in the risk ratio observed in Table 4. In addition, no additional NMAC is induced by CP116, and there is only one case where it decreases the VMD.

6.1.3 Logic Understanding Group

The construction of state charts and review of both state charts and pseudocode by the RWG Logic Understanding Group provided additional assurance that CP116 produces the desired result without affecting other aspects of the logic.

The logic assessment of CP116 began with examining the variables modified by CP116 and described the impact of CP116 in detail. CP116 modifies three variables, a new variable G.EXTALT and two existing variables, G.CORRECTIVE_DES and G.ANYPRECOR. Each variable was traced manually following the modification by CP116 and their impact is summarized below.

G.EXTALT

This global variable is introduced by CP116 to flag low altitude extreme conditions. It is used solely by CP116 to suppress displaying "green arc" and annunciating "Adjust Vertical Speed Adjust" when a Descend RA is weakened to a Don't Climb RA in low altitude extreme condition. This variable does not have adverse side effect.

G.CORRECTIVE_DES

This is an existing global variable that is set without CP116 and cleared with CP116 in low altitude extreme condition. If G.CORRECTIVE_DES is set, it will have the following impact:

(1) In the subsequent cycle, PROCESS Corrective_preventive_test will evaluate if the corrective Don't Climb RA should be reduced to a preventive RA. If the pilot is not climbing faster than the hysteresis correction, G.CORRECITVE_DES will be cleared and then reset in PROCESS Set_up_display_outputs, as intended by the TCAS 7 "green arc" change. Otherwise, the Don't Climb RA remains corrective and the "green arc" change will be skipped.

(2) In the same cycle, PROCESS Set_up_global_flags will determine if the Don't Climb RA is a weakened RA, which will be true, and indicate that the changed RA is corrective and should be announced to pilots.

(3) In the subsequence cycle, PROCESS Set_up_display_outputs will determine if the "green arc" change should be applied. Assume the aircraft has not changed its altitude rate and G.CORRECTIVE_DES is cleared in Corrective_preventive_test, the "green arc" change will be applied and G.CORRECTIVE_DES will be set.

(4) In the same cycle, PROCESS Load_display_and_aural_info will flag the display unit to display the green arc.

(5) In the same cycle, PROCESS Set_up_ARA will set the bit in the ARA field in the RA Report, RA Broadcast Interrogation Message, and Coordination Reply Message to indicate that the current RA is corrective.

If G.CORRECTIVE_DES is cleared, it will have the following impact:

(1) In the subsequent cycle, Corrective_preventive_test will evaluate if the Don't Climb RA should be strengthened to a corrective RA. If the current altitude rate has not achieved the RA's goal rate, G.CORRECTIVE_DES will be set. Otherwise, it remains cleared.

(2) In the subsequent cycle, Set_up_display_outputs will invoke the "green arc" change subject to CP116 negation.

Comparing the effects of whether G.CORRECTIVE_DES is set indicates that adopting CP116 will result in no green arc in the display, no announcement of the Don't Climb RA, and correctly setting the RA as preventive in the outgoing messages. These are the intended effects of CP116.

G.ANYPRECOR

This is an existing global variable that is set without CP116 and cleared with CP116 in low altitude extreme condition. If G.ANYPRECOR is set, it will set G.ALARM which will be used by the display announce the alarm "Adjust Vertical Speed Adjust" to pilots. If G.ANYPRECOR is not set, no alarm will be announced to pilots. This is the intended effect of CP116.

6.2 Other Simulation Testing

Simulation testing of V7.1 (V7+CP112E+CP115+CP116) was performed by the Eurocontrol SIRE+ team and FAA William J. Hughes Technical Center using the safety simulations' standard encounter models. The expectation was that there would be no difference when comparing the results of V7+CP112E+CP115 with V7.1. This would show that CP116 did not adversely affect any parts of the CAS logic.

6.2.1 Egis Avia / DSNA (Eurocontrol SIRE+ team)

The Eurocontrol SIRE+ team ran their safety simulation using the European encounter model. Table 5 shows the risk ratios obtained with the SIRE+ reference scenario (see section 6.1.2 above), using the indicated logic versions. As can be seen in the table, as expected, adding CP116 does not change the risk ratio. The conclusion was that no issues were introduced by the addition of CP116 into the CAS logic.

	V7	V7+CP112E	V7+CP112E+CP115	V7.1
Risk ratio	22.0%	21.0%	20.7%	20.7%

Table 5.

Risk ratios computed on European encounter model

6.2.2 FAA William J. Hughes Technical Center

The William J. Hughes Technical Center ran their Fast-Time Encounter Generator (FTEG) "stress testing" simulation with V7.1 (V7+CP112E+CP115+CP116). Previous simulation results for V7 and V7+CP112E were compared to the V7.1 results. All difference in the results between V7.1 and V7 were either previously observed in the V7+CP112E results or they were directly attributable to CP115.

7. Summary and Recommendations

CP116 proposes to remove the corrective annunciation and green arc when a positive Resolution Advisory (RA) weakens solely due to an extreme low-altitude condition.

This paper was reviewed during an SC-147 Requirements Working Group telecom on 16 October 2007. The RWG agreed to the intent of CP116, deemed the CP116 testing to be appropriate and sufficient, and agreed to the pseudocode and statechart changes presented in this paper.

The RWG recommends that the proposed changes be included in DO-185B, the revision to the current TCAS II MOPS (DO-185A).

References

[1] Hervé Drévillon, "Safety validation of final CP112E, CP115, and CP116," SIRE+/WP6/52/W, Eurocontrol Mode S Programme, DSNA and Egis Avia, 1 October 2007

Abbreviations

ALIM	Altitude Limit, the vertical separation that TCAS attempts to achieve
ALPA	Air Line Pilots Association
AVSA	Adjust Vertical Speed, Adjust
DSNA	Directorate of Air Navigation Services
OWG	(RTCA SC-147) Operations Working Group
RWG	(RTCA SC-147) Requirements Working Group
SIRE+	Safety Issue Rectification Extension+

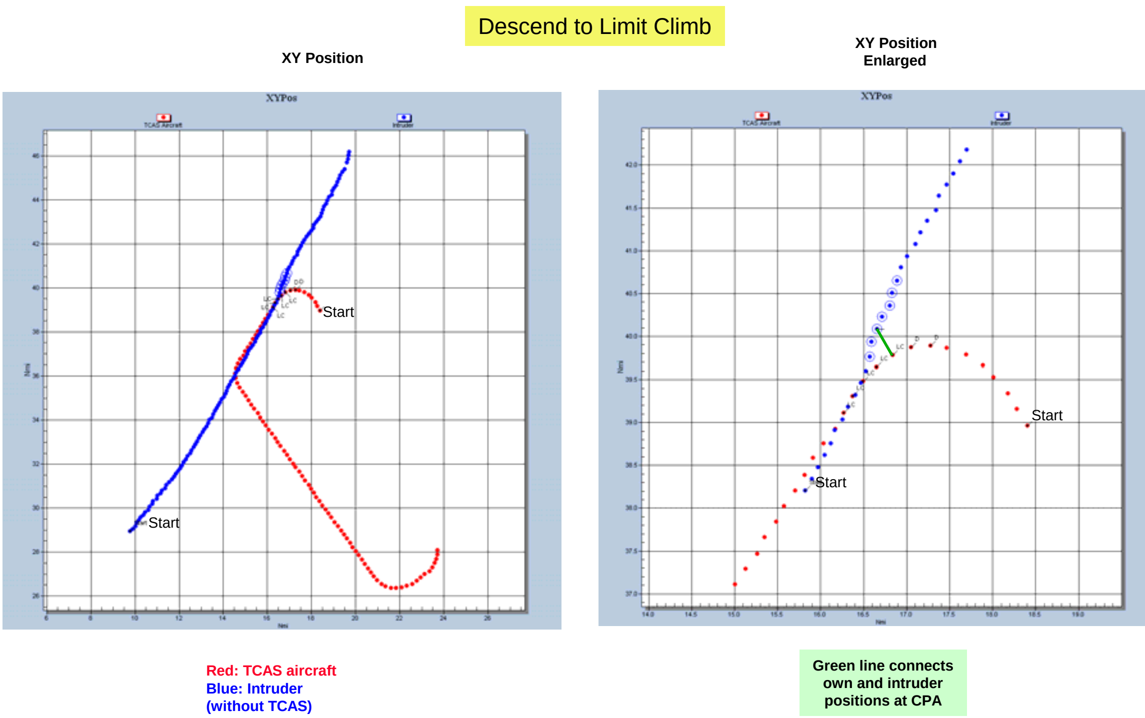
Appendix A
Example Encounters

Appendix A shows plots for two encounters that occurred in the Boston airspace. The first two figures (A-1 and A-2) illustrate an encounter in which the "green arc on weakening" was intended and is appropriate. As seen in the altitude plot (Figure A-2), the pilot followed the positive RA correctly and then leveled off when he had achieved ALIM feet separation and the RA weakened.

The last two figures (A-3 and A-4) illustrate an encounter in which we believe the "green arc on weakening" was not intended and is not appropriate. As seen in the altitude plot (Figure A-4), if the TCAS pilot had leveled off in response to the AVSA RA, he would have moved in the direction of the intruder above.

Note that encounter one (Figures A-1 and A-2) is a TCAS-nonTCAS encounter. Encounter two (Figures A-3 and A-4) is a TCAS-TCAS encounter. Encounter two is presented from the point of view of the TCAS aircraft that received the AVSA RA. This means that the RAs shown on the plot are those seen by the aircraft that received the AVSA RA. The other TCAS aircraft received complementary coordinated RAs.

Figure A-1
AVSA functions as intended
x/y plot

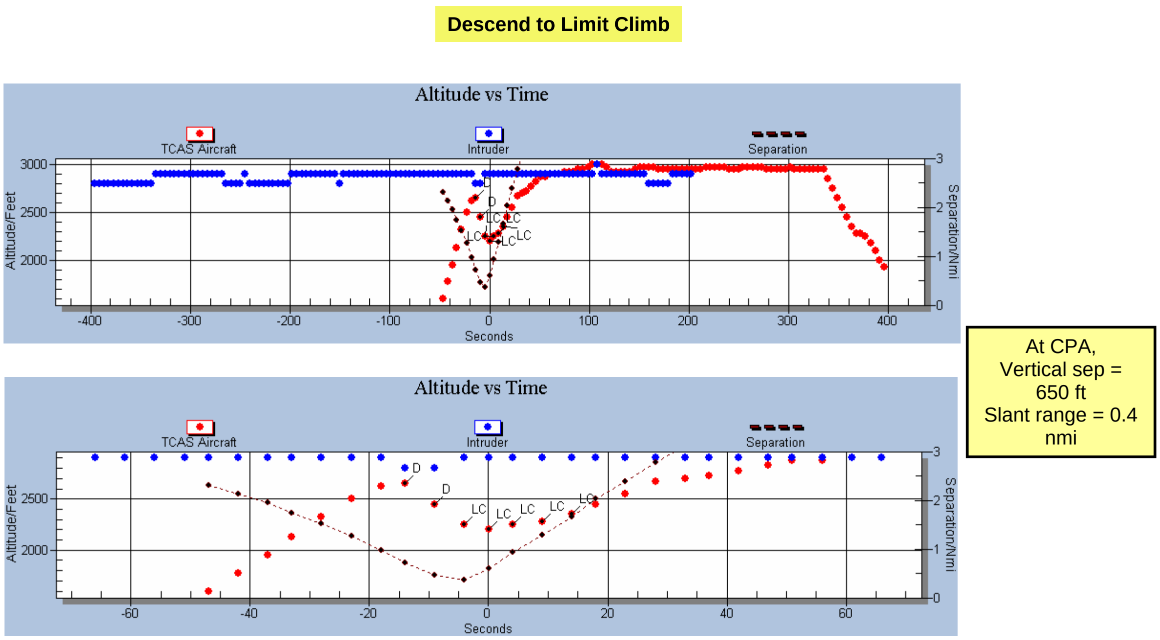


This slide shows x/y position plots for an encounter in which a Descend RA weakened to a down sense AVSA (Limit Climb). The right plot is an enlargement of the left plot. As indicated by the words, “Start,” the surveillance data for the TCAS equipped aircraft (in red) begins at the middle and right in the plots, and the surveillance data for the intruder (in blue) begins at the bottom.

The circled blue dots indicate the intruder positions at the time of the TCAS RAs. In the right plot, the green line connects two points: the position of the TCAS aircraft at closest point of approach and the intruder position at that same time.

At the time of the RA, the TCAS aircraft is climbing and turns toward a level intruder above.

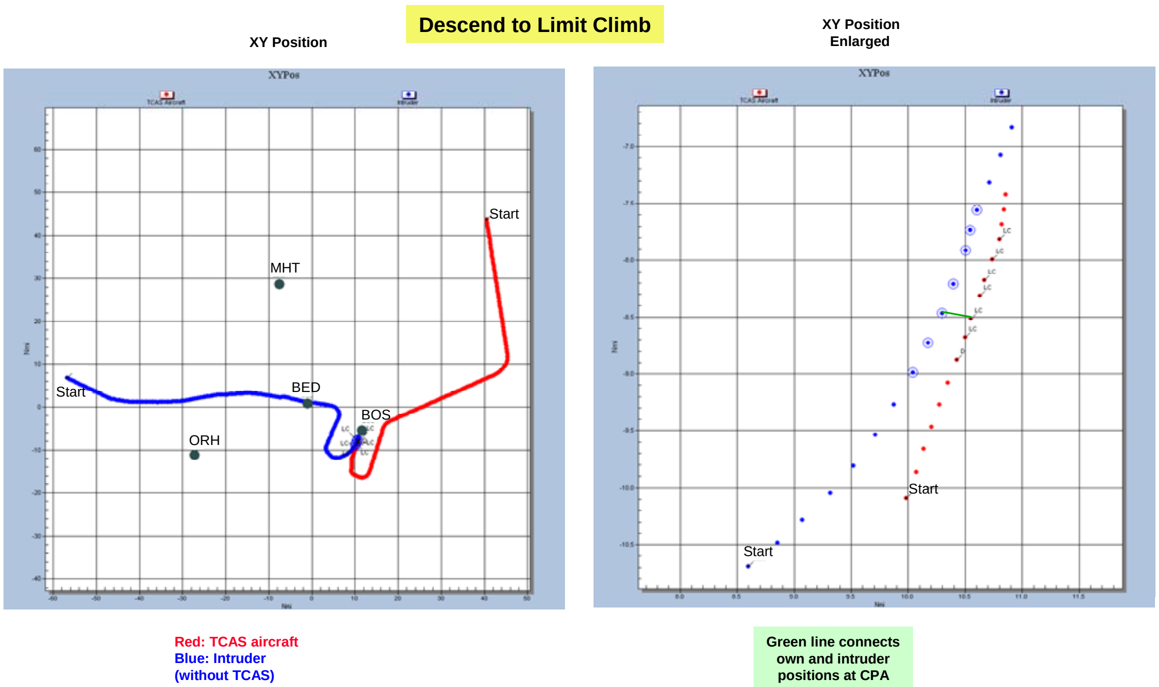
Figure A-2
AVSA functions as intended
Altitude plot



This slide shows altitude vs. time plots for the sample encounter. The TCAS aircraft is shown in red, the intruder in blue. Also shown is slant range (separation) between the two aircraft (see "V" in the center of the plot) with the point of the V indicating the closest point of approach (CPA). The separation scale in nautical miles is shown on the right side of the plot; the altitude scale in feet is shown on the left side of the plot.

This is an example of an encounter in which the "green arc on weakening" is appropriate, and the pilot correctly follows both the original and subsequent RAs. At the time of the RA, the TCAS aircraft is climbing and the intruder is level above. The TCAS pilot appears to correctly follow the Descend RA. When ALIM feet separation is achieved (at this altitude, ALIM is 300 ft), the RA weakens to a down sense AVSA (Limit Climb). The pilot levels off.

Figure A-3
AVSA does not function as intended
x/y plot

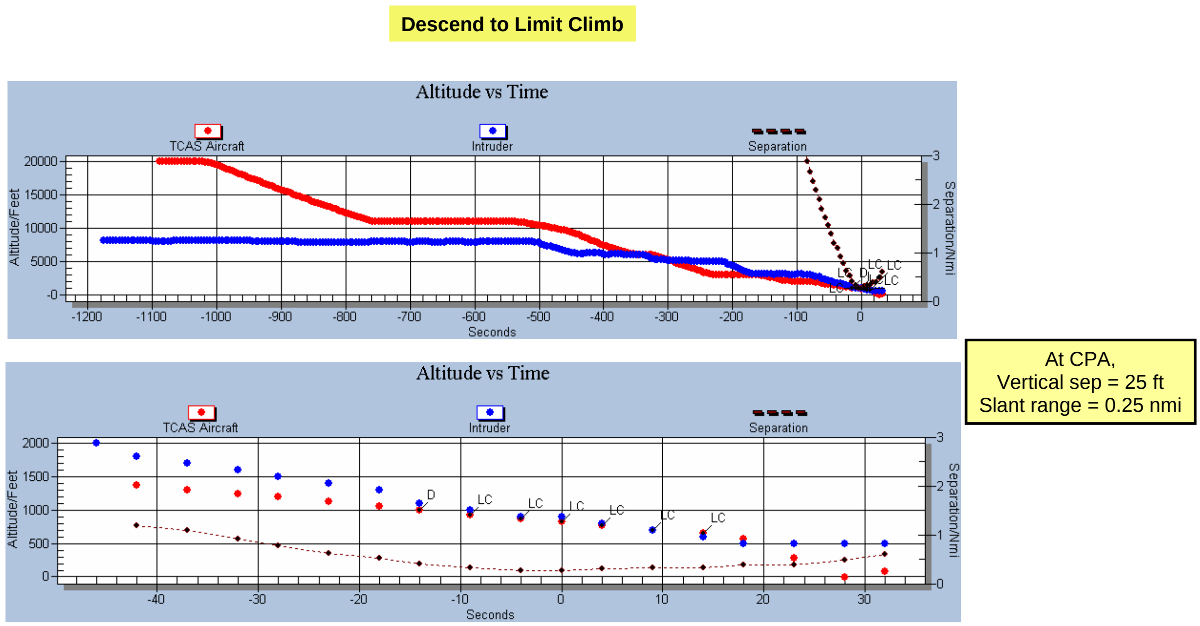


This slide shows x/y position plots for an encounter in which a Descend RA weakened to a down sense AVSA (Limit Climb). The right plot is an enlargement of the left plot.

In this encounter, both aircraft are TCAS-equipped. However, the plots (both Figures A-3 and A-4) are presented from the point of view of one of the TCAS aircraft (the one that received the AVSA RA). This aircraft is shown in red and is called the "TCAS aircraft." The other aircraft, though also TCAS-equipped, is simply referred to as the "intruder." At the time of the RA, both aircraft are on final for a parallel approach into Boston. Both aircraft receive RAs, and this is a TCAS-TCAS coordinated encounter.

The circled blue dots indicate the intruder positions at the time of the TCAS RAs. In the right plot, the green line connects two points: the position of the TCAS aircraft at closest point of approach and the intruder position at that same time.

Figure A-4
AVSA does not function as intended
Altitude plot



This slide shows altitude vs. time plots for the sample encounter. The TCAS aircraft is shown in red, the intruder in blue. Also shown is slant range (separation) between the two aircraft (see “V” in the center of the plot) with the point of the V indicating the closest point of approach (CPA). The separation scale in nautical miles is shown on the right side of the plot; the altitude scale in feet is shown on the left side of the plot.

At the time of the RA, the TCAS aircraft is on final for a parallel approach into Boston, with the intruder slightly above. As the TCAS aircraft descends through 1000 ft AGL, the RA changes to a Don’t Climb. (All CAS logic versions prohibit positive descend RAs below 1000 ft AGL). The TCAS aircraft continues its descent. However, the RA displayed to the pilot shows a green arc at 0 fpm, indicating that the pilot should level off. This would be a incorrect action, given that the intruder is above. We believe that the “green arc on weakening” was not intended to be applied in this geometry and that “Adjust Vertical Speed, Adjust” is not the appropriate annunciation here.

In the RA sequence above, the last four RAs have the RA Terminated (RAT) bit set, indicating that the RA Report is being sent to the ground, but the command is no longer being displayed to the pilot.

Appendix B
Proposed Pseudocode Changes

```
PROCESS Extreme_altitude_check;

Initialize to not indicate an extreme low altitude condition;

    IF (positive CLIMB selected)
        THEN IF (own aircraft can't climb AND reversal RA not in effect)
                THEN convert advisory to DON'T DESCEND;

    ELSEIF (positive DESCEND selected)
        THEN IF (altitude above ground is below threshold where descent allowed)
                THEN convert advisory to DON'T CLIMB;
                        Indicate reversal RA not in effect;
                        IF (not a multiaircraft situation)
                            THEN indicate an extreme low altitude condition;

END Extreme_altitude_check;
```

```
PROCESS Extreme_altitude_check;

    CLEAR G.EXTALT;

    IF (OWNTENT(7) EQ $FALSE AND OWNTENT(5) EQ $FALSE)
        THEN IF ((G.CLIMBINHIB EQ $TRUE) AND (ITF.REV_RA EQ $FALSE))
                    THEN OWNTENT(5,6,11,12) = '10','00';

    ELSEIF (OWNTENT(7) EQ $TRUE AND OWNTENT(5) EQ $FALSE)
        THEN IF (G.NODESCENT EQ $TRUE)
                    THEN OWNTENT(5,6,11,12) = '10','00';
                            CLEAR ITF.REV_RA;
                            IF (G.MACFLG EQ $FALSE)
                                THEN SET G.EXTALT;

END Extreme_altitude_check;
```

```
PROCESS Set_up_display_outputs;

    <Determine advisory annunciation precedence>
    IF (an RA is to be displayed this cycle)
        THEN IF (increase rate RA issued)
                THEN CLEAR reversal, maintain rate, and altitude crossing flags;
                        IF (increase rate RA was not present last cycle)
                            THEN indicate that RA changed to increase rate this cycle;
                ELSE    CLEAR indication that increase rate RA was present last cycle;
                        IF (RA requires maintenance of rate)
                            THEN SET maintain rate indication;
                                    CLEAR sense reversal indication, if any;  <announce maintain>
                            ELSE IF (previous cycle's RA was dual negative AND current RA is
                                            either single negative or positive)
                                        THEN CLEAR maintain rate indication;
                        IF (sense of previously displayed RA has been reversed)
                            THEN CLEAR altitude crossing flag;  <Reversal needs to be
                                        announced even if the reversed RA is altitude crossing>
                                    CLEAR maintain rate indication;  <If reversing maintain RA>
                        IF (RA is preventive)  <Initial preventive neg. or VSL RA or weakening>
                                                <Note:  All positive RAs are now corrective>
                            THEN IF (RA is dual negative) <Don't Climb/Don't Descend>
                                        THEN SET maintain rate indication;  <announce maintain>
                                        ELSE CLEAR maintain rate indication;
                                                IF (positive Climb is weakening to negative
                                                    Don't Descend OR (positive Descend is
                                                    weakening to negative Don't Climb AND
                                                    not in extreme low altitude condition) )
                                                    THEN indicate that weakened RA is corrective;
                                                            <Results in green "fly-to" arc plus
                                                            corrective aural annunciation for initial
                                                            weakening>
                                    Set displayed-model-goal rate to 0 fpm;  <RA display device
                                            will use prescribed vertical rates for neg. & VSL RAs>
                            ELSE IF (RA is corrective negative or VSL)
                                        THEN CLEAR maintain rate indication;
                                                Set displayed-model-goal rate to 0 fpm;
            CLEAR clear of conflict flag;

        ELSE    CLEAR maintain rate indication;  <no RA is to be displayed this cycle>
                Set displayed-model-goal rate to 0 fpm;
                IF (an altitude-reporting threat became non-altitude-reporting during preceding RA)
                    THEN CLEAR track drop and clear of conflict flags;
                    ELSE    IF (a threat's track was dropped during preceding RA)
                                THEN CLEAR clear of conflict flag;

    PERFORM Load_display_and_aural_info; <Load display information to be sent to the RA display,
                                                TA display and aural annunciation subsystem.>

END Set_up_display_outputs;
```

PROCESS Set_up_display_outputs;

```
IF (any bit in G.RA(1–10) EQ $TRUE)
    THEN IF (G.ANYINCREASE EQ $TRUE)
                THEN CLEAR G.ANYREVERSE, G.MAINTAIN, G.ANYCROSS;
                        IF (G.PREVINCREASE EQ $FALSE)
                            THEN SET G.ANYCORCHANG, G.PREVINCREASE;
                ELSE    CLEAR G.PREVINCREASE;
                        IF ((G.RA(1) EQ $TRUE AND G.ZDMODEL GT P.CLMRT AND
                                G.ZDOWN GT P.CLMRT) OR (G.RA(6) EQ $TRUE AND
                                G.ZDMODEL LT P.DESRT AND G.ZDOWN LT P.DESRT))
                            THEN SET G.MAINTAIN;
                                    CLEAR G.ANYREVERSE;
                            ELSE IF ((G.CLSTROLD EQ 4 AND G.DESTROLD EQ 4) AND
                                            (G.CLSTRONG EQ 0 OR G.DESTRONG EQ 0))
                                        THEN CLEAR G.MAINTAIN;
                        IF (G.ANYREVERSE EQ $TRUE)
                            THEN CLEAR G.ANYCROSS;
                                    CLEAR G.MAINTAIN;
                        IF (G.CORRECTIVE_CLM EQ $FALSE AND
                                G.CORRECTIVE_DES EQ $FALSE)
                            THEN IF (G.RA(2) EQ $TRUE AND G.RA(7) EQ $TRUE)
                                        THEN SET G.MAINTAIN;
                                        ELSE    CLEAR G.MAINTAIN;
                                                IF (G.CLSTRONG EQ 4 AND G.CLSTROLD EQ 8)
                                                    THEN SET G.CORRECTIVE_CLM,
                                                                    G.ANYPRECOR;
                                                    ELSE IF (G.DESTRONG EQ 4 AND
                                                                    G.DESTROLD EQ 8 AND
                                                                    G.EXTALT EQ $FALSE)
                                                                    THEN SET
                                                                      G.CORRECTIVE_DES,
                                                                      G.ANYPRECOR;
                                    G.ZDMODEL = 0;
                            ELSE IF (G.RA(1 and 6) EQ $FALSE)
                                        THEN CLEAR G.MAINTAIN;
                                                G.ZDMODEL = 0;
            CLEAR G.ALLCLEAR;

    ELSE    CLEAR G.MAINTAIN, G.ANYINCREASE;
            G.ZDMODEL = 0;
            IF (ANYALTLOST EQ $TRUE)
                THEN CLEAR ANYTRACKDROP, G.ALLCLEAR;
                ELSE    IF (ANYTRACKDROP EQ $TRUE)
```

Appendix C
Proposed Statecharts Changes

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2.1.11.3 Corrective_Descend

Transition(s): Yes → No

Location: Advisory_Status$_{\text{s-104}}$ ⊳ Corrective_Descend$_{\text{s-124}}$

Trigger Event: Corrective_Climb_Evaluated_Event$_{\text{e-682}}$

Condition:

AND		OR			
	Descend_RA_Weakened$_{\text{m-375}}$	T	T	.	T
	Descend_Goal$_{\text{f-459}}$ = 0 ft/min	F	T	.	T
	Own_Tracked_Alt_Rate$_{\text{f-549}}$ < Descend_Goal$_{\text{f-459}}$	T	.	.	.
	Own_Tracked_Alt_Rate$_{\text{f-549}}$ < 300 ft/min$_{\text{(HYSTERCOR)}}$	.	T	.	T
	Own_Tracked_Alt_Rate$_{\text{f-549}}$ ≥ –300 ft/min$_{\text{(HYSTERCOR)}}$	.	T	.	.
	Climb_Goal$_{\text{f-452}}$ = 0 ft/min	.	T	.	.
	Not_Meeting_Climb_Goal$_{\text{m-407}}$	.	.	T	.
	Extreme_Alt_Check$_{\text{m-375}}$	.	.	.	T
	Multiple_Threats$_{\text{m-400}}$	.	.	.	F

Output Action: Corrective_Descend_Evaluated_Event$_{\text{e-682}}$

Notes: 1. ***Description:*** *Transition out of corrective descend occurs for a weakened descend RA condition when ~~either~~ (1) the own aircraft altitude rate is less than a non-zero descend goal, or (2) the aircraft is considered level (i.e., within hysteresis) for a zero climb and descend goal~~. This transition also occurs whenever~~, or (3) the aircraft is not meeting the current climb goal, or (4) a descend RA is weakened to a zero climb rate goal under low extreme altitude against a single threat aircraft.*

2. ***Pseudocode Reference:*** *Corrective_preventive_test, Set_up_display_outputs, Extreme_altitude_check.*